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[Continued on next page]

(54) Title: LIGHT INTENSITY CONTROL FOR NEAR INFRARED SPECTROSCOPY

(57) Abstract: A system for near infrared spectroscopy includes a controller that automates selection of light intensities for one or more light sources. The system may stepwise increase or decrease a current driving a light source until a signal received at a light detector is within a desired range. The system may maintain closed loop control over the intensity of a light source after the intensity has been set. The closed loop control may be based on a signal from a second light detector that senses light from the light source. Current/intensity settings may be established for each of multiple light detectors. In response to selection of a light detector, the corresponding current may be delivered to drive the light source.

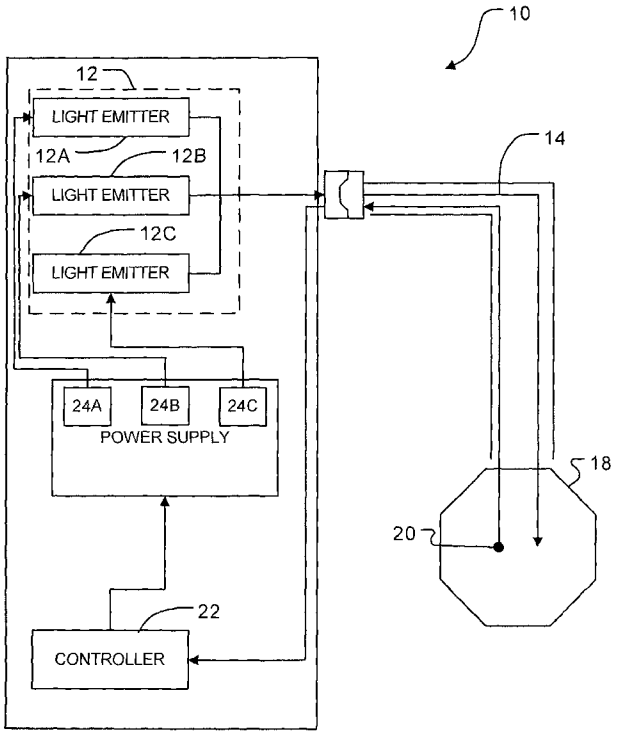

FIGURE 1

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ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

LIGHT INTENSITY CONTROL FOR NEAR INFRARED SPECTROSCOPY

Cross-Reference to Related Application

[0001] This application claims priority from United States patent application No. 60/915402 filed on 1 May 2007 and entitled LIGHT INTENSITY CONTROL FOR NEAR INFRARED SPECTROSCOPY. For purposes of the United States of America, this application claims the benefit under 35 U.S.C. §119 of United States patent application No. 60/915402 filed on 1 May 2007 and entitled LIGHT INTENSITY CONTROL FOR NEAR INFRARED SPECTROSCOPY which is hereby incorporated herein by reference.

Field of the Invention

[0002]This invention relates to near infrared spectroscopy (NIRS). Embodiments provide apparatus and methods for measuring the concentrations of compounds (typically biological compounds) in the tissues of living subjects using NIRS.

Background

[0003] Near Infrared Spectroscopy ("NIRS") is a technique which involves emitting near infrared ("NIR") light and receiving the NIR light after it has passed through a tissue or other medium of interest. NIRS can be applied to study and monitor biochemical compounds in the body. Emitted NIR light penetrates skin and other tissues and some of it is absorbed by biochemical compounds which have an absorption spectrum in the NIR region. NIR light which is not absorbed is scattered. Each biochemical compound has a different absorption spectrum. It is possible to estimate the concentration of biochemical compounds in the tissues by measuring characteristics of NIR light that has been detected after it has passed through the tissues.

[0004] A typical NIRS apparatus emits light of a number of wavelengths (typically two or more wavelengths) and detects light after it has passed through tissues of a living subject. Since light detectors are only sensitive within a given range, it is necessary that the intensity of the light emitted be sufficient to be detected by the light detector. It is also necessary that the intensity of the light not be so great that it saturates the detector.

[0005] There is a need for cost-effective, simple to operate apparatus for performing NIRS on living subjects.

Brief Description of the Drawings

[0006] The appended drawings illustrate non-limiting example embodiments of the invention.

[0007] Figure 1 is a block diagram illustrating a NIRS apparatus according to an embodiment of the invention.

