US008649839B2

(12) **United States Patent**
Chin et al.

(10) **Patent No.: US 8,649,839 B2**
(45) **Date of Patent: Feb. 11, 2014**

(54) **MOTION COMPATIBLE SENSOR FOR NON-INVASIVE OPTICAL BLOOD ANALYSIS**

(75) Inventors: **Rodney Chin**, Oakland, CA (US); **Paul D Mannheimer**, Danville, CA (US); **Ross Flewelling**, Oakland, CA (US)

(73) Assignee: **Covidien LP**, Mansfield, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/822,898**

(22) Filed: **Jun. 24, 2010**

(65) **Prior Publication Data**

US 2010/0261986 A1 Oct. 14, 2010

Related U.S. Application Data

(60) Continuation of application No. 11/827,858, filed on Jul. 13, 2007, now abandoned, which is a continuation of application No. 10/991,111, filed on Nov. 16, 2004, now Pat. No. 7,260,425, which is a continuation of application No. 10/080,433, filed on Feb. 21, 2002, now Pat. No. 6,845,256, which is a division of application No. 09/348,437, filed on Jul. 7, 1999, now Pat. No. 6,374,129, which is a division of application No. 08/722,443, filed on Oct. 10, 1996, now Pat. No. 6,018,673.

(51) **Int. Cl.**
A61B 5/1455 (2006.01)

(52) **U.S. Cl.**
USPC **600/324**

(58) **Field of Classification Search**
USPC 600/310, 323, 336, 340, 476
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,403,555	A	10/1968	Versaci et al.
3,536,545	A	10/1970	Traynor et al.
D222,454	S	10/1971	Beeber
3,721,813	A	3/1973	Condon et al.
4,098,772	A	7/1978	Bonk et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	3405444	8/1985
DE	3516338	11/1986

(Continued)

OTHER PUBLICATIONS

Azhar, N., et al.; "Automatic Feedback Control of Oxygen Therapy Using Pulse Oximetry," *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, vol. 13, No. 4, pp. 1614-1615 (1991).

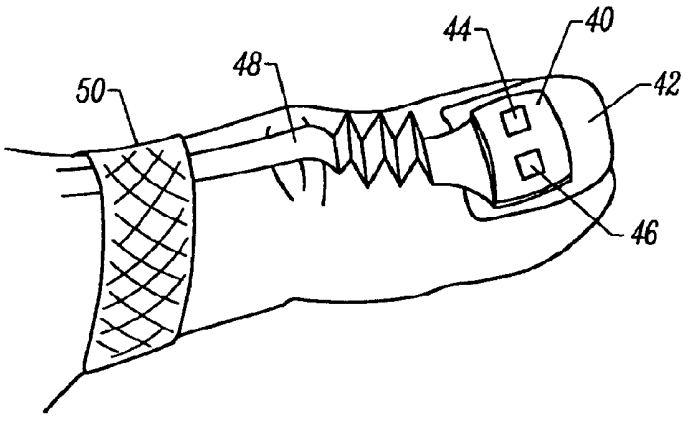
(Continued)

Primary Examiner — Tse Chen
Assistant Examiner — Rochelle Reardon
(74) *Attorney, Agent, or Firm* — Fletcher Yoder

(57) **ABSTRACT**

A non-invasive optical sensor which uses the motion signal to calculate the physiological characteristic being measured. For pulse oximetry, a least squares or a ratio-of-ratios technique can be applied to the motion signal itself. This is made possible by selecting a site on the patient where variations in motion produce signals of two wavelengths which are sufficiently correlated. In particular, it has been determined that a sensor placed on a nail, in particular a thumbnail, exhibits the characteristics of having the red and infrared signals correlated when used for pulse oximetry, and the resulting signals correlate to arterial oxygen saturation.

