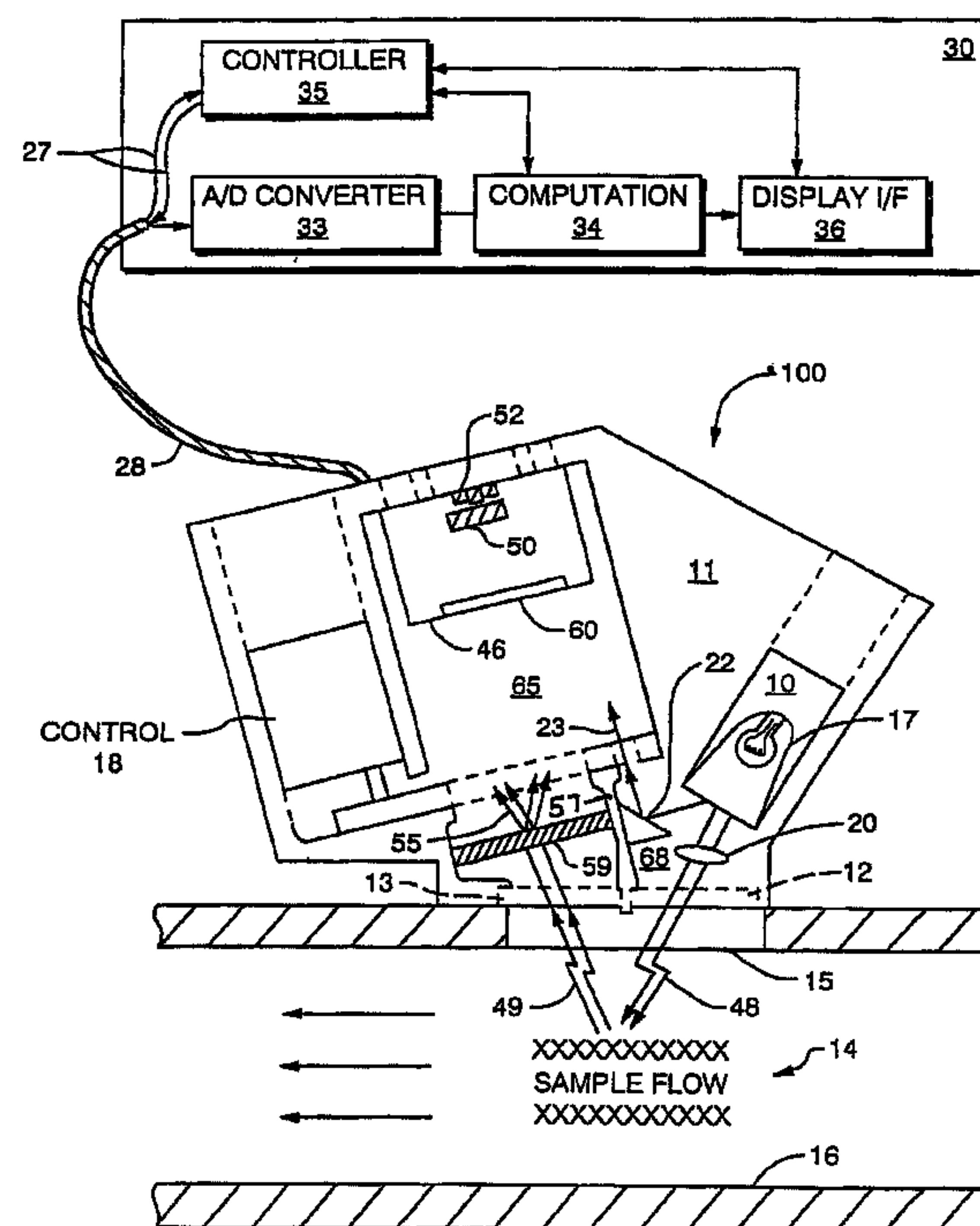




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(57) Abrégé/Abstract:

Percentage concentrations of constituents of a sample of cereal grain or other agricultural product in a flowing stream are determined while harvesting or processing using a short wave near infrared analyzer. The analyzer irradiates the sample, picks up diffuse reflectance of individual wavelengths from the sample and spatially separates the diffuse reflectance into a response at individual wavelengths. The result is to simultaneously detect the intensities of the individual wavelengths in parallel from the same portion of the product being analyzed. Percentage constituents of the composite substance may then be compared with known percentage constituents to determine the constituents in the sample product. The inventive wavelength analyzer is suitable for attaching to the agricultural combine to perform real time measurements in the field.