[0008] Figure 2 is a flowchart illustrating a method for operating NIRS apparatus according to an embodiment of the invention.

Detailed Description

[0009] Figure 1 shows apparatus **10** for practicing NIRS. Apparatus **10** has several light emitters **12** (individually labeled **12A**, **12B** and **12C**). The number of light emitters may depend upon the intended application. Typically there will be two or three or four light emitters. Other numbers of light emitters are also possible. Some embodiments may provide five or more light emitters.

[0010] In some embodiments, light emitters **12** comprise solid state lasers (such as laser diodes) or high intensity light emitting diodes, or other light emitters that emit light having an appropriate wavelength. Light from light emitters **12** is carried by an optical fibre **14** or other light conduit to a probe or patch **18** which can be placed against the skin of a subject. Patch **18** also has disposed upon it one or more light detectors **20**.

[0011] In operation, light is emitted by light sources **12**. Each light emitter **12** emits light having a spectral character different from that of other light emitters **12**. For example, each light emitter **12** may emit light within a narrow wavelength band that is different from that of other light emitters **12**. Apparatus **10** can be made sensitive to changes in concentration of different compounds or other materials that interact differentially with light of different wavelengths. The wavelengths emitted by light emitters **12** are typically in the near-infrared portion of the spectrum (although the apparatus and methods described herein are not limited to any specific wavelengths or wavelength regions).

[0012] The light is carried by optical fibre **14** to patch **18** where it enters the tissues of a patient. Within the tissues of the patient the light is backscattered. Backscattered light is picked up by light detector(s) **20**. Measuring the amount of

backscattered light detected at detector **20** at various wavelengths permits changes in concentration of various biological compounds (and/or other materials present in the subjects' tissues) to be monitored.

[0013] It is desirable that the light output by each light emitter **12** have an intensity such that the backscattered (or transmitted) light emitted from that light emitter **12** and subsequently detected at detector **20** has an intensity in a portion of the range of detector **20** such that light detector **20** can detect changes in intensity of the backscattered (or transmitted) light and is not saturated.

[0014] The intensity of the detected light depends on a number of factors which may include:

- the intensity of light emitted by a light emitter **12**;
- the length of the path taken by light from the emitter **12** through the subject's tissues to detector **20**;
- the sensitivity of detector **20** to light from the light emitter **12**;
- the nature of the tissues through which the light propagates; and,
- the efficiency of any optical paths or devices which transmit light from light emitter **12** to the subject and from the subject to light detector **20**.

[0015] Apparatus **10** comprises a controller **22** which adjusts the output of each light emitter **12** in such a manner that the backscattered light detected at light detector **20** is within this desired range of operation, preferably somewhere near the center of the range of light intensities to which light detector **20** is sensitive. Since light detector **20** may have a sensitivity that is wavelength dependent, the desired intensity may be different for each light emitter **12.**

[0016] Controller **22** controls current sources **24A**, **24B** and **24C** (shown as individually-controllable outputs of a power supply **25** in the illustrated embodiment) which regulate the current supplied to each of light emitters **12A**, **12B** and **12C** respectively.

[0017] Controller **22** may comprise:

- a programmable controller, such as a digital signal processor, micro-processor, or the like;

- logic circuits provided by a field programmable gate array (FPGA), a set of discreet logic circuits, an application specific integrated circuit (ASIC) or the like;
- a combination thereof.

[0018] Controller **22** has a calibration mode wherein it adjusts the outputs of light emitters **12** (i.e. the intensity of emitted light) in response to measurements of the light detected at light detector **20**. The outputs of light emitters **12** may be varied by varying the electrical current driving each light emitter **12** in some embodiments. Controller **22** varies the light output of each light emitter **12** (for example by adjusting the driving current) until the light detected at light detector **20** is in a suitable portion of the range of light detector **20**.

[0019] If controller **22** completes its calibration sequence without being able to set the current driving a light source to a value which will result in the light source having a desired intensity then controller **22** may signal an alarm condition, for example by displaying a trouble light, a trouble message on a user interface, signaling an audible alarm, or the like.

[0020] In typical embodiments, during operation, each light emitter **12** is pulsed. For example, each light emitter may be operated to emit a pulse of light a few milliseconds or microseconds long. Light emitters **12** may be operated such that only one light emitter **12** is operating at any given time. This permits the variation in the amount of backscattered light at the wavelength of each light emitter **12** to be independently determined. In alternative embodiments, two or more light emitters **12** may be operated simultaneously, but in different combinations at different times, to permit variations in the amount of light backscattered at each of a plurality of wavelengths to be determined.