13 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,120,296 A * 10/1978 Prinz 600/503
D250,275 S 11/1978 Bond
D251,387 S 3/1979 Ramsey et al.
D262,488 S 12/1981 Rossman et al.
4,334,544 A 6/1982 Hill et al.
4,350,165 A 9/1982 Striese
4,353,372 A 10/1982 Ayer
4,380,240 A 4/1983 Jobsis et al.
4,406,289 A 9/1983 Wesseling et al.
4,510,551 A 4/1985 Brainard, II
4,586,513 A 5/1986 Hamaguri
4,603,700 A 8/1986 Nichols et al.
4,621,643 A 11/1986 New, Jr. et al.
4,653,498 A 3/1987 New, Jr. et al.
4,677,528 A 6/1987 Miniet
4,685,464 A 8/1987 Goldberger et al.
4,694,833 A 9/1987 Hamaguri
4,697,593 A 10/1987 Evans et al.
4,700,708 A 10/1987 New, Jr. et al.
4,714,080 A 12/1987 Edgar, Jr. et al.
4,714,341 A 12/1987 Hamaguri et al.
4,722,120 A 2/1988 Lu
4,726,382 A 2/1988 Boehmer et al.
4,759,369 A 7/1988 Taylor
4,770,179 A 9/1988 New, Jr. et al.
4,773,422 A 9/1988 Isaacson et al.
4,776,339 A 10/1988 Schreiber
4,781,195 A 11/1988 Martin
4,783,815 A 11/1988 Buttner
4,796,636 A 1/1989 Branstetter et al.
4,800,495 A 1/1989 Smith
4,800,885 A 1/1989 Johnson
4,802,486 A 2/1989 Goodman et al.
4,805,623 A 2/1989 Jöbsis
4,807,630 A 2/1989 Malinouskas
4,807,631 A 2/1989 Hersh et al.
4,819,646 A 4/1989 Cheung et al.
4,819,752 A 4/1989 Zelin
4,824,242 A 4/1989 Frick et al.
4,825,872 A 5/1989 Tan et al.
4,825,879 A 5/1989 Tan et al.
4,830,014 A 5/1989 Goodman et al.
4,832,484 A 5/1989 Aoyagi et al.
4,846,183 A 7/1989 Martin
4,848,901 A 7/1989 Hood, Jr.
4,854,699 A 8/1989 Edgar, Jr.
4,859,056 A 8/1989 Prosser et al.
4,859,057 A 8/1989 Taylor et al.
4,863,265 A 9/1989 Flower et al.
4,865,038 A 9/1989 Rich et al.
4,867,557 A 9/1989 Takatani et al.
4,869,253 A 9/1989 Craig, Jr. et al.
4,869,254 A 9/1989 Stone et al.
4,880,304 A 11/1989 Jaeb et al.
4,883,055 A 11/1989 Merrick
4,883,353 A 11/1989 Hausman et al.
4,890,619 A 1/1990 Hatschek
4,892,101 A 1/1990 Cheung et al.
4,901,238 A 2/1990 Suzuki et al.
4,908,762 A 3/1990 Suzuki et al.
4,911,167 A 3/1990 Corenman et al.
4,913,150 A 4/1990 Cheung et al.
4,926,867 A 5/1990 Kanda et al.
4,927,264 A 5/1990 Shiga et al.
4,928,692 A 5/1990 Goodman et al.
4,934,372 A 6/1990 Corenman et al.
4,938,218 A 7/1990 Goodman et al.
4,942,877 A 7/1990 Sakai et al.
4,948,248 A 8/1990 Lehman
4,955,379 A 9/1990 Hall
4,960,126 A 10/1990 Conlon et al.
4,964,408 A 10/1990 Hink et al.
4,971,062 A 11/1990 Hasebe et al.
4,974,591 A 12/1990 Awazu et al.
5,007,423 A 4/1991 Branstetter et al.
5,025,791 A 6/1991 Niwa
RE33,643 E 7/1991 Isaacson et al.
5,028,787 A 7/1991 Rosenthal et al.
5,035,243 A 7/1991 Muz
5,040,539 A 8/1991 Schmitt et al.
5,041,187 A 8/1991 Hink et al.
5,054,488 A 10/1991 Muz
5,055,671 A 10/1991 Jones
5,058,588 A 10/1991 Kaestle
5,065,749 A 11/1991 Hasebe et al.
5,066,859 A 11/1991 Karkar et al.
5,069,213 A 12/1991 Polczynski
5,078,136 A 1/1992 Stone et al.
5,086,229 A 2/1992 Rosenthal et al.
5,088,493 A 2/1992 Giannini et al.
5,090,410 A 2/1992 Saper et al.
5,094,239 A 3/1992 Jaeb et al.
5,094,240 A 3/1992 Muz
5,099,841 A 3/1992 Heinonen et al.
5,099,842 A 3/1992 Mannheimer et al.
H1039 H 4/1992 Tripp et al.
5,101,825 A 4/1992 Gravenstein et al.
5,104,623 A 4/1992 Miller
5,109,849 A 5/1992 Goodman et al.
5,111,817 A 5/1992 Clark et al.
5,113,861 A 5/1992 Rother
D326,715 S 6/1992 Schmidt
5,125,403 A 6/1992 Culp
5,127,068 A 6/1992 Baer et al.
5,127,406 A 7/1992 Yamaguchi
5,131,391 A 7/1992 Sakai et al.
5,140,989 A 8/1992 Lewis et al.
5,152,296 A 10/1992 Simons
5,154,175 A 10/1992 Gunther
5,158,082 A 10/1992 Jones
5,170,786 A 12/1992 Thomas et al.
5,188,108 A 2/1993 Secker et al.
5,190,038 A 3/1993 Polson et al.
5,193,542 A 3/1993 Missanelli et al.
5,193,543 A 3/1993 Yelderman
5,203,329 A 4/1993 Takatani et al.
5,209,230 A 5/1993 Swedlow et al.
5,213,099 A 5/1993 Tripp et al.
5,216,598 A 6/1993 Branstetter et al.
5,217,012 A 6/1993 Young et al.
5,217,013 A 6/1993 Lewis et al.
5,218,207 A 6/1993 Rosenthal
5,218,962 A 6/1993 Mannheimer et al.
5,224,478 A 7/1993 Sakai et al.
5,226,417 A 7/1993 Swedlow et al.
5,228,440 A 7/1993 Chung et al.
5,237,994 A 8/1993 Goldberger
5,239,185 A 8/1993 Ito et al.
5,246,002 A 9/1993 Prosser
5,246,003 A 9/1993 DeLonzor
5,247,931 A 9/1993 Norwood
5,247,932 A 9/1993 Chung et al.
5,249,576 A 10/1993 Goldberger et al.
5,253,645 A 10/1993 Friedman et al.
5,253,646 A 10/1993 Delpy et al.
5,259,381 A 11/1993 Cheung et al.
5,259,761 A 11/1993 Schnettler et al.
5,263,244 A 11/1993 Centa et al.
5,266,803 A * 11/1993 Heffelfinger 250/582
5,267,562 A 12/1993 Ukawa et al.
5,267,563 A 12/1993 Swedlow et al.
5,267,566 A 12/1993 Choucair et al.
5,273,036 A 12/1993 Kronberg et al.
5,275,159 A 1/1994 Griebel
5,278,627 A 1/1994 Aoyagi et al.
5,279,295 A 1/1994 Martens et al.
5,285,783 A 2/1994 Secker
5,285,784 A 2/1994 Seeker
5,287,853 A 2/1994 Vester et al.
5,291,884 A 3/1994 Heinemann et al.
5,297,548 A 3/1994 Pologe
5,299,120 A 3/1994 Kaestle
5,299,570 A 4/1994 Hatschek
5,309,908 A 5/1994 Friedman et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,311,865 A 5/1994 Mayeux
5,313,940 A 5/1994 Fuse et al.
5,323,776 A 6/1994 Blakely et al.
5,329,922 A 7/1994 Atlee, III
5,337,744 A 8/1994 Branigan
5,339,810 A 8/1994 Ivers et al.
5,343,818 A 9/1994 McCarthy et al.
5,343,869 A 9/1994 Pross et al.
5,348,003 A 9/1994 Caro
5,348,004 A 9/1994 Hollub et al.
5,348,005 A 9/1994 Merrick et al.
5,349,519 A 9/1994 Kaestle
5,349,952 A 9/1994 McCarthy et al.
5,349,953 A 9/1994 McCarthy et al.
5,351,685 A 10/1994 Potratz
5,353,799 A 10/1994 Chance
5,355,880 A 10/1994 Thomas et al.
5,355,882 A 10/1994 Ukawa et al.
5,361,758 A 11/1994 Hall et al.
5,365,066 A 11/1994 Krueger, Jr. et al.
5,368,025 A 11/1994 Young et al.
5,368,026 A 11/1994 Swedlow et al.
5,368,224 A 11/1994 Richardson et al.
5,372,136 A 12/1994 Steuer et al.
5,377,675 A 1/1995 Ruskewicz et al.
5,385,143 A 1/1995 Aoyagi
5,387,122 A 2/1995 Goldberger et al.
5,390,670 A 2/1995 Centa et al.
5,392,777 A 2/1995 Swedlow et al.
5,398,680 A 3/1995 Polson et al.
5,402,777 A 4/1995 Warring et al.
5,402,779 A 4/1995 Chen et al.
5,411,023 A 5/1995 Morris, Sr. et al.