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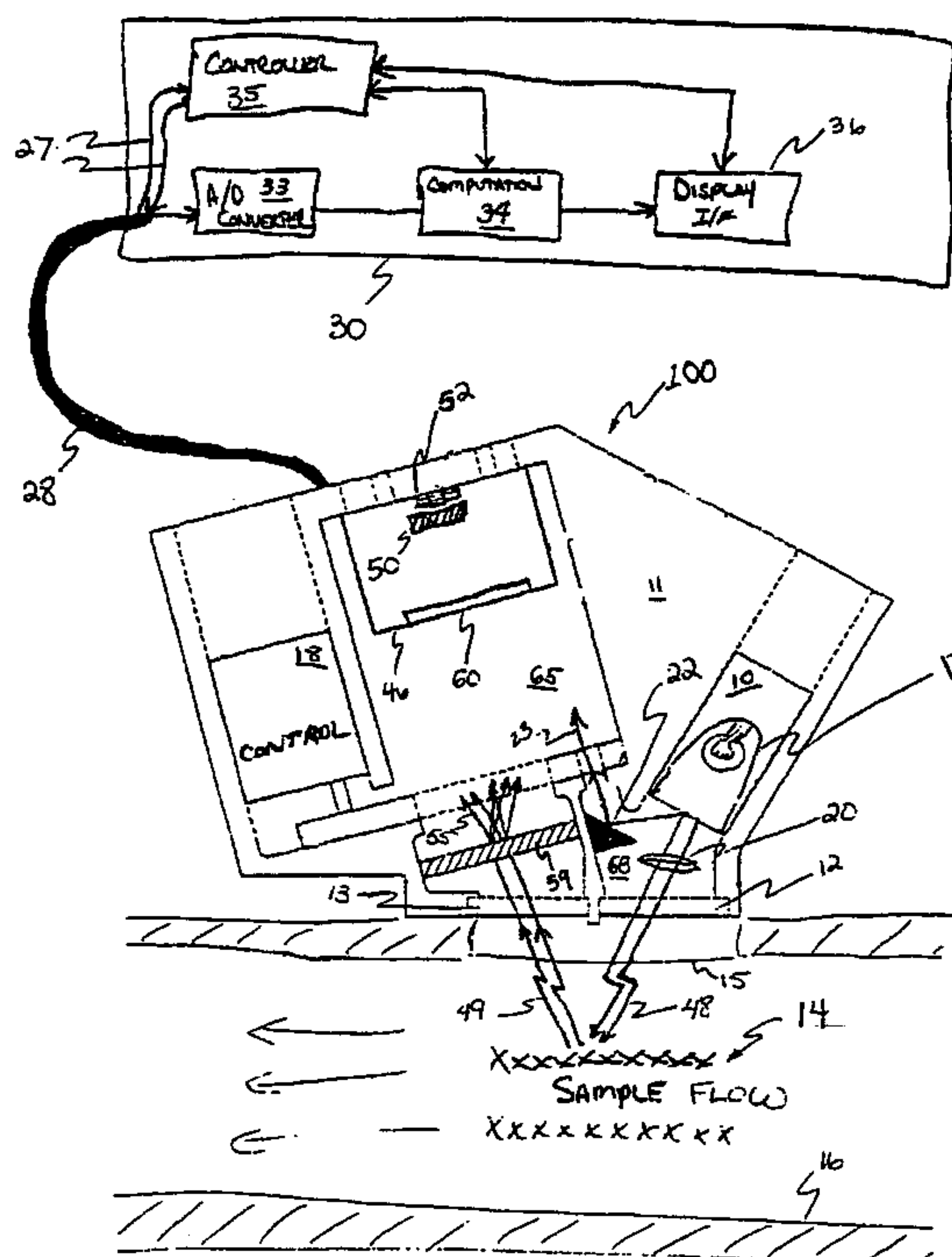
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(54) Title: **INTEGRATED OPTICS BLOCK FOR SPECTROSCOPY**



(57) Abstract: Percentage concentrations of constituents of a sample of cereal grain or other agricultural product in a flowing stream are determined while harvesting or processing using a short wave near infrared analyzer. The analyzer irradiates the sample, picks up diffuse reflectance of individual wavelengths from the sample and spatially separates the diffuse reflectance into a response at individual wavelengths. The result is to simultaneously detect the intensities of the individual wavelengths in parallel from the same portion of the product being analyzed. Percentage constituents of the composite substance may then be compared with known percentage constituents to determine the constituents in the sample product. The inventive wavelength analyzer is suitable for attaching to the agricultural combine to perform real time measurements in the field.

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INTEGRATED OPTICS BLOCK FOR SPECTROSCOPY

RELATED APPLICATIONS

This application is a continuation of and claims
5 priority to U.S. Application No. 09/354,497 filed July
16, 1999, the entire teachings of which are incorporated
herein by this reference.

BACKGROUND OF THE INVENTION

It has been long recognized that the value of
10 agricultural products such as cereal grains and the like
are affected by the quality of their inherent
constituent components. In particular, cereal grains
with desirable protein, oil, starch, fiber, and moisture
content and desirable levels of carbohydrates and other
15 constituents can command a premium price. Favorable
markets for these grains and their processed commodities
have therefore created the need for knowing content and
also other physical characteristics such as hardness.

Numerous analyzer systems have been developed using
20 near infrared (NIR) spectroscopy techniques to analyze
the percentage concentrations of protein and moisture.
Some of these systems target cereal grains in milled
form as explained, for example, in U.S. Patent No.
5,258,825. The value added by milling in some instances
25 decreases the economic gain that is obtained by first
sorting, and thus others target the analysis of whole
grains, as in U.S. Patent No. 4,260,262.

NIR spectrophotometric techniques are typically
favored because of their speed, requiring typically only
30 thirty to sixty seconds to provide results, as compared
with the hours of time which would be needed to separate

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and analyze constituents using wet chemical and other laboratory methods. NIR spectrophotometric techniques are also favored because they do not destroy the samples analyzed. In a typical analysis of wheat grains, for
 5 example, a sample is irradiated serially with selected wavelengths. Next, either the sample's diffuse transmissivity or its diffuse reflectance is measured. Either measurement then lends itself to use in algorithms that are employed to determine the percentage
 10 concentration of constituents of a substance.

For example, the analyzer described in U.S. Patent No. 4,260,262 determines the percentage of oil, water, and protein constituents by using the following equations:

$$\begin{aligned}
 15 \quad \text{oil \%} &= K_0 + K_1(\Delta OD)_w + K_2(\Delta OD)_o + K_3(\Delta OD)_p \\
 \text{water \%} &= K_4 + K_5(\Delta OD)_w + K_6(\Delta OD)_o + K_7(\Delta OD)_p \\
 \text{protein \%} &= K_8 + K_9(\Delta OD)_w + K_{10}(\Delta OD)_o + K_{11}(\Delta OD)_p
 \end{aligned}$$

where $(\Delta OD)_w$ represents the change in optical density using a pair of wavelengths sensitive to the percentage
 20 moisture content, $(\Delta OD)_o$ represents the change in optical density using a pair of wavelengths sensitive to the percentage oil content, and $(\Delta OD)_p$ represents the change in optical density using a pair of wavelengths sensitive to the percentage protein contents. K_0 - K_{11} are constants
 25 or influence factors.

The change in optical density of any given constituent may thus be found from the following equation:

$$\Delta OD = \log (I_i/I_r)_1 - \log (I_i/I_r)_2$$

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where $(I_i/I_r)_1$ is the ratio of the intensity of incident light to the intensity of reflected light at one selected wavelength, and $(I_i/I_r)_2$ is the ratio of the intensity of incident light to the intensity of reflected light at a second selected wavelength.