[0021] In the calibration mode, each light emitter **12** may be pulsed at a current level set by the corresponding current supply **24** under control of controller **22**. Controller **22** can determine from the intensity of light detected by light detector **20** at the instant the light emitter **12** is pulsed, whether or not a signal can be detected that corresponds to light being backscattered from light emitter **12** and also, whether or not that backscattered light has an intensity suitable to cause the detected signal to have a level within the desired range. If the backscattered light is too bright then controller **22** may reduce the current driving the light emitter **12** until the

backscattered light has an intensity within a desired range. If the backscattered light is too dim, then controller **22** may increase the driving current of the light emitter **12** until the backscattered light is within the desired range. Adjustments to the current driving each light source **12** may be made in a step wise manner during calibration.

[0022] In some embodiments, the size of the steps is varied, depending upon how different the light intensity detected at detector **20** is from the desirable light intensity. If the intensity of light detected at light detector **20** is very much greater or less than the desired light intensity then the current driving the light emitter **12** may be varied in relatively large steps. If the intensity detected at light detector **20** is not optimum but is fairly close to the optimum light intensity then the current driving the corresponding light emitter **12** may be adjusted in smaller steps.

[0023] After each light emitter **12** has been adjusted so that backscattered light can be detected successfully at light detector **20** within a desired part of the range of light detector **20** then the current supplied to each of the light emitters **12** may be controlled to keep the current for each light emitter **12** (and therefore the intensity of light emitted by each light emitter **12**) at the optimum value.

[0024] Figure 2 shows a method **40** according to an example embodiment of the invention. Method **40** may be implemented in a data processor or other programmable advice by providing instructions which are executed by the programable device to cause it to execute method **40**.

[0025] In block **42**, an initial starting current is set for each light emitter **12**. This initial value may be approximately at the threshold current for operating each light emitter **12**. In block **44**, an appropriate target signal level is set and one of light emitters **12** is selected for initial adjustment. In block **45**, the selected light emitter is operated with a current at the initial value and the resulting signal received at light detector **20** is measured.

[0026] In block **46**, a determination is made as to whether a signal detected is within the desired range. If there is a "yes" result in block **46** then a flag is set in block **47** to indicate that the selected light emitter **12** has been adjusted. Block **48** then determines if all light emitters **12** have been adjusted. In the event of a "no" result

in block **48** then the next light emitter **12** is selected in block **49** and method **40** returns to block **45** where the next light emitter **12** is selected.

[0027] In the event of a "yes" result in block **48**, all light emitters **12** have been adjusted and method **40** ends at block **99**.

[0028] In the even of a "no" result in block **46**, block **50** determines whether the current selected for the current light emitter **12** has a value that is outside of an allowable current range. If so then, in block **51**, the current driving the selected light emitter **12** is brought back into the allowable range and in block **52** the target signal level is evaluated to determine whether it could be reduced. If there exists an allowable target signal level lower than the existing target signal level then, in block **54**, the target signal level is set to the lower value and control returns to block **44**. If there is no lower signal level allowed then in block **55**, a flag is set indicating that it was not possible to achieve suitable signal levels and method **40** terminates at block **99**.

[0029] In the event of a "no" result at block **50**, then block **57** determines whether or not the detected signal is less than the maximum allowable detected signal. If yes, then the driving current for the current light emitter **12** is decreased in block **58**. If no, then the driving current for the current light emitter **12** is increased in block **59**. In block **60**, method **40** selects the next light emitter **12** and returns to block **45** for further processing.

[0030] It can be appreciated that, in some embodiments at least, the methods and apparatus of this invention are advantageous because they automatically take into account differences in the sensitivity of light detector(s) **20** to different wavelengths of light.

[0031] In some embodiments, after the desired intensity of each light emitter **12** has been determined, the light output of each light emitter **12** is controlled with reference to a signal from a separate light detector (not shown) that directly detects the light emitted from the light emitter **12** before that light passes through tissues of a subject. The light intensity of each light emitter **12** may be controlled in a closed-loop control.