5,411,024 A 5/1995 Thomas et al.
5,413,099 A 5/1995 Schmidt et al.
5,413,100 A 5/1995 Barthelemy et al.
5,413,101 A 5/1995 Sugiura
5,413,102 A 5/1995 Schmidt et al.
5,417,207 A 5/1995 Young et al.
5,421,329 A 6/1995 Casciani et al.
5,425,360 A 6/1995 Nelson
5,425,362 A 6/1995 Siker et al.
5,427,093 A 6/1995 Ogawa et al.
5,429,128 A 7/1995 Cadell et al.
5,429,129 A 7/1995 Lovejoy et al.
5,431,159 A 7/1995 Baker et al.
5,431,170 A 7/1995 Mathews
5,437,275 A 8/1995 Amundsen et al.
5,438,986 A 8/1995 Disch et al.
5,448,991 A 9/1995 Polson et al.
5,452,717 A 9/1995 Branigan et al.
5,465,714 A 11/1995 Scheuing
5,469,845 A 11/1995 DeLonzor et al.
RE35,122 E 12/1995 Corenman et al.
5,482,034 A 1/1996 Lewis et al.
5,482,036 A 1/1996 Diab et al.
5,485,847 A 1/1996 Baker, Jr.
5,490,505 A 2/1996 Diab et al.
5,490,523 A 2/1996 Isaacson et al.
5,491,299 A 2/1996 Naylor et al.
5,494,032 A 2/1996 Robinson et al.
5,494,043 A 2/1996 O'Sullivan et al.
5,497,771 A 3/1996 Rosenheimer
5,499,627 A 3/1996 Steuer et al.
5,503,148 A 4/1996 Pologe et al.
5,505,199 A 4/1996 Kim
5,507,286 A 4/1996 Solenberger
5,511,546 A 4/1996 Hon
5,517,988 A 5/1996 Gerhard
5,520,177 A 5/1996 Ogawa et al.
5,521,851 A 5/1996 Wei et al.
5,522,388 A 6/1996 Ishikawa et al.
5,524,617 A 6/1996 Mannheimer
5,529,064 A 6/1996 Rall et al.
5,533,507 A 7/1996 Potratz et al.
5,551,423 A 9/1996 Sugiura
5,551,424 A 9/1996 Morrison et al.
5,553,613 A 9/1996 Parker
5,553,614 A 9/1996 Chance
5,553,615 A 9/1996 Carim et al.
5,555,882 A 9/1996 Richardson et al.
5,558,096 A 9/1996 Palatnik
5,560,355 A 10/1996 Merchant et al.
5,564,417 A 10/1996 Chance
5,575,284 A 11/1996 Athan et al.
5,575,285 A 11/1996 Takanashi et al.
5,577,500 A 11/1996 Potratz
5,582,169 A 12/1996 Oda et al.
5,584,296 A 12/1996 Cui et al.
5,588,425 A 12/1996 Sackner et al.
5,588,427 A 12/1996 Tien
5,590,652 A 1/1997 Inai
5,595,176 A 1/1997 Yamaura
5,596,986 A 1/1997 Goldfarb
5,611,337 A 3/1997 Bukta
5,617,852 A 4/1997 MacGregor
5,619,992 A 4/1997 Guthrie et al.
5,626,140 A 5/1997 Feldman et al.
5,630,413 A 5/1997 Thomas et al.
5,632,272 A 5/1997 Diab et al.
5,632,273 A 5/1997 Suzuki
5,634,459 A 6/1997 Gardosi
5,638,593 A 6/1997 Gerhardt et al.
5,638,816 A 6/1997 Kiani-Azarbayjany et al.
5,638,818 A 6/1997 Diab et al.
5,645,060 A 7/1997 Yorkey et al.
5,645,440 A 7/1997 Tobler et al.
5,660,567 A 8/1997 Nierlich et al.
5,662,105 A 9/1997 Tien
5,662,106 A 9/1997 Swedlow et al.
5,664,270 A 9/1997 Bell et al.
5,666,952 A 9/1997 Fuse et al.
5,671,529 A 9/1997 Nelson
5,673,692 A 10/1997 Schulze et al.
5,673,693 A 10/1997 Solenberger
5,676,139 A 10/1997 Goldberger et al.
5,676,141 A 10/1997 Hollub
5,678,544 A 10/1997 DeLonzor et al.
5,680,857 A 10/1997 Pelikan et al.
5,685,299 A 11/1997 Diab et al.
5,685,301 A 11/1997 Klomhaus
5,687,719 A 11/1997 Sato et al.
5,687,722 A 11/1997 Tien et al.
5,692,503 A 12/1997 Kuenstner
5,692,505 A 12/1997 Fouts
5,709,205 A 1/1998 Bukta
5,713,355 A 2/1998 Richardson et al.
5,724,967 A 3/1998 Venkatachalam
5,727,547 A 3/1998 Levinson et al.
5,730,124 A 3/1998 Yamauchi
5,731,582 A 3/1998 West
D393,830 S 4/1998 Tobler et al.
5,743,260 A 4/1998 Chung et al.
5,743,262 A 4/1998 Lepper, Jr. et al.
5,743,263 A 4/1998 Baker, Jr.
5,746,206 A 5/1998 Mannheimer
5,746,697 A 5/1998 Swedlow et al.
5,752,914 A 5/1998 DeLonzor et al.
5,755,226 A 5/1998 Carim et al.
5,758,644 A 6/1998 Diab et al.
5,760,910 A 6/1998 Lepper, Jr. et al.
5,766,125 A 6/1998 Aoyagi et al.
5,766,127 A 6/1998 Pologe et al.
5,769,785 A 6/1998 Diab et al.
5,772,587 A 6/1998 Gratton et al.
5,774,213 A 6/1998 Trebino et al.
5,776,058 A 7/1998 Levinson et al.
5,776,059 A 7/1998 Kaestle
5,779,630 A 7/1998 Fein et al.
5,779,631 A 7/1998 Chance
5,782,237 A 7/1998 Casciani et al.
5,782,756 A 7/1998 Mannheimer
5,782,757 A * 7/1998 Diab et al. 600/323
5,782,758 A 7/1998 Ausec et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,786,592 A 7/1998 Hök
5,788,634 A 8/1998 Suda et al.
5,790,729 A 8/1998 Pologe et al.
5,792,052 A 8/1998 Isaacson et al.
5,795,292 A 8/1998 Lewis et al.
5,797,841 A 8/1998 DeLonzor et al.
5,800,348 A 9/1998 Kaestle
5,800,349 A 9/1998 Isaacson et al.
5,803,910 A 9/1998 Potratz
5,807,246 A 9/1998 Sakaguchi et al.
5,807,247 A 9/1998 Merchant et al.
5,807,248 A 9/1998 Mills
5,807,266 A * 9/1998 Itonaga et al. 600/499
5,810,724 A 9/1998 Gronvall
5,813,980 A 9/1998 Levinson et al.
5,817,008 A 10/1998 Rafert et al.
5,817,009 A 10/1998 Rosenheimer et al.
5,818,985 A 10/1998 Merchant et al.
5,820,550 A 10/1998 Polson et al.
5,823,950 A 10/1998 Diab et al.
5,823,952 A 10/1998 Levinson et al.
5,827,179 A 10/1998 Lichter et al.
5,829,439 A 11/1998 Yokosawa et al.
5,830,135 A 11/1998 Bosque et al.
5,830,136 A 11/1998 DeLonzor et al.
5,839,439 A 11/1998 Nierlich et al.
5,842,981 A 12/1998 Larsen et al.
5,842,982 A 12/1998 Mannheimer
5,846,190 A 12/1998 Woehrle
5,851,178 A 12/1998 Aronow
5,851,179 A 12/1998 Ritson et al.
5,853,364 A 12/1998 Baker, Jr. et al.
5,860,919 A 1/1999 Kiani-Azarbayjany et al.
5,879,294 A 3/1999 Anderson et al.
5,885,213 A 3/1999 Richardson et al.
5,891,022 A 4/1999 Pologe
5,891,025 A 4/1999 Buschmann et al.
5,891,026 A 4/1999 Wang et al.
5,902,235 A 5/1999 Lewis et al.
5,910,108 A 6/1999 Solenberger
5,911,690 A 6/1999 Rall
5,912,656 A 6/1999 Tham et al.
5,913,819 A 6/1999 Taylor et al.
5,916,155 A 6/1999 Levinson et al.
5,919,133 A 7/1999 Tyalor et al.
5,924,979 A 7/1999 Swedlow et al.
5,934,277 A 8/1999 Mortz
5,934,925 A 8/1999 Tobler et al.
5,940,182 A 8/1999 Lepper, Jr. et al.
5,957,840 A 9/1999 Terasawa et al.
5,961,450 A 10/1999 Merchant et al.
5,961,452 A 10/1999 Chung et al.
5,964,701 A 10/1999 Asada et al.
5,978,691 A 11/1999 Mills
5,983,120 A 11/1999 Groner et al.
5,995,855 A 11/1999 Kiani et al.
5,995,856 A 11/1999 Mannheimer et al.
5,995,859 A 11/1999 Takahashi
5,997,343 A 12/1999 Mills et al.
5,999,834 A 12/1999 Wang et al.
6,002,952 A 12/1999 Diab et al.
6,005,658 A 12/1999 Kaluza et al.
6,006,120 A 12/1999 Levin
6,011,985 A 1/2000 Athan et al.
6,011,986 A 1/2000 Diab et al.