Typically, grain analyzers use selected wavelengths in the range of about 1100 to 2500 nanometers. However, in U.S. Patent No. 5,258,825, particle size effects of flour were overcome by additionally using a 540 nanometer wavelength.

Analyzers of the prior art typically use a filter wheel or scanning diffraction grating to serially generate the specific wavelengths that are of interest in analyzing grain constituents. Because of moving parts, filter wheels and scanning diffraction gratings are sensitive to vibration and are not reliable in analyzing grain during harvesting. They therefore are not suitable for withstanding the mechanical vibrations generated by a combine or other agricultural harvesting equipment, and therefore have not found use in real-time measurement of grain constituents during harvesting.

Optical systems typically include fiber optic cables to conveniently direct light from a source to a destination located at a distance. Unfortunately, fiber optic cables can not be used in certain applications, such as a combine or harvester, without further conditioning of the optical signal because the mechanical vibrations of the machinery can cause undesirable modal disturbances within the optical fiber. These modal disturbances or higher order reflections create light intensity disturbances that are not related to the properties of a sample. Therefore, without incorporating costly conditioning mechanisms, the

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quality of an optical signal can be degraded. This detracts from the accuracy of the measuring device such as a grain analyzer, especially when it is expected to be used in the field.

5 SUMMARY OF THE INVENTION

This invention is a spectral analysis system and method for determining percentage concentration of constituents in a flowing stream of agricultural product and related substances as they are fed through a combine
10 harvester, grain processor, or storage equipment. Such agricultural products may include, but are not limited to, for example, cereal grains such as wheat, corn, rye, oats, barley, rice, soybeans, amaranth, triticale, and other grains, grasses and forage materials.

15 The invention uses the diffuse reflectance properties of light to obtain percentage concentrations of constituents of the flowing stream of an agricultural substance. In the preferred embodiment, techniques of the invention involve measuring a spectral response to
20 short wavelength, near infrared (NIR) radiant energy in the range from 600 to about 1100 nanometers (nm) as well as light in the visible spectrum, including wavelengths as low as about 570 nanometers (nm). Other wavelengths, up to mid infrared near 5000 nanometers, are optionally
25 used in the present invention, where the range of wavelengths analyzed depends on the limited bandwidth of the detector. The spectral response at shorter wavelengths helps in the modeling of proteins and other constituents in conjunction with the response at longer
30 wavelengths.

The analyzer includes an optical lamp having a suitably broad bandwidth for simultaneously irradiating

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the flowing agricultural product stream with multiple wavelengths of light. A detector receives the radiation diffusely reflected from an agricultural sample so that the received optical signal can be analyzed by a real-time computation subsystem to determine constituents in the sample.

The lamp is angularly positioned in a first chamber to irradiate the flowing product sample through a window formed of a suitable protective material such as sapphire. The light source is focused using a lens or parabolic mirror to intensify the light irradiating the agricultural product sample. This enhances reception of reflected light off the sample into the detector, which is angularly positioned in a second chamber. The design of each chamber ensures that stray light from the lamp is not received by the detector from within the detection apparatus itself during a sample measurement. Rather, light received by the detector is essentially only light reflecting off the product sample back into the second chamber.

The second chamber includes a diffuser in line with the light received from the irradiated sample. The diffused optical signal emanating from the diffuser is then fed into a wavelength separator, such as a linear variable filter (LVF) within the second chamber to spatially separate the wavelengths of interest.

The wavelength separator in turn feeds the optical signal into a suitable detection device, such as a charge coupled device (CCD), which is capable of simultaneously detecting the spatially separated wavelengths reflected from the irradiated sample. Electrical signals from the detection device corresponding to individual wavelengths of light from

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the irradiated sample are converted into digital data where they are spectrally analyzed by a computation device to calculate the percentage concentration of various constituents in the sample.

5 The invention includes a reflective device in the first chamber to direct a portion of the optical lamp light, which serves as an optical reference, into the detector located in the second chamber. A controllable shutter mechanism is used to block this reference light
10 when a sample is spectrally analyzed. Conversely, another shutter mechanism blocks light reflected from the sample when the reference light is spectrally analyzed. Based on a combination of reference and sample measurements, a precise wavelength analysis is
15 used to determine constituents in a sample agricultural product. According to the principles of the present invention, an entire harvest can be analyzed and recorded to provide a correlation between a harvested product and a particular geographic region.

20 The analyzer advantageously monitors a flowing sample without requiring an expensive and restrictive fiber optic cable or mode mixing apparatus. Modal disturbances caused by mechanical vibrations in the optical fibers are therefore avoided. Furthermore, the
25 aperture angle of monitored light from the irradiated sample can be much larger because there is no need to incorporate an optical pickup to guide the sample light into a narrow fiber optic cable. The wide angle optical return signal results in greater received light
30 intensity strength which leads to more accurate constituent measurements.

BRIEF DESCRIPTION OF THE DRAWINGS

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The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

10 Fig. 1 is a high level schematic illustration of a short wave near infrared grain quality analysis system according to the invention.

Fig. 2 depicts a process for measuring absorptivity of a sample according to the principles of the present invention.

15

DETAILED DESCRIPTION OF THE INVENTION

Referring now more particularly to Fig. 1, the present invention is a system 100 for analyzing the constituent components of a flowing stream of an agricultural product as it is being processed or harvested. The agricultural products which may be analyzed by the system 100 include, but are not limited to, cereal grains such as wheat, corn, rye, oats, barley, rice, soybeans, amaranth, triticale, and other grains, grasses and forage materials. The constituent components being analyzed may include, but are not limited to, protein, oil, starch, fiber, moisture, carbohydrates and other constituents and physical characteristics such as hardness. Although the following discussion describes a particular example wherein the product being analyzed is a cereal grain, it

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should be understood that other agricultural products may be analyzed as well.

The system 100 uses a suitable continuous irradiating device such as an infrared light source 10. Radiation from the light source 10 shines forward through a first window 12 to a sample of a flowing agricultural product 14 being harvested, processed, or otherwise flowing through a conveyance such as a duct 16.