[0032] Separate calibrations may be provided for each of a number of different light detectors **20** located at different locations to detect light that has been backscattered by a section of tissue and/or has passed through the section of tissue. Controller **22** may be programmed or otherwise configured to apply different driving currents to light sources **12** depending upon which light detector **20** is being monitored. For example, there may be ten different light detectors **20** at different distances from or different positions relative to the point at which light is emitted into the subject from optical fibre **14**. A different set of driving current values (or other intensity-determining values) may be determined for each light detector **20**. Controller **22** may select a set of current values corresponding to a particular light detector **20** and then operate the light emitters **12** with those current values while monitoring the light detector **20** and then repeat the procedure for other light detectors **20**.

[0033] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. For example:

- Light detected at light detector **20** is not necessarily backscattered light. The light may be detected after passing through a section of tissue in a forward direction.
- Light detector **20** is not necessarily mounted on patch **18**. Light detector **20** could be located remotely from patch **18**. Light detector **20** could be provided on a separate probe or patch from patch **18** or light could be carried to light detector **20** by an optical fiber or other optical conduit extending from patch **18** to light detector **20**.

[0034] Certain implementations of the invention comprise computer processors which execute software instructions which cause the processors to perform a method of the invention. For example, one or more processors in a NIRS apparatus may implement the methods of the invention by executing software instructions in a program memory accessible to the processors. The invention may also be provided in the form of a program product. The program product may comprise any medium which carries a set of computer-readable signals comprising instructions which, when executed by a computer processor, cause the data processor to execute a method of the invention. Program products according to the invention may be in any of a wide variety of forms. The program product may comprise, for example, physical media such as magnetic data storage media including floppy diskettes, hard disk drives, optical data storage media including CD ROMs, DVDs, electronic data

storage media including ROMs, flash RAM, or the like. The computer-readable signals on the program product may optionally be encoded, compressed or encrypted.

[0035] Where a component (e.g. a software module, processor, assembly, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

WHAT IS CLAIMED IS:

1. Apparatus for near infrared spectroscopy (NIRS) comprising:

a light source;

at least one first light detector positionable to detect light from the light source after the light has passed through tissues of a subject;

a controller connected to receive an output signal from the first light detector and configured to set an intensity of light emitted by the light source based at least in part on the output signal from the first light detector to cause the output signal from the first light detector to be in a predetermined range.

2. Apparatus according to claim 1 wherein the light source comprises a solid-state light source.

3. Apparatus according to claim 2 wherein the solid-state light source comprises a laser diode.

4. Apparatus according to any of claims 1 to 3 wherein the controller is configured to stepwise increase an electrical current drawn by the light source in response to determining that the output signal from the first light detector is below a lower threshold.

5. Apparatus according to claim 4 wherein the controller is configured to stepwise decrease an electrical current drawn by the light source in response to determining that the output signal from the first light detector is above an upper threshold.

6. Apparatus according to claim 4 or 5 wherein the controller is configured to set a step-size for the stepwise increase of electrical current based at least in part on a difference between the output signal from the first light detector and a desired output signal value.

7. Apparatus according to claim 5 or 6 wherein the controller is configured to set a step-size for the stepwise decrease of electrical current based at least in part on a difference between the output signal from the first light detector and a desired output signal value.

8. Apparatus according to any one of claims 1 to 7 wherein the light source constitutes a first one of a plurality of light sources and the controller is configured to independently set the intensity for each one of the plurality of light sources.

9. Apparatus according to claim 8 wherein each of the plurality of light sources is capable of emitting light having spectral characteristics distinct from spectral characteristics of at least one other one of the plurality of light sources and the first light detector has different sensitivities to the light emitted by different ones of the light sources.

10. Apparatus according to claim 8 or 9 wherein the controller is configured to sequentially set the light output for each of the plurality of light sources.

11. Apparatus according to claim 8 or 9 wherein the controller is configured to: operate light sources of the plurality of light sources in a plurality of different combinations; determine a value for the output signal from the first light detector corresponding to each one of the different combinations; and, set the intensity of the first one of a plurality of light sources based upon the values for the output signal corresponding to a plurality of the combinations.

12. Apparatus according to claim 8 comprising a control configured to regulate current drawn by each of the plurality of light sources to have a value corresponding to the intensity set by the controller for the light source.

13. Apparatus according to claim 12 wherein the control comprises a closed-loop control.

14. Apparatus according to claim 13 comprising one or more second light detectors positioned to receive light emitted by light sources of the plurality of light sources wherein the closed-loop control controls the current drawn by each of the plurality of light sources in response to a signal from the second light detectors.