6,014,576 A 1/2000 Raley et al.
6,018,673 A 1/2000 Chin et al.
6,018,674 A 1/2000 Aronow
6,022,321 A 2/2000 Amano et al.
6,023,541 A 2/2000 Merchant et al.
6,026,312 A 2/2000 Shemwell et al.
6,026,314 A 2/2000 Amerov et al.
6,031,603 A 2/2000 Fine et al.
6,035,223 A 3/2000 Baker, Jr.
6,036,642 A 3/2000 Diab et al.
6,041,247 A 3/2000 Weckstrom et al.
6,044,283 A 3/2000 Fein et al.
6,047,201 A 4/2000 Jackson, III
6,055,447 A 4/2000 Well
6,061,584 A 5/2000 Lovejoy et al.
6,064,898 A 5/2000 Aldrich
6,064,899 A 5/2000 Fein et al.
6,067,462 A 5/2000 Diab et al.
6,073,038 A 6/2000 Wang et al.
6,078,829 A 6/2000 Uchida
6,078,833 A 6/2000 Hueber
6,081,735 A 6/2000 Diab et al.
6,083,157 A 7/2000 Noller
6,083,172 A 7/2000 Baker, Jr. et al.
6,088,607 A 7/2000 Diab et al.
6,094,592 A 7/2000 Yorkey et al.
6,095,974 A 8/2000 Shemwell et al.
6,104,938 A 8/2000 Huiku et al.
6,104,939 A 8/2000 Groner
6,112,107 A 8/2000 Hannula
6,113,541 A 9/2000 Dias et al.
6,115,621 A 9/2000 Chin
6,122,535 A 9/2000 Kaestle et al.
6,133,994 A 10/2000 Mathews et al.
6,135,952 A 10/2000 Coetzee
6,144,444 A 11/2000 Haworth et al.
6,144,867 A 11/2000 Walker et al.
6,144,868 A 11/2000 Parker
6,149,481 A 11/2000 Wang et al.
6,151,107 A 11/2000 Schöllermann et al.
6,151,516 A 11/2000 Kiani-Azarbayjani et al.
6,151,518 A 11/2000 Hayashi
6,152,754 A 11/2000 Gerhardt et al.
6,154,667 A 11/2000 Miura et al.
6,157,850 A 12/2000 Diab et al.
6,159,147 A 12/2000 Lichter
6,163,715 A 12/2000 Larsen et al.
6,165,005 A 12/2000 Mills et al.
6,173,196 B1 1/2001 Delonzor et al.
6,178,343 B1 1/2001 Bindszus et al.
6,179,159 B1 1/2001 Gurley
6,181,958 B1 1/2001 Steuer et al.
6,181,959 B1 1/2001 Schöllermann et al.
6,184,521 B1 2/2001 Coffin, IV et al.
6,188,470 B1 2/2001 Grace
6,192,260 B1 2/2001 Chance
6,195,575 B1 2/2001 Levinson
6,198,951 B1 3/2001 Kosuda et al.
6,206,830 B1 3/2001 Diab et al.
6,213,952 B1 4/2001 Finarov et al.
6,217,523 B1 4/2001 Amano et al.
6,222,189 B1 4/2001 Misner et al.
6,223,064 B1 4/2001 Lynn
6,226,539 B1 5/2001 Potratz
6,226,540 B1 5/2001 Bernreuter et al.
6,229,856 B1 5/2001 Diab et al.
6,230,035 B1 5/2001 Aoyagi et al.
6,233,470 B1 5/2001 Tsuchiya
6,236,871 B1 5/2001 Tsuchiya
6,236,872 B1 5/2001 Diab et al.
6,240,305 B1 5/2001 Tsuchiya
6,253,097 B1 6/2001 Aronow et al.
6,253,098 B1 6/2001 Walker et al.
6,256,523 B1 7/2001 Diab et al.
6,256,524 B1 7/2001 Walker et al.
6,261,236 B1 7/2001 Grinblatov
6,263,221 B1 7/2001 Chance et al.
6,263,222 B1 7/2001 Diab et al.
6,263,223 B1 7/2001 Shepherd et al.
6,266,546 B1 7/2001 Steuer et al.
6,266,547 B1 7/2001 Walker et al.
6,272,363 B1 8/2001 Casciani et al.
6,278,522 B1 8/2001 Lepper, Jr. et al.
6,280,213 B1 8/2001 Tobler et al.
6,280,381 B1 8/2001 Malin et al.
6,285,894 B1 9/2001 Oppelt et al.
6,285,895 B1 9/2001 Ristolainen et al.
6,285,896 B1 9/2001 Tobler et al.
6,298,252 B1 10/2001 Kovach et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,308,089 B1 10/2001 Von der Ruhr et al.
6,321,100 B1 11/2001 Parker
6,330,468 B1 12/2001 Scharf
6,334,065 B1 12/2001 Al-Ali et al.
6,339,715 B1 1/2002 Bahr et al.
6,342,039 B1 1/2002 Lynn
6,343,223 B1 1/2002 Chin et al.
6,343,224 B1 1/2002 Parker
6,349,228 B1 2/2002 Kiani et al.
6,351,658 B1 2/2002 Middleman et al.
6,353,750 B1 3/2002 Kimura
6,356,774 B1 3/2002 Bernstein et al.
6,360,113 B1 3/2002 Dettling
6,360,114 B1 3/2002 Diab et al.
6,361,501 B1 3/2002 Amano et al.
6,363,269 B1 3/2002 Hanna et al.
D455,834 S 4/2002 Donars et al.
6,370,409 B1 4/2002 Chung et al.
6,371,921 B1 4/2002 Caro
6,374,129 B1 4/2002 Chin et al.
6,377,829 B1 4/2002 Al-Ali et al.
6,381,479 B1 4/2002 Norris
6,381,480 B1 4/2002 Stoddar et al.
6,385,471 B1 5/2002 Mortz
6,385,821 B1 5/2002 Modgil et al.
6,388,240 B2 5/2002 Schulz et al.
6,393,310 B1 5/2002 Kuenstner
6,393,311 B1 5/2002 Edgar, Jr. et al.
6,397,091 B2 5/2002 Diab et al.
6,397,092 B1 5/2002 Norris et al.
6,397,093 B1 5/2002 Aldrich
6,400,971 B1 6/2002 Finarov et al.
6,400,972 B1 6/2002 Fine
6,400,973 B1 6/2002 Winter
6,402,690 B1 6/2002 Rhee et al.
6,408,198 B1 6/2002 Hanna et al.
6,411,832 B1 6/2002 Guthermann
6,411,833 B1 6/2002 Baker, Jr. et al.
6,421,549 B1 7/2002 Jacques
6,430,423 B2 8/2002 DeLonzor et al.
6,430,513 B1 8/2002 Wang et al.
6,430,525 B1 8/2002 Weber et al.
6,434,408 B1 8/2002 Heckel et al.
6,438,396 B1 8/2002 Cook
6,438,399 B1 8/2002 Kurth
6,449,501 B1 9/2002 Reuss
6,453,183 B1 9/2002 Walker
6,453,184 B1 9/2002 Hyogo et al.
6,456,862 B2 9/2002 Benni
6,461,305 B1 10/2002 Schnall
6,463,310 B1 10/2002 Swedlow et al.
6,463,311 B1 10/2002 Diab
6,466,808 B1 10/2002 Chin et al.
6,466,809 B1 10/2002 Riley
6,470,199 B1 10/2002 Kopotic et al.
6,470,200 B2 10/2002 Walker et al.
6,480,729 B2 11/2002 Stone
6,490,466 B1 12/2002 Fein et al.
6,493,568 B1 12/2002 Bell
6,496,711 B1 12/2002 Athan et al.
6,498,942 B1 12/2002 Esenaliev et al.
6,501,974 B2 12/2002 Huiku
6,501,975 B2 12/2002 Diab et al.
6,505,060 B1 1/2003 Norris
6,505,061 B2 1/2003 Larson
6,505,133 B1 1/2003 Hanna et al.
6,510,329 B2 1/2003 Heckel
6,510,331 B1 1/2003 Williams et al.
6,512,937 B2 1/2003 Blank et al.
6,515,273 B2 2/2003 Al-Ali
6,519,484 B1 2/2003 Lovejoy et al.
6,519,486 B1 2/2003 Edgar, Jr. et al.
6,519,487 B1 2/2003 Parker
6,525,386 B1 2/2003 Mills et al.
6,526,300 B1 2/2003 Kiani et al.
6,526,301 B2 2/2003 Larsen et al.
6,541,756 B2 4/2003 Schulz et al.
6,542,764 B1 4/2003 Al-Ali et al.
6,546,267 B1 4/2003 Sugiura et al.
6,553,241 B2 4/2003 Mannheimer et al.
6,553,242 B1 4/2003 Sarussi
6,553,243 B2 4/2003 Gurley
6,554,788 B1 4/2003 Hunley
6,556,852 B1 4/2003 Schulze et al.
6,560,470 B1 5/2003 Pologe
6,564,077 B2 5/2003 Mortara
6,564,088 B1 5/2003 Soller et al.
6,571,113 B1 5/2003 Fein et al.
6,571,114 B1 5/2003 Koike et al.
6,574,491 B2 6/2003 Elghazzawi
6,580,086 B1 6/2003 Schulz et al.
6,584,336 B1 6/2003 Ali et al.
6,587,703 B2 7/2003 Cheng et al.
6,587,704 B1 7/2003 Fine et al.
6,589,172 B2 7/2003 Williams et al.
6,591,122 B2 7/2003 Schmitt
6,591,123 B2 7/2003 Fein et al.
6,594,511 B2 7/2003 Stone et al.
6,594,512 B2 7/2003 Huang