10 The light source 10 continuously and simultaneously produces infrared light of multiple wavelengths in a region of interest such as between 570 to about 1120 nanometers (nm). Other applications of the present invention include wavelength analysis in a range between
15 visible and mid-infrared corresponding to 400 to 5000 nanometers and, therefore, require a source light capable of emitting such wavelengths. The desired range of analysis depends on the characteristics of the detector, which typically is bandwidth limited. For
20 example, a fairly inexpensive silicon photodiode array is capable of detecting light intensities of wavelengths between 600 and 1100 nanometers. Other detectors optionally used in the invention are lead sulfide and lead selenide detectors, which support a response
25 between 1000 to 3000 nanometers and 3000 to 5000 nanometers respectively. The detector will be discussed in more detail later in the application.

The preferred light source 10 is a quartz halogen or tungsten filament bulb and is widely available. A
30 typical light source 10 is a tungsten filament bulb operating at 5 volts (vDC) and drawing one amp of current. The light source 10 may be further stabilized by filtering or by using an integral light sensitive

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feedback device in a manner which is known in the art (not shown).

The light source 10 is positioned to shine upon the flowing product 14 as it is flowing through a conveyance
5 such as a duct 16 within an agricultural combine or other grain processing apparatus. The flow of the agricultural product 14 through the duct 16 is generally in the direction of the illustrated arrows, but optionally is reversed.

10 The light source 10 and related components positioned adjacent the duct 16 are positioned within a suitable housing 11. In such an instance, a first window 12 is preferably disposed between the light source 10 and the flowing agricultural product 14. This
15 prevents the flowing agricultural product from clogging the system 100. The first window 12 is formed of a suitable material, such as sapphire, which is transparent at the wavelengths of interest, and which does not see a significant absorption shift due to
20 temperature changes. Sapphire also resists scratching and, therefore, debris such as stones flowing in concert with the agricultural product will not damage the window. The first window 12 may be integrally formed with the housing 11 or the duct 16 as desired.

25 The housing 11, including the enclosed light source 10, first window 12, and other related components to be described, is thus positioned to monitor a continuous flow of the agricultural product 14 through the duct 16. This is accomplished by mounting the housing 11 such
30 that the first window 12 is disposed adjacent an opening 15 in the duct 16 so that the light source 10 shines through the window 12 and opening 15 onto the flowing product 14.

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The housing 11 may be a separate physical housing or it may be integrally formed within the duct 16.

A parabolic mirror or reflector 17 is disposed within the lamp cavity to direct light from the light
5 source 10 to the sample 14 being analyzed. In the preferred embodiment, the light is collimated to enhance the intensity of the spectrally analyzed light that is reflected off the sample. However, lens 20 optionally provides a means of additionally focusing or de-focusing
10 the light into a more or less intense beam. In other words, the irradiated light shining on the sample is optionally angular rather than collimated.

In an alternate embodiment, more than one light source 10 can be used, such as an array of infrared
15 emitters, as long as they are focused on the same point.

It is preferred that the light source 10 be placed such that it directly illuminates the flowing product 14 through the first window 12 with no fiber optic or other device other than the first window 12 itself being
20 disposed between the light source 10 and the flowing product 14. In the preferred embodiment, the illumination spot size from the light source 10 onto the sample of flowing agricultural product 14 is approximately a half to one inch in diameter. In
25 particular, incident light 48 from the light source 10 is focused onto a flowing sample 14 practically touching or near the surface of the first and second window 12, 13. Effectively, the incident light 48 shines through the first window 12 and flowing sample 14 to produce
30 sample light 49 directed towards a second window 13 and analysis chamber where light intensities are analyzed. A wider illumination spot size, such as up to a few inches in diameter, is optionally used in applications

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where the sample is located farther away from the surface of the first and second window 12,13.

A wide illumination spot size and viewing aperture is preferred because it results in more accurate sample
5 measurements of the flowing agricultural product. Each measurement based on the wide spot size typically involves analyzing multiple pieces of illuminated grain, resulting in a beneficial averaging effect.

Other spectral analyzers incorporate costly optical
10 hardware for receiving the light reflected off a sample 49 and directing it to an optical detector located far away. To view even a small spot with these systems requires a high intensity light source. This method of using optical hardware to redirect the reflected sample
15 light 49 limits the spot size to a narrow diameter because the reflected light must be focused into a narrow fiber optic cable.

The present invention, on the other hand, advantageously positions a detector 52 with a wide
20 viewing aperture located in a second chamber 65 immediately adjacent the first chamber 68 to receive the reflected sample light 49. This eliminates the need for costly fiber optic hardware because received light no longer needs to be directed to a detector at a remote
25 location. Rather, reflected sample light 49 naturally strikes the detector 52 located immediately in the second chamber. To match the performance of the present invention, a fiber system would require a very large fiber bundle for redirecting reflected sample light to a
30 remote detector.

Eliminating the fiber optic pickup and associated fiber optic cables has advantages in addition to enabling the use of a wider illumination spot size.

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Typically, fiber optic cables have a limited bandwidth. Hence, when they are used to steer reflected light to a detector located far away, the spectral range of directed light is limited to the bandwidth of the cable.

5 This negatively impacts constituent measurements because a narrow spectral bandwidth can produce inaccurate results. Moreover, the use of fiber optic cables are further prohibitive because the fiber optic cables supporting the a bandwidth of mid infrared are

10 particularly expensive. In some cases, just a few meters of this type of cable can be more than a thousand dollars. The present invention is not bandwidth limited nor burdened with unnecessary additional cost because it does not incorporate any fiber optic cables to redirect

15 light. As a result, any broadband light source and complementary detector can be used to perform constituent sampling.

The use of a fiber optic cable to redirect the reflected sample light 49 is additionally undesirable

20 because the integrity of the optical signal within a fiber optic cable is susceptible to heat distortion and mechanical vibrations. This is especially true when the fiber optic cable supports the transmission of light in the infrared region. Both the heat distortion and

25 mechanical vibrations, particularly prevalent in a combine or harvester, negatively impact the integrity of the optical signal used to detect constituents in a sample. By placing the detector 52 in a second chamber

65 immediately adjacent the light source without

30 incorporating an optical fiber in the reflected sample light path 49, the present invention advantageously avoids the aforementioned problems.

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size can be adjusted to create a variable field of view and allows a large sample to be imaged from a distance.