15. Apparatus according to any one of claims 1 to 14 wherein the controller is configured to generate an alarm indication in the event that the controller

fails to cause the output signal from the first light detector to be in a predetermined range after a predetermined number of attempts.

16. Apparatus according to any one of claims 1 to 12 comprising a second light detector located to detect light emitted by the light source.

17. Apparatus according to claim 16 comprising a closed-loop control set to control a light output of the light source to have the intensity set by the controller in response to a signal from the second light detector.

18. Apparatus according to any one of claims 1 to 17 wherein the controller comprises a programmed data processor.

19. Apparatus according to any one of claims 1 to 18 comprising a plurality of first light detectors wherein the controller is configured to determine and store information specifying a set light intensity for the light source corresponding to each of the plurality of first light detectors.

20. An automated method for set up of apparatus for near infrared spectroscopy (NIRS) comprising a solid-state light source and a first light detector positionable to detect light from the light source after the light has passed through tissues of a subject, the method comprising the steps of:

(a) setting a current drawn by the solid-state light source to an initial value;

(b) comparing an output signal of the light detector to a desired range;

(c) if the output signal is outside of the desired range stepwise increasing or decreasing the current to cause the light output to approach the desired range; and,

(d) repeating steps (b) and (c) until the output signal is within the desired range or a termination condition is satisfied.

21. A method according to claim 20 comprising repeating the method for each one of a plurality of different solid-state light sources.

22. A method according to claim 20 or 21 comprising setting a step size for step (c) based at least in part upon a difference between the output signal and a desired value for the output signal.

23. A method according to any one of claims 20 to 22 wherein the first light detector constitutes one of a plurality of first light detectors wherein the method comprises repeating the method for each one of the plurality of first light detectors.

24. A method according to claim 23 comprising, for at least one of the plurality of first light detectors storing information specifying a current for the first light source.

25. A method according to claim 24 comprising, upon selection of the one of the plurality of first light detectors, retrieving the information specifying a current for the first light source and controlling the current to the first light source according to the specified current.

26. A method according to any one of claims 20 to 25 comprising operating the light source while maintaining closed loop control of current to the light source.

27. A method according to claim 26 wherein maintaining closed loop control of current to the light source comprises monitoring an intensity of light output by the solid-state light source by way of a second light sensor and controlling the current to the solid-state light source based on an output from the second light sensor.

28. Apparatus comprising any new, useful and inventive feature, combination of features or sub-combination of features as described herein.

29. A method comprising any new useful and inventive step, act, combination of steps and/or acts or sub-combination of steps and/or acts as described herein.