6,594,513 B1 7/2003 Jobsis et al.
6,597,931 B1 7/2003 Cheng et al.
6,597,933 B2 7/2003 Kiani et al.
6,600,940 B1 7/2003 Fein et al.
6,606,510 B2 8/2003 Swedlow et al.
6,606,511 B1 8/2003 Ali et al.
6,606,512 B2 8/2003 Muz et al.
6,608,562 B1 8/2003 Kimura et al.
6,609,016 B1 8/2003 Lynn
6,615,064 B1 9/2003 Aldrich
6,615,065 B1 9/2003 Barrett et al.
6,618,602 B2 9/2003 Levin et al.
6,618,614 B1 9/2003 Chance
6,622,034 B1 9/2003 Gorski et al.
6,628,975 B1 9/2003 Fein et al.
6,631,281 B1 10/2003 Kästle
6,632,181 B2 10/2003 Flaherty
6,640,116 B2 10/2003 Diab
6,643,530 B2 11/2003 Diab et al.
6,643,531 B1 11/2003 Katarow
6,647,279 B2 11/2003 Pologe
6,647,280 B2 11/2003 Bahr et al.
6,650,916 B2 11/2003 Cook
6,650,917 B2 11/2003 Diab et al.
6,650,918 B2 11/2003 Terry
6,654,621 B2 11/2003 Palatnik et al.
6,654,622 B1 11/2003 Eberhard et al.
6,654,623 B1 11/2003 Kästle
6,654,624 B2 11/2003 Diab et al.
6,658,276 B2 12/2003 Kianl et al.
6,658,277 B2 12/2003 Wassermann
6,662,033 B2 12/2003 Casciani et al.
6,665,551 B1 12/2003 Suzuki
6,668,182 B2 12/2003 Hubelbank
6,668,183 B2 12/2003 Hicks et al.
6,671,526 B1 12/2003 Aoyagi et al.
6,671,528 B2 12/2003 Steuer et al.
6,671,530 B2 12/2003 Chung et al.
6,671,531 B2 12/2003 Al-Ali et al.
6,671,532 B1 12/2003 Fudge et al.
6,675,031 B1 1/2004 Porges et al.
6,678,543 B2 1/2004 Diab et al.
6,681,126 B2 1/2004 Solenberger
6,681,128 B2 1/2004 Steuer et al.
6,681,454 B2 1/2004 Modgil et al.
6,684,090 B2 1/2004 Ali et al.
6,684,091 B2 1/2004 Parker
6,694,160 B2 2/2004 Chin
6,697,653 B2 2/2004 Hanna
6,697,655 B2 2/2004 Sueppel et al.
6,697,656 B1 2/2004 Al-Ali
6,697,658 B2 2/2004 Al-Ali
RE38,476 E 3/2004 Diab et al.
6,699,194 B1 3/2004 Diab et al.
6,699,199 B2 3/2004 Asada et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,701,170	B2	3/2004	Stetson
6,702,752	B2	3/2004	Dekker
6,707,257	B2	3/2004	Norris
6,708,049	B1	3/2004	Berson et al.
6,709,402	B2	3/2004	Dekker
6,711,424	B1	3/2004	Fine et al.
6,711,425	B1	3/2004	Reuss
6,712,762	B1	3/2004	Lichter
6,714,803	B1	3/2004	Mortz
6,714,804	B2	3/2004	Al-Ali et al.
6,714,805	B2	3/2004	Jeon et al.
RE38,492	E	4/2004	Diab et al.
6,719,686	B2	4/2004	Coakley et al.
6,719,705	B2	4/2004	Mills
6,720,734	B2	4/2004	Norris
6,721,584	B2	4/2004	Baker, Jr. et al.
6,721,585	B1	4/2004	Parker
6,725,074	B1	4/2004	Kästle
6,725,075	B2	4/2004	Al-Ali
6,731,962	B1	5/2004	Katarow
6,731,963	B2	5/2004	Finarov et al.
6,731,967	B1	5/2004	Turcott
6,735,459	B2	5/2004	Parker
6,745,060	B2	6/2004	Diab et al.
6,745,061	B1	6/2004	Hicks et al.
6,748,253	B2	6/2004	Norris et al.
6,748,254	B2	6/2004	O'Neil et al.
6,754,515	B1	6/2004	Pologe
6,754,516	B2	6/2004	Mannheimer
6,760,607	B2	7/2004	Al-Ali
6,760,609	B2	7/2004	Jacques
6,763,255	B2	7/2004	DeLonzor et al.
6,773,397	B2	8/2004	Kelly
6,778,923	B2	8/2004	Norris et al.
6,780,158	B2	8/2004	Yarita
6,791,689	B1	9/2004	Weckstrom
6,792,300	B1	9/2004	Diab et al.
6,801,797	B2	10/2004	Mannheimer et al.
6,801,798	B2	10/2004	Geddes et al.
6,801,799	B2	10/2004	Mendelson
6,801,802	B2	10/2004	Sitzman et al.
6,802,812	B1	10/2004	Walker et al.
6,805,673	B2	10/2004	Dekker
6,810,277	B2	10/2004	Edgar, Jr. et al.
6,813,511	B2	11/2004	Diab et al.
6,816,741	B2	11/2004	Diab
6,819,950	B2	11/2004	Mills
6,822,564	B2	11/2004	Al-Ali
6,825,619	B2	11/2004	Norris
6,826,419	B2	11/2004	Diab et al.
6,829,496	B2	12/2004	Nagai et al.
6,830,711	B2	12/2004	Mills et al.
6,836,679	B2	12/2004	Baker, Jr. et al.
6,839,579	B1	1/2005	Chin
6,839,580	B2	1/2005	Zonios et al.
6,839,582	B2	1/2005	Heckel
6,839,659	B2	1/2005	Tarassenko et al.
6,842,635	B1	1/2005	Parker
6,845,256	B2	1/2005	Chin et al.
6,850,787	B2	2/2005	Weber et al.
6,954,664	B2	10/2005	Sweitzer
6,968,221	B2	11/2005	Rosenthal
6,979,812	B2	12/2005	Al-Ali
7,003,339	B2	2/2006	Diab et al.
7,020,507	B2	3/2006	Scharf et al.
7,024,233	B2	4/2006	Ali et al.
7,024,235	B2	4/2006	Melker et al.
7,128,622	B2	10/2006	Tsai
7,130,671	B2	10/2006	Baker, Jr. et al.
7,132,641	B2	11/2006	Schulz et al.
7,215,984	B2	5/2007	Diab et al.
7,228,161	B2	6/2007	Chin
7,254,433	B2	8/2007	Diab et al.
7,315,753	B2	1/2008	Baker, Jr. et al.
7,397,172	B2	7/2008	Kikushima
2002/0016537	A1	2/2002	Muz et al.
2002/0026109	A1	2/2002	Diab et al.
2002/0072681	A1	6/2002	Schnall
2002/0116797	A1	8/2002	Modgil et al.
2002/0128544	A1	9/2002	Diab et al.
2003/0045785	A1	3/2003	Diab et al.
2004/0068164	A1	4/2004	Diab et al.
2004/0117891	A1	6/2004	Hannula et al.
2004/0147824	A1	7/2004	Diab et al.
2004/0158134	A1	8/2004	Diab et al.
2004/0167381	A1	8/2004	Lichter
2004/0204637	A1	10/2004	Diab et al.
2004/0204638	A1	10/2004	Diab et al.
2004/0204639	A1	10/2004	Casciani et al.
2004/0210146	A1	10/2004	Diab et al.
2004/0215085	A1	10/2004	Schnall
2004/0236196	A1	11/2004	Diab et al.
2005/0014999	A1	1/2005	Rahe-Meyer
2005/0033131	A1	2/2005	Chen
2005/0043600	A1	2/2005	Diab et al.
2005/0049468	A1	3/2005	Carlson
2005/0070773	A1	3/2005	Chin
2005/0075546	A1	4/2005	Samsoondar
2005/0085704	A1	4/2005	Schulz
2005/0090720	A1	4/2005	Wu
2005/0228248	A1	10/2005	Dietiker
2005/0256386	A1	11/2005	Chan
2005/0272986	A1	12/2005	Smith
2006/0020179	A1	1/2006	Anderson
2006/0030764	A1	2/2006	Porges
2006/0074280	A1	4/2006	Martis
2006/0084166	A1	4/2006	Appel
2006/0084878	A1	4/2006	Banet
2006/0086678	A1	4/2006	Mattesky
2006/0122517	A1	6/2006	Banet
2006/0129039	A1	6/2006	Lindner
2006/0155198	A1	7/2006	Schmid
2006/0173257	A1	8/2006	Nagai
2007/0032710	A1	2/2007	Raridan et al.
2007/0032712	A1	2/2007	Raridan et al.
2007/0032715	A1	2/2007	Eghbal et al.
2007/0060808	A1	3/2007	Hoarau
2007/0073117	A1	3/2007	Raridan
2007/0073121	A1	3/2007	Hoarau et al.
2007/0073122	A1	3/2007	Hoarau
2007/0073123	A1	3/2007	Raridan
2007/0073125	A1	3/2007	Hoarau et al.
2007/0073126	A1	3/2007	Raridan
2007/0073128	A1	3/2007	Hoarau
2007/0078315	A1	4/2007	Kling et al.
2007/0078316	A1	4/2007	Hoarau
2007/0084793	A1	4/2007	Wenden
2007/0260129	A1	11/2007	Chin
2007/0260130	A1	11/2007	Chin
2007/0260131	A1	11/2007	Chin
2008/0058622	A1	3/2008	Baker et al.
2008/0076982	A1	3/2008	Ollerdessen
2009/0163783	A1	6/2009	Bowman et al.
2009/0163787	A1	6/2009	Bowman et al.