5 Moreover, the design of each chamber, i.e., the first chamber 68 and the second chamber 65, ensures that stray light from the light source 10 is not received by the detector 50 from within the housing 11 of the system 100 during a sample measurement. Rather, the light received by the detector 50 is essentially only reflected sample light 49. In particular, a wall 57 separating the first chamber 68 and the second chamber 65 of the of housing 11
10 extends to the first window 12 and the second window 13 to form an optical blocking element that forces the incident light 48 into the sample 14 and inhibits the incident light 48 from directly reaching the detector 50.

Light emitted by the light source 10 passes through the first window 12 and opening 15 in the duct 16 onto the flowing agricultural product 14. Incident source light 48 then
15 reflects off the sample 14, where the reflected sample light 49 is angularly directed back through opening 15 in the duct and second window 13.

In the preferred embodiment, the angle of the light source and detector unit 52 in the second chamber 65 are optimized so that most of the reflected sample light 49 is directed to the second chamber 65 for spectral analysis of the flowing agricultural product. For
20 example, the light source may be optimally angled at approximately 60° relative to the first window 12 while the detector unit 52 in the-second chamber 65 may be angled at approximately 60° relative to the second window as shown in illustrative Fig. 1.

The second chamber 65, as mentioned, includes optical devices for detecting the reflected sample light 49. Specifically, the reflected sample light 49 passes through the
25 second window 13 into the second chamber 65 where it is spectrally analyzed. Diffuser 59 acts to scatter the reflected sample light 49, spatially distributing the intensity of the light throughout the second chamber 65 for more accurate simultaneous spectral readings. For example, reflected sample light 49 of various wavelengths is more evenly distributed throughout the second chamber 65. Otherwise, high intensity light regions caused by
30 reflected sample light 49 from the flowing product 14 result in less accurate constituent measurements due to imaging effects.

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spectral readings. For example, reflected sample light 49 of various wavelengths is more evenly distributed throughout the second chamber 65. Otherwise, high intensity light regions caused by reflected sample light 49 from the flowing product 14 result in less accurate constituent measurements due to imaging effects.

Hermetically sealed chamber 46 is positioned in the second chamber 65 to receive reflected sample light 49. An optically transmissive third window 60 allows
10 diffused light emanating from the diffuser to shine onto wavelength separator 50 and CCD array detector 52, both of which are positioned within the hermetically sealed chamber 46. This airtight chamber protects sensitive optical components from corrosive and measurement-
15 inhibiting elements such as humidity and dust. Without the hermetically sealed chamber 46, a buildup of dust and other debris on the detection unit 52 and wavelength separator 50 will negatively effect constituent measurements. It should be noted that all or part of
20 the second chamber 65 is optionally designed to be hermetically sealed.

The wavelength separator 50 within hermetically sealed chamber 46 in a preferred embodiment provides spatial separation of the various wavelengths of
25 diffusely reflected light energy of interest. Suitable wavelength separators 50 include linearly variable filters (LVF), gratings, prisms, interferometers or similar devices. The wavelength separator 50 is preferably implemented as a linearly variable filter
30 (LVF) having a resolution ($\Delta\lambda/\lambda$) of approximately one to four percent.

The now spatially separated wavelengths in turn are fed to the detector 52. The detector 52 is positioned

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such that it simultaneously measures the response at a broad range of wavelengths. In the preferred embodiment, the detector 52 is an array of charge coupled devices (CCDs), which individually measure the light intensity at each of the respective wavelengths. In other words, each cell of the CCD array is tuned to measure the intensity of an individual bandpass of light.

Other suitable detectors 52, however, are constructed from fast scan photodiodes, charge injection devices (CIDs), or any other arrays of detectors suitable for the task of simultaneously detecting, in parallel, the wavelengths of interest.

In a preferred embodiment, the detector 52 is a silicon CCD array product, such as a Fairchild CCD 133A available from Loral-Fairchild. The device preferably has a spatial resolution of about 13 micrometers. The frequency resolution is the selected bandwidth of interest (as determined by the linear variable filter 50), divided by the number of CCD elements. In the preferred embodiment the CCD array 52 is a 1,024 element array processing wavelengths in the range from about 570 to about 1120 nm. Other detectors, as mentioned, supporting different bandwidths are optionally used.

In addition, the detector 52 such as a CCD array is typically temperature sensitive so that stabilization is usually preferred.

In the preferred embodiment, because of the relatively close positioning of LVF 50 and CCD array 52, both of these components can be temperature stabilized together. The temperature stabilization can be by suitable heat sink surfaces, a thermoelectric cooler (Peltier cooler) or fan. The preferred embodiment

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of the invention includes a reflector 22 disposed in the first chamber to reflect reference light rays 23 to the wavelength separator 50 and detector 52 positioned in the second chamber 65 depending on the position of light blocking shutters. The reflector 22 is preferably fixed such that repeated measurements are based upon the same reference light intensity.

A first shutter controls the passage of reflected sample light 49 into the second chamber 65, whereas a second shutter controls the passage of reference light rays 23 reflected off reference light reflector 22 into the second chamber 65. At any given time, the first and second shutter are controlled to allow the appropriate light to flow into the second chamber 65. It should be noted that a single shutter is optionally designed to provide a way of controlling which light, reference light rays 23 or reflected sample light 49, eventually shines on the detector 52.

Control electronics 18 located adjacent to the second chamber 65 provides a means of controlling the shutter mechanisms. Shutter position commands are received via electronic signals transmitted by controller 35 residing in the electronics block 30.

The shutters are used to perform three measurements. A first measurement involves blocking both the reflected sample light 49 and reference light rays 23. This reference measurement of the "dark" second chamber 65 serves as a means of calibrating the detector unit or array 52. A second measurement involves blocking the reflected sample light 49 and measuring the reference light rays 23. This measurement serves to calibrate the system to the light source 10. Finally, a third measurement involves blocking the

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reference rays 23 and measuring the reflected sample light rays 49. Details of the measurements and related computations are further described in Fig. 2.