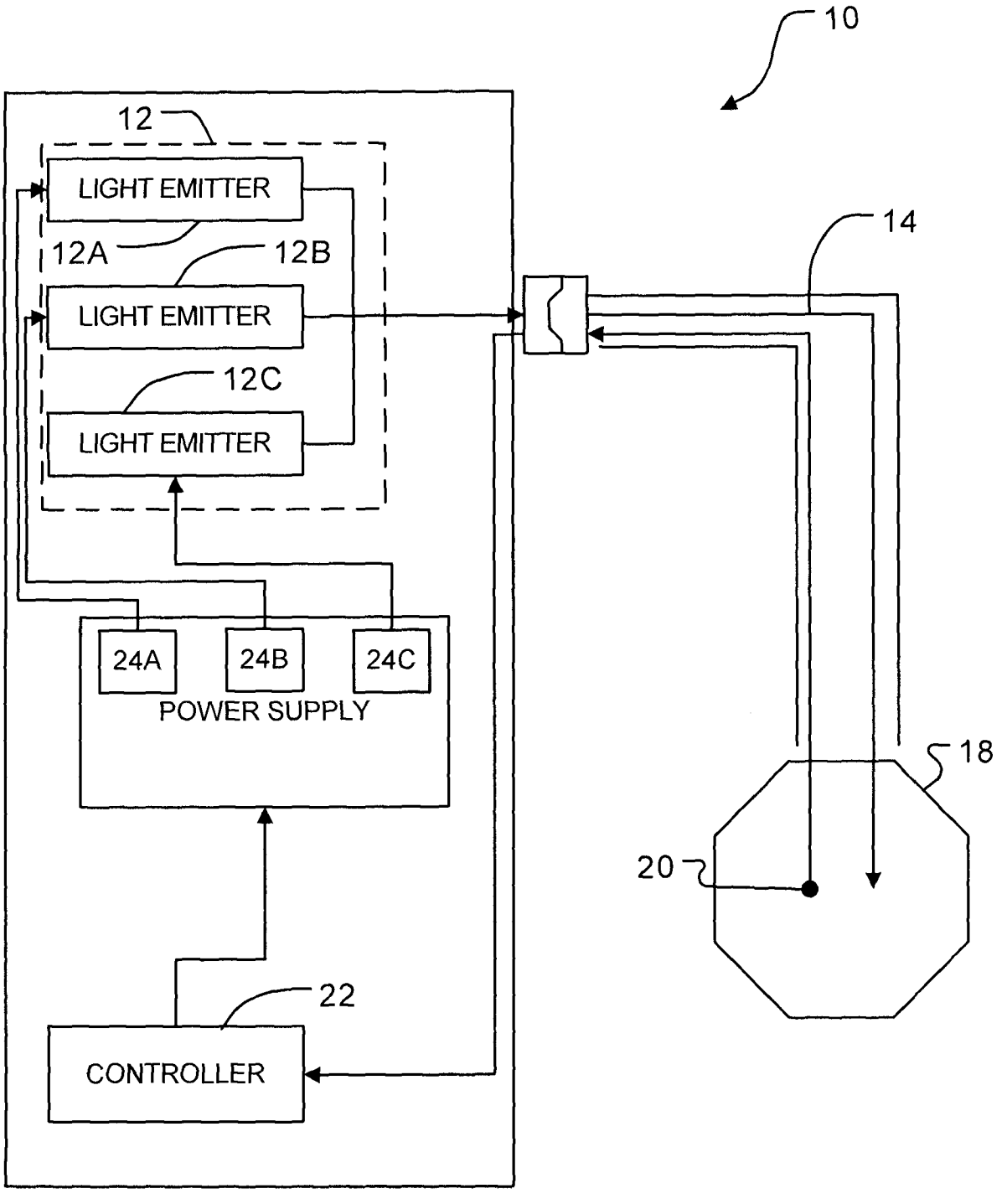
10
12
LIGHT EMITTER
12A
12B
LIGHT EMITTER
12C
LIGHT EMITTER
14
24A
24B
24C
POWER SUPPLY
18
20
22
CONTROLLER