FOREIGN PATENT DOCUMENTS

DE	3703458	8/1988
DE	3938759	5/1991
DE	4210102	9/1993
DE	4423597	8/1995
DE	19632361	2/1997
DE	69123448	5/1997
DE	19703220	7/1997
EP	0127947	5/1984
EP	0194105	9/1986
EP	0204459	12/1986
EP	0262779	4/1988
EP	0315040	10/1988
EP	0314331	5/1989
EP	0352923	1/1990
EP	0360977	4/1990
EP	0430340	6/1991
EP	0435500	7/1991

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

EP	0572684	5/1992
EP	0497021	8/1992
EP	0529412	8/1992
EP	0531631	9/1992
EP	0566354	4/1993
EP	0587009	8/1993
EP	0630203	9/1993
EP	0572684	12/1993
EP	0615723	9/1994
EP	0702931	3/1996
EP	0724860	8/1996
EP	0864293	9/1998
EP	0898933	3/1999
FR	2685865	1/1992
GB	2259545	3/1993
JP	63275325	11/1988
JP	2191434	7/1990
JP	3170866	7/1991
JP	3173536	7/1991
JP	3245042	10/1991
JP	4174648	6/1992
JP	4191642	7/1992
JP	4332536	11/1992
JP	5049624	3/1993
JP	5049625	3/1993
JP	3115374	4/1993
JP	5200031	8/1993
JP	5212016	8/1993
JP	06014906	1/1994
JP	6016774	3/1994
JP	3116255	4/1994
JP	6029504	4/1994
JP	6098881	4/1994
JP	6154177	6/1994
JP	6269430	9/1994
JP	6285048	10/1994
JP	7001273	1/1995
JP	7124138	5/1995
JP	7136150	5/1995
JP	3116259	6/1995
JP	3116260	6/1995
JP	7155311	6/1995
JP	7155313	6/1995
JP	3238813	7/1995
JP	7171139	7/1995
JP	3134144	9/1995
JP	7236625	9/1995
JP	7246191	9/1995
JP	8256996	10/1996
JP	11188019	7/1999
JP	3124073	1/2001
WO	WO8909566	10/1989
WO	WO9001293	2/1990
WO	WO9004352	5/1990
WO	WO9101678	2/1991
WO	WO9111137	8/1991
WO	WO9200513	1/1992
WO	WO9221281	12/1992
WO	WO9309711	5/1993
WO	WO9313706	7/1993
WO	WO9316629	9/1993
WO	WO9403102	2/1994
WO	WO9423643	10/1994
WO	WO9502358	1/1995
WO	WO9512349	5/1995
WO	WO9516970	6/1995
WO	WO9613208	5/1996
WO	WO9639927	12/1996
WO	WO9736536	10/1997
WO	WO9736538	10/1997
WO	WO9900053	1/1999
WO	WO9963884	12/1999
WO	WO0167946	9/2001
WO	WO02085202	10/2002
WO	WO03020129	3/2003
WO	WO03063697	8/2003
WO	WO2004069046	8/2004
WO	WO2005065540	7/2005

OTHER PUBLICATIONS

Aoyagi, T., et al.; "Analysis of Motion Artifacts in Pulse Oximetry," *Japanese Society ME*, vol. 42, p. 20 (1993) (Article in Japanese—contains English summary of article).

Barreto, A.B., et al.; "Adaptive Cancelation of Motion artifact in Photoplethysmographic Blood Volume Pulse Measurements for Exercise Evaluation," *IEEE—EMBC and CMBEC—Theme 4: Signal Processing*, pp. 983-984 (1995).

Vincente, L.M., et al.; "Adaptive Pre-Processing of Photoplethysmographic Blood Volume Pulse Measurements," pp. 114-117 (1996).

Rheineck-Leyssius, Aart t., et al.; "Advanced Pulse Oximeter Signal Processing Technology Compared to Simple Averaging: I. Effect on Frequency of Alarms in the Operating Room," *Journal of clinical Anestesia*, vol. 11, pp:192-195 (1999).