An electronic signal or signals 27 between the electronics block 30 and system housing 11 provide a way for the controller 35 to pass signals controlling the position of the first and second shutter, and specifically the flow of reference light rays 23 and reflected sample light 49 into the second chamber 65 where the detector unit 52 resides. For example, the first shutter is placed in the open position to allow light to pass to the sample and to be diffusely reflected by the flowing product sample 14 during sample measurement operations, and placed in a closed position to occlude light from the sample and diffusely reflected light from the shutter during reference measurements. The second shutter is used to block the reference light rays 23 from entering the second chamber 65 during detector unit 50 calibration and flowing product 14 sampling.

The electronic signals 27 are bundled together in a wire harness 28 connecting the system housing 11 and electronics block 30. In a practical deployment of the system 100 such as in an agricultural harvester, it is preferred that the cable sheath 28 be sufficiently long such that housing 11 can be placed adjacent the duct 16 while electronics block 30 may be placed in a less harsh environment such as the protective cab of the harvester. This distance is generally three meters, for example, and is optionally more or less.

The electronics block 30 includes an analog to digital converter 33, a constituent computation function 34, a controller 35, and a display interface 36. In the

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preferred embodiment, the constituent computation function 34, controller 35 and display interface 36 are implemented as software in a computer, microcontroller, microprocessor and/or digital signal processor.

5 Electronic signals 27 in wire harness 28 provide connectivity between the electronics in the system housing 11 and the electronics block 30.

Typically, the electronics block is mounted in a shielded environment, such as a cab, while the housing
10 11 of the optical system 100 is mounted in a position to detect the flowing agricultural product 14. Therefore, based on this separation, the electronics are designed to ensure that signal integrity does not suffer because of the length of the wire harness 28. For example, the
15 electronic signals 27 within wire harness 28 are properly shielded to prevent excess coupling noise, which may deleteriously effect A/D readings of the CCD array detector 52. The controller 35 coordinating the A/D sampling process, as mentioned, controls the shutter
20 mechanisms positioned in the second chamber 65 for the various spectral measurements.

The individual electrical signals provided by the CCD for each wavelength are then fed from the output of the detector 52 to analog to digital converter 33 where
25 the electrical signals are converted to digital signals for processing.

A computation block 34, preferably implemented in a microcomputer or digital signal processor as described above, then carries out calculations on the basis of the
30 received wavelength intensities to obtain percentage concentrations of constituents of the sample 14. The percentage of constituents, which are determined using a chemometric model, are then shown in any desired way

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such as by a meter or presenting them to a display. The display may be integral to a laptop computer or other computer placed in the cab of the harvester. The computation block may be part of the electronics block
5 30 or may be physically separated from it.

Techniques for calculating percentage concentrations of grain based upon samples of light and particular wavelengths are the multi-variate techniques detailed in the book by Sharaf, M.A., Illman, D.L., and
10 Kowalski, B.R., entitled "Chemometrics" (New York: J. Wiley & Sons, 1986).

Preferred wavelengths of interest depend upon the constituents being measured. For example, when measuring protein concentration, the algorithms make use
15 of absorptance attributable to the vibration-rotational overtone bands of the sub-structure of protein. At longer wavelengths absorptivity coefficients are large, the path length is short, and thus one would not sample the interior of the grain particles. At shorter
20 wavelengths the absorptivity coefficients are small and the signal is thus weak.

The system 100 thus provides for irradiation of the sample followed by spatial separation and detection of multiple wavelengths in parallel, making for rapid
25 analysis of this sample. Moreover, because the optical portions of the unit are stable to vibrations, it is substantially insensitive to vibrations such as found in agricultural combines or other harvesting and processing equipment. The system 100 may therefore be easily
30 deployed in environments where real time analysis of harvested grain or other agricultural produce may be carried out during harvesting and other processing operations. The data obtained thereby may be compared

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with reference data to provide percentage concentrations of constituents for use in mapping field layout according to the so called global positioning system (GPS).

5 Furthermore, the use of the CCD array as detector unit 52 provides advantages over prior art techniques that use discrete or scanned diode arrays. In particular, the CCD bins are all filled with charge at the same time in parallel with one another, until one of
10 them is nearly full. They are then emptied and the results read out by the controller 35 while the CCD array begins filling again. Therefore, each pixel has seen the same grains over the same time intervals. In contrast, diode arrays must be read sequentially so that
15 for example, any given element is producing a signal from a volume of grain if it is distinct from those seen by previous pixels.

 The signal to noise ratio of the system 100 may be improved by averaging over the course of many
20 measurements.

 The preferred absorptivity measurement includes the following process (also depicted in Fig. 2):

1. Block both the sample reflection light and
25 reference light from the wavelength detector unit (step 301)
2. Perform a reading on the wavelength detector unit, storing measurement data in D for dark spectrum (step 302).

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3. Block the sample reflection light and allow reference light to shine on wavelength detector unit (step 303).
4. Perform a reading on the wavelength detector unit, storing measurement data in R for reference light spectrum (step 304).
5. Block the reference light and allow sample reflection light to shine on wavelength detector unit (step 305).
6. Perform a reading on the wavelength detector unit, storing measurement data in S for sample spectrum (step 306).
7. Calculate the absorptance spectrum A, where the light absorption as derived from these diffuse reflectance measurements is given by:
$$A = \text{LOG}_{10} (R-D/S-D).$$

In addition, since the absorptivity variations from the presence of protein are quite small, multiple realizations, averaging, and second derivative analysis are typically used to produce the desired absorptivity number at a particular wavelength. Further data processing therefore may provide a second derivative of this function to remove constant and linear offsets so that only quadratic and higher order features in the absorptivity spectrum are utilized in the determination of protein content.

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EQUIVALENTS

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described specifically herein. Such equivalents are intended to be encompassed in the scope of the claims.