FIGURE 1

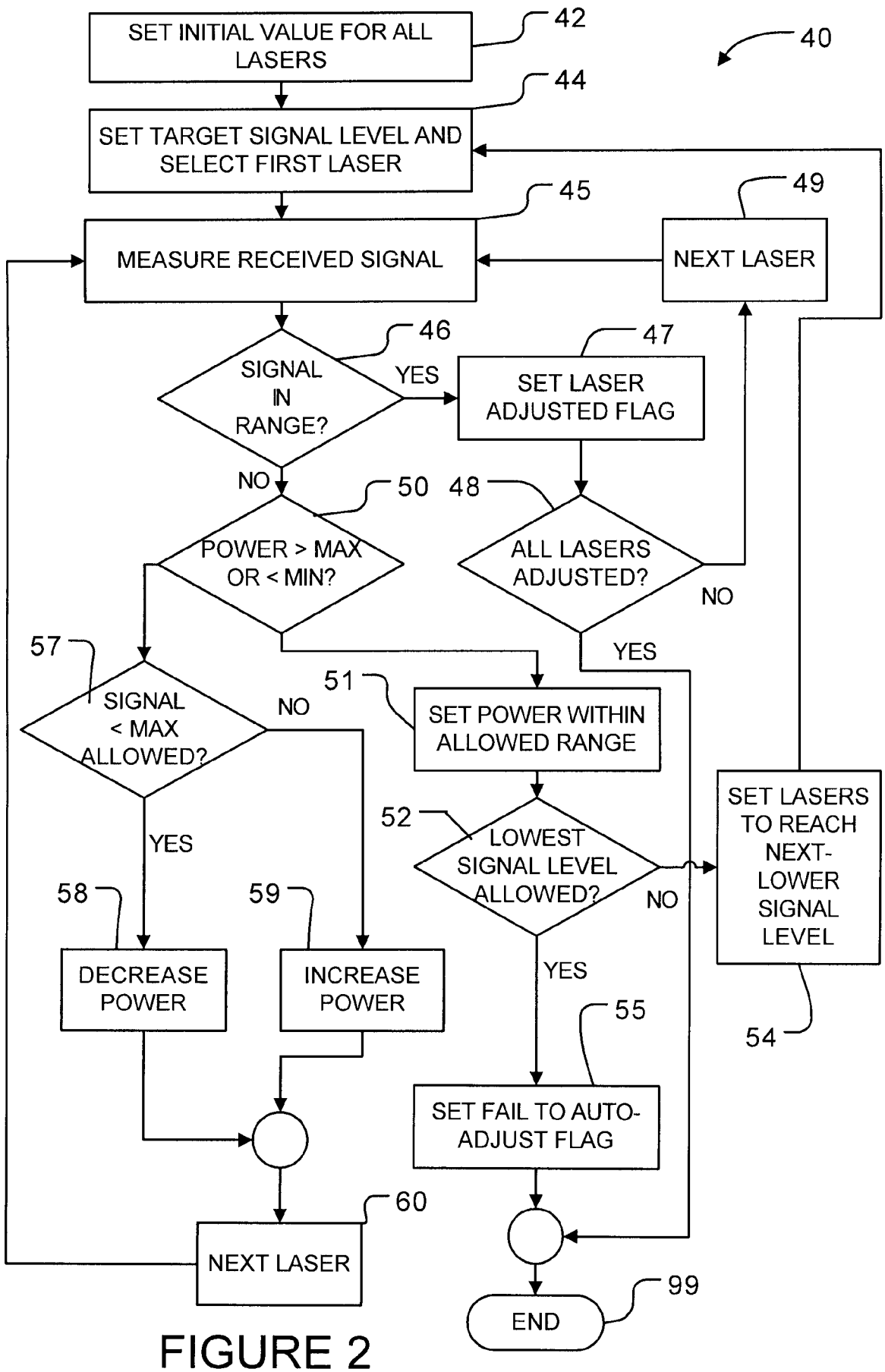
SET INITIAL VALUE FOR ALL LASERS
42
40
SET TARGET SIGNAL LEVEL AND SELECT FIRST LASER
44
MEASURE RECEIVED SIGNAL
45
NEXT LASER
49
SIGNAL IN RANGE?
46
YES
SET LASER ADJUSTED FLAG
47
NO
POWER > MAX OR < MIN?
50
ALL LASERS ADJUSTED?
48
NO
YES
SIGNAL < MAX ALLOWED?
57
NO
SET POWER WITHIN ALLOWED RANGE
51
YES
LOWEST SIGNAL LEVEL ALLOWED?
52
NO
SET LASERS TO REACH NEXT-LOWER SIGNAL LEVEL
54
YES
DECREASE POWER
58
INCREASE POWER
59
SET FAIL TO AUTO-ADJUST FLAG
55
NEXT LASER
60
END
99

FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2008/000820

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***A61B 6/00*** (2006.01) , ***A61B 5/00*** (2006.01) , ***A61B 5/1455*** (2006.01) , *G01J 3/10* (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC A61B 6* (2006.01)(all subgroups in combination with keywords)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Delphion, Canadian Patent Databse, USPTO West, IEEE Xplore, Google Scholar (keywords: infrared spectroscopy, light intensity, source, detector, controller, laser diode)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7,047,054 B2 (Benni) 16 May 2006 (16-05-2006) * column 3, lines 2-5, 39 * column 11, line 60 - column 12, line 2	1-27
A	US 4,975,581 (Robinson et al.) 4 December 1990 (04-12-1990) * see entire document	1-27
A	US 6,040,578 (Malin et al.) 21 March 2000 (21-03-2000) * see entire document	1-27
A	US 4,496,839 (Bernstein et al.) 29 January 1985 (29-01-1985) * see entire document	1-27

[ ] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 June 2008 (27-06-2008)	5 September 2008 (05-09-2008)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Saadia Khan 819-934-6752

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2008/000820

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

1. [X] Claim Nos. : 28 and 29
because they relate to subject matter not required to be searched by this Authority, namely :

Claims 28 and 29 do not comply with PCT Article 6 because the language used is broader in scope than the teaching of the description, therefore the claims cannot be examined.

2. [ ] Claim Nos. :
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. [ ] Claim Nos. :
because they are dependant claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos. :

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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