* cited by examiner

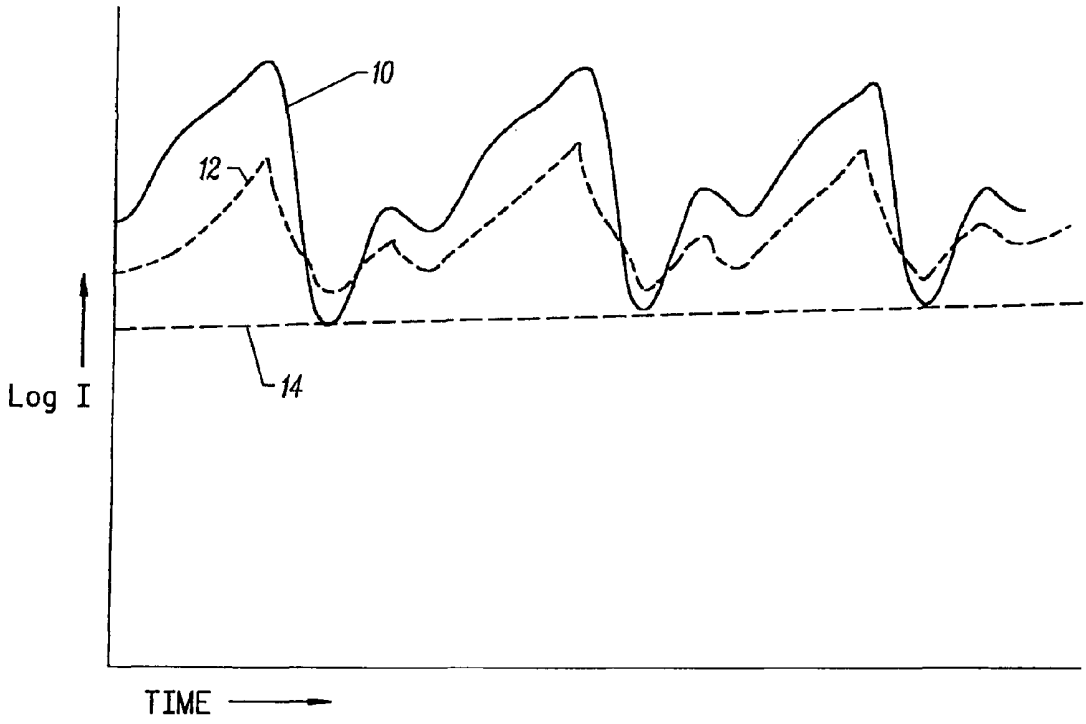


FIG. 1

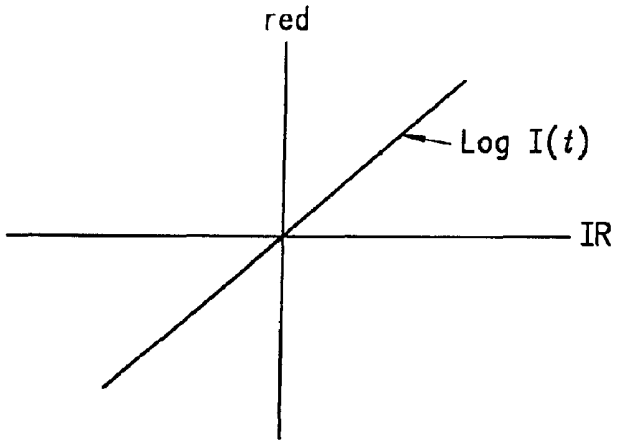


FIG. 2

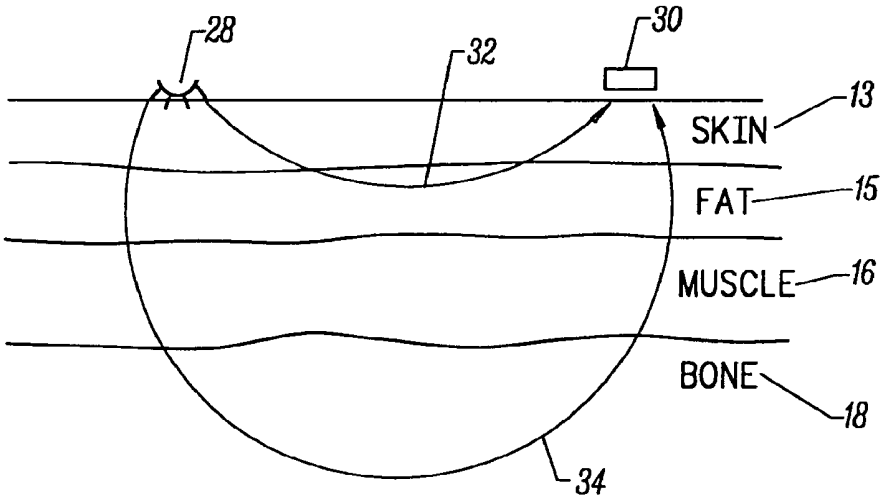


FIG. 3

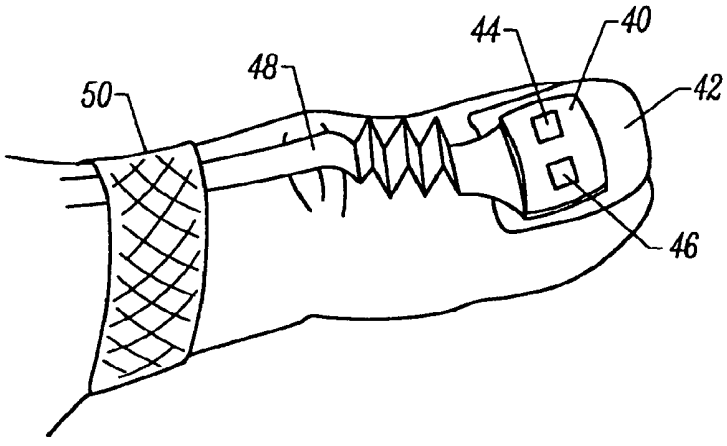


FIG. 4

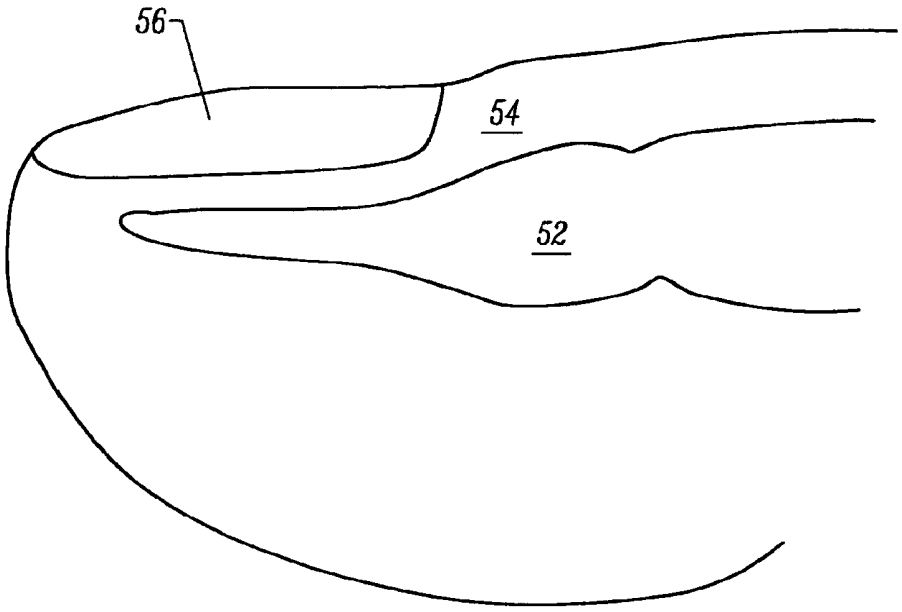


FIG. 5

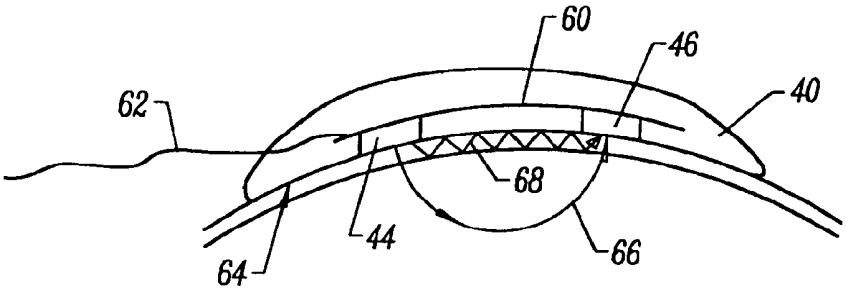


FIG. 6

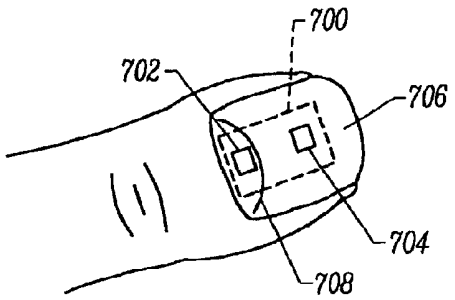


FIG. 7

FIG. 8A

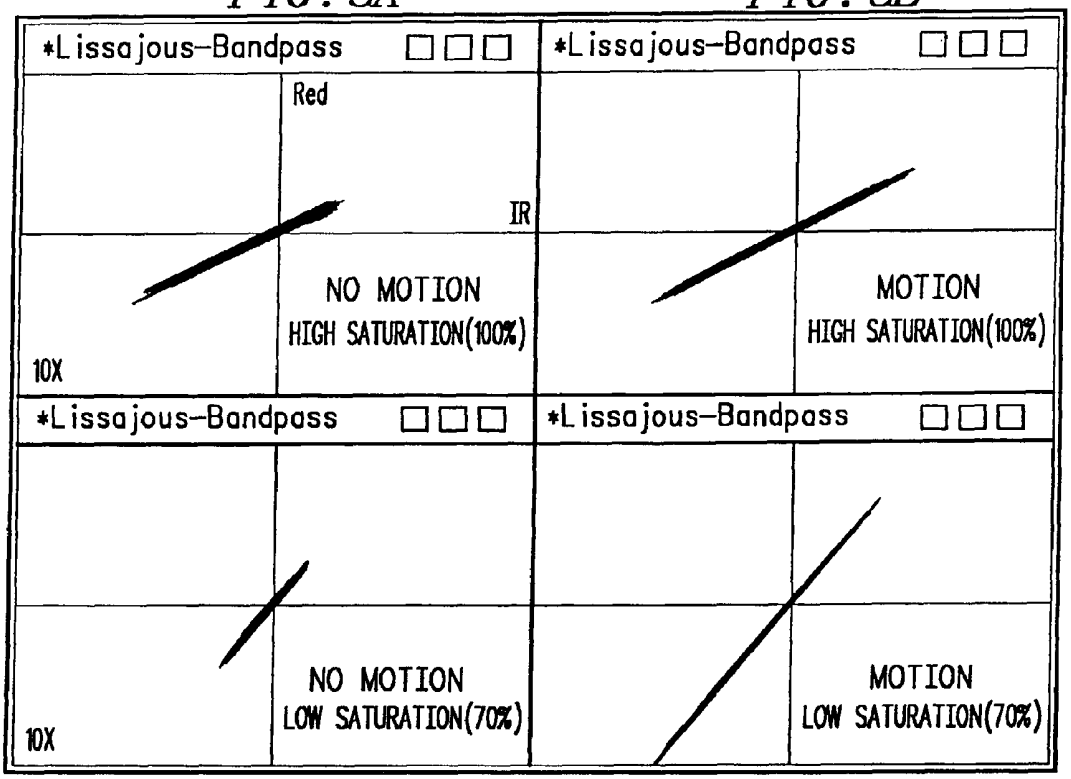


FIG. 8C

FIG. 8B

FIG. 8D

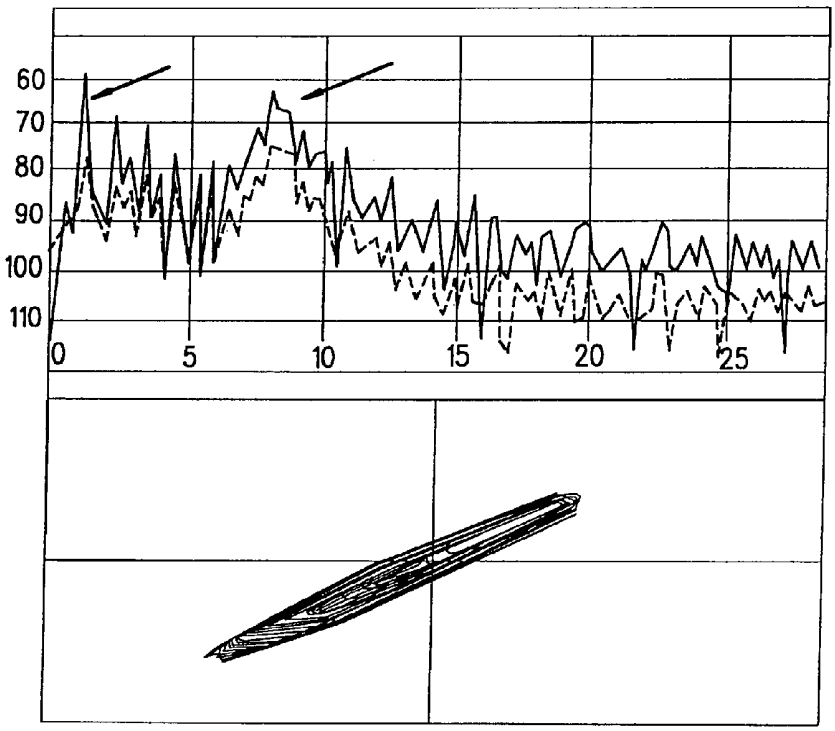


FIG. 9A

FIG. 9B

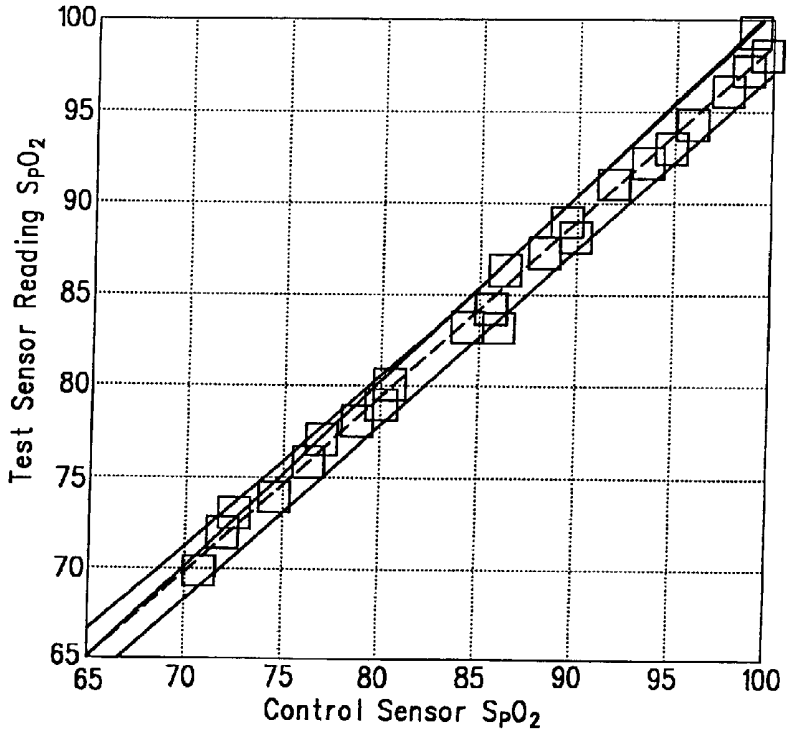


FIG. 10

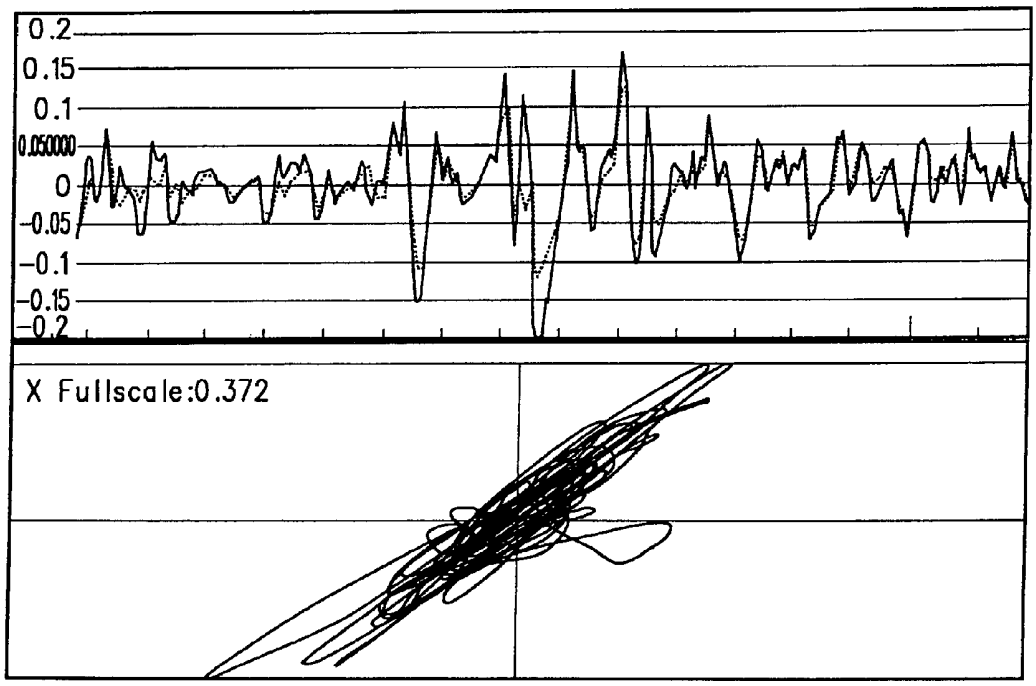


FIG. 11A
(PRIOR ART)