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CLAIMS

What is claimed is:

- 5 1. A probe head (100) for use with a spectrometer (30) to analyze a material (14), the probe head comprising:
 - a housing (11) having a first chamber (65) separated from a second chamber (68),
 - a light source (10) disposed in the first chamber (65) and arranged to irradiate a sample volume of the material with a plurality of wavelengths of light (48),
 - 10 a wavelength separator (50) disposed in the second chamber (65), the wavelength separator (50) receiving light (49) reflected from the irradiated sample volume to produce spatially separated light of different wavelengths, and
 - a detector (52) connected to the spectrometer, the detector being disposed in the second chamber (65) and positioned to receive the spatially separated light from the
 - 15 wavelength separator, the detector (52) transmitting an electrical signal to the spectrometer (30) representative of the intensity of the spatially separated light received from the wavelength separator (50).
- 20 2. The probe head (100) of claim 1, wherein the first chamber (68) of the housing (11) includes a first window (12) and the light source (10) irradiates light through the first window (12) onto a sample volume.
- 25 3. The probe head (100) of claim 2, wherein the second chamber (65) of the housing (11) includes a second window (13) and the wavelength separator (50) receives light through the second window (13) from the irradiated sample volume.
4. The probe head (100) of claim 3, wherein the detector (52) in the second chamber (65) is hermetically sealed.
- 30 5. The probe head (100) of claim 3, further comprising a reflector (22) positioned in the housing (11) to reflect a portion of light emanating from the light source (10) into the second chamber (65) for calibration measurements.

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6. The probe head (100) of claim 3, further comprising a reference shutter (53) for selectively blocking light emitted from the irradiated sample volume from reaching the detector (52) to facilitate calibration of the spectrometer.
- 5
7. The probe head (100) of claim 1, wherein the light source (10) irradiates the sample volume with light in a visible to mid infrared spectral region.
8. The probe head (100) of claim 1, further comprising a diffuser (59) for diffusing light reflected from the irradiated sample volume into the wavelength separator (50).
- 10
9. The probe head (100) of claim 1, wherein color components of the sample volume are determined based on intensities of the wavelengths of the spatially separated light received by the detector.
- 15
10. The probe head (100) of claim 1, wherein the detector (52) has a viewing aperture of 100 mm² to 500 mm².
11. The probe head (100) of claim 1, further comprising an optical blocking element (57) positioned between the light source (10) and the detector (52) to force the light (48) from the light source (10) into the sample volume.
- 20
12. The probe head (100) of claim 1, wherein the optical blocking element (57) is a wall separating the first chamber (68) and the second chamber (65) of the housing (11).
- 25
13. A spectrometer for analyzing a material, the spectrometer comprising:
a probe head (100) comprising
a housing (11) having a first chamber (68) separated from a second chamber (65),
a light source (10) disposed in the first chamber (68) arranged to irradiate a sample volume of the material (14) with a plurality of wavelengths of light (48).
- 30

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5 a wavelength separator (50) disposed in the second chamber (65), the wavelength separator (50) receiving light (49) reflected from the irradiated sample volume to produce spatially separated light of different wavelengths, and

10 a detector (52) disposed in the second chamber (65) and positioned to receive the spatially separated light from the wavelength separator, the detector (52) generating an electrical signal representative of the intensity of the spatially separated light received from the wavelength separator (50), and

a computer (34) electrically coupled to the detector (52) and housed separately from the probe head, the computer (52) receiving the signal generated by the detector (52) and analyzing the sample volume based on the signal.

15 14. The spectrometer of claim 13, further comprising an analog to digital converter (33) coupled to the detector (52) and the computer (34), the analog to digital converter (33) converting the electrical signal from the detector (52) from an analog signal to a digital signal for receipt by the computer (34).

20 15. The spectrometer of claim 13, wherein the housing (11) of the probe head (100) is configured for positioning in a sample containment apparatus to monitor a material flowing through the sample containment apparatus.

25 16. A method of spectroscopically analyzing a material with a spectrometer, the method comprising:

irradiating a sample volume of the material with a plurality of wavelengths of light (48) from a light source (10) positioned in a first chamber (68),

receiving light (49) reflected from the irradiated sample volume in a second chamber (65),

30 separating wavelengths of the received light to produce spatially separated light of different wavelengths, and

detecting intensity of the spatially separated light with a detector (52) positioned in the second chamber (65) and electrically connected to the spectrometer.

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17. The method of claim 16, further comprising selectively reflecting a portion of light emanating from the light source into the second chamber (65) for calibration measurements.
18. The method of claim 16, wherein light from the light source is within a visible to mid infrared spectral region.
- 10 19. The method of claim 16, further comprising diffusing light reflected from the irradiated sample volume.
20. The method of claim 16, further comprising determining constituent components of the sample volume based on the detected intensity.
- 15 21. The method of claim 16, further comprising determining color components of the sample volume based on the detected intensity.
22. The method of claim 16, wherein the detector (52) has a viewing aperture of 100 mm² to 500 mm².
- 20 23. The method of claim 16, further comprising forcing light (48) from the light source (10) into the sample to inhibit the light from directly reaching the detector (52).

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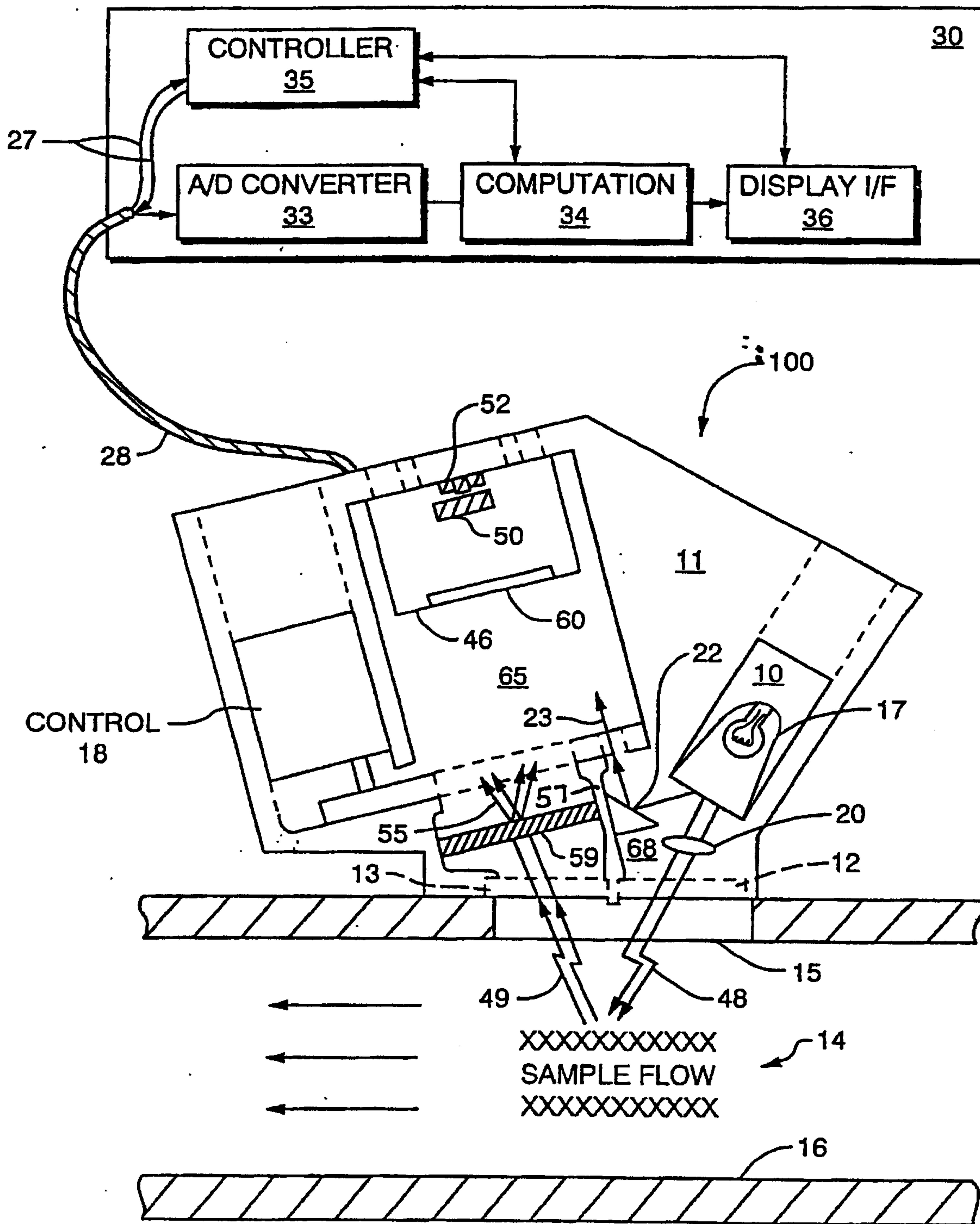
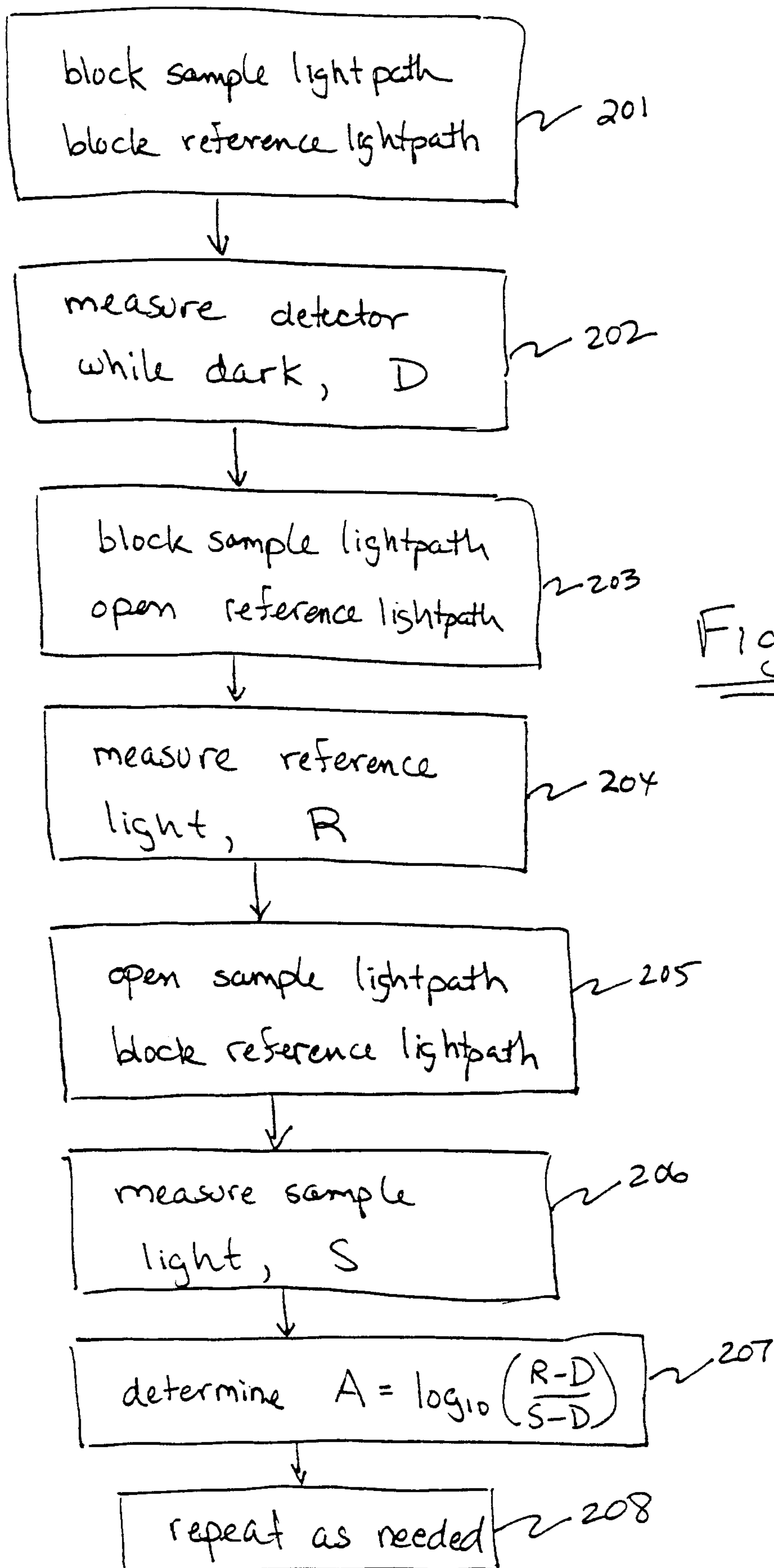


FIG. 1

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Fig. 2