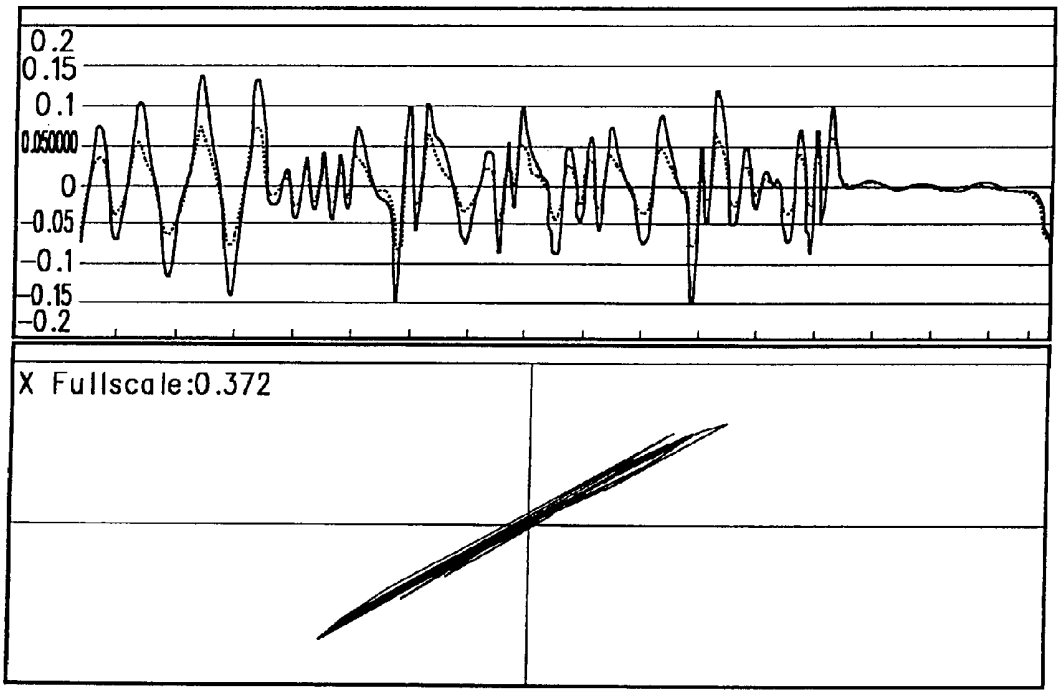


FIG. 11B

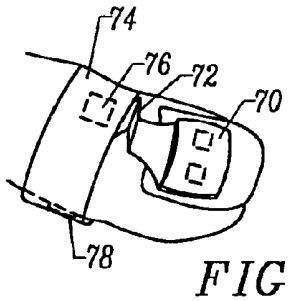


FIG. 12

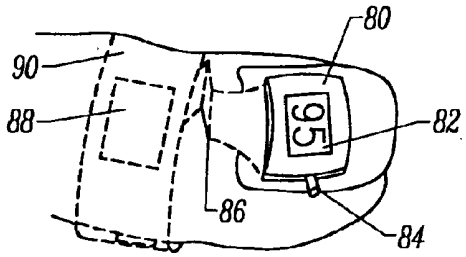


FIG. 13

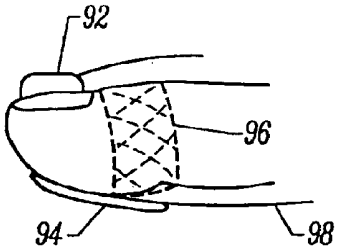


FIG. 14

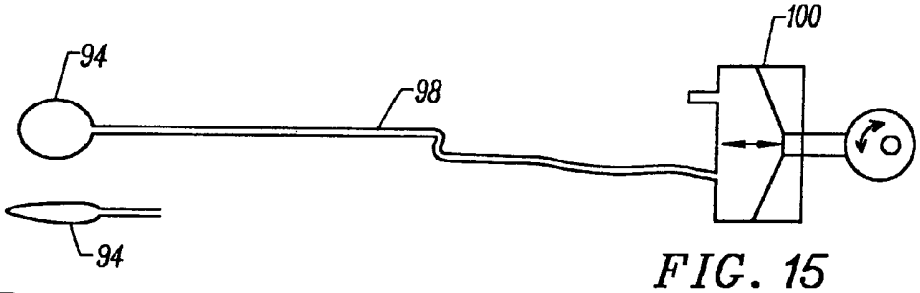


FIG. 16

FIG. 15

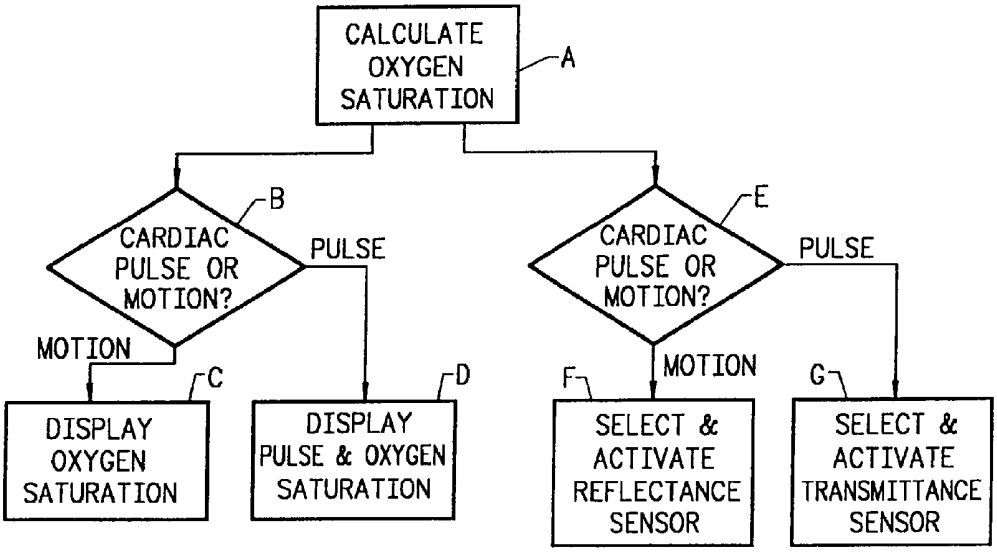

CALCULATE OXYGEN SATURATION
A
CARDIAC PULSE OR MOTION?
B
PULSE
MOTION
C
DISPLAY OXYGEN SATURATION
D
DISPLAY PULSE & OXYGEN SATURATION
CARDIAC PULSE OR MOTION?
E
PULSE
MOTION
F
SELECT & ACTIVATE REFLECTANCE SENSOR
G
SELECT & ACTIVATE TRANSMITTANCE SENSOR

FIG. 17

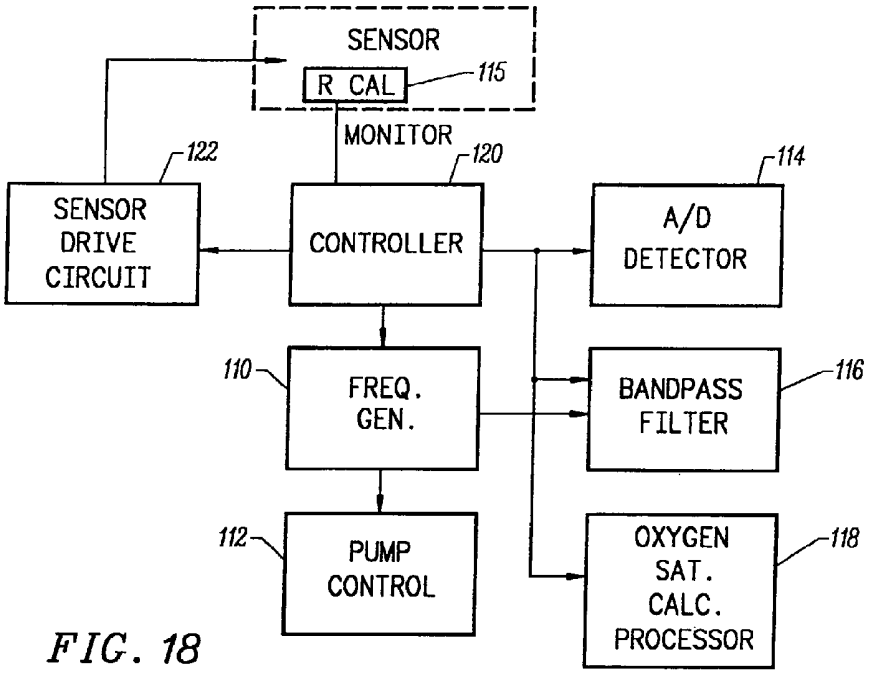

SENSOR
R CAL
115
MONITOR
122
120
114
SENSOR DRIVE CIRCUIT
CONTROLLER
A/D DETECTOR
110
FREQ. GEN.
BANDPASS FILTER
116
112
PUMP CONTROL
OXYGEN SAT. CALC. PROCESSOR
118

FIG. 18

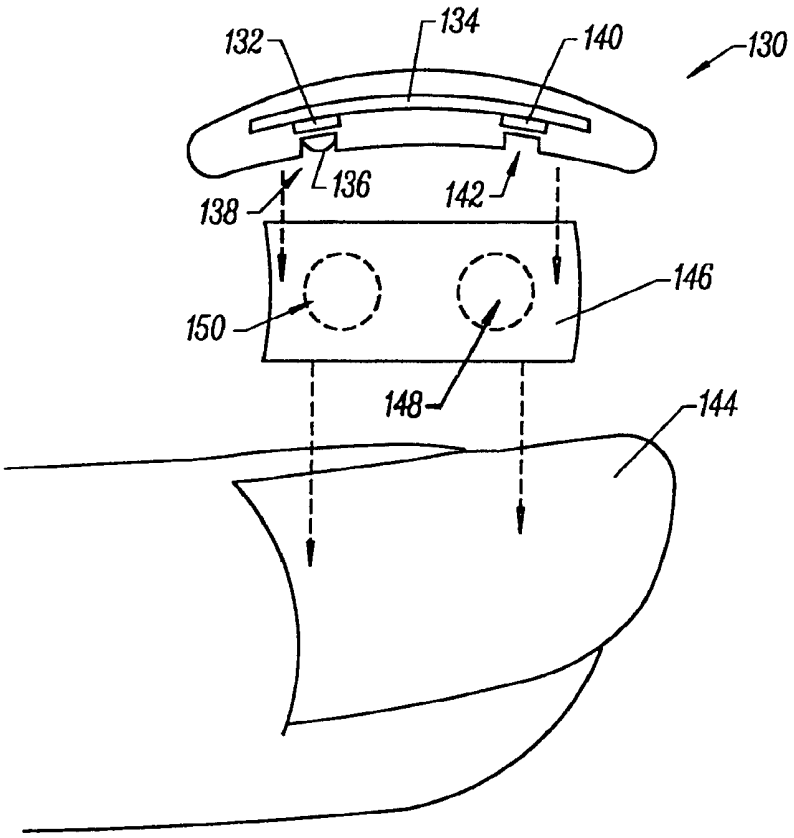


FIG. 19

MOTION COMPATIBLE SENSOR FOR NON-INVASIVE OPTICAL BLOOD ANALYSIS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 11/827,858, filed on Jul. 11, 2007, which is a continuation of U.S. application Ser. No. 10/991,111 filed Nov. 16, 2004, now U.S. Pat. No. 7,260,425, which is a continuation of U.S. application Ser. No. 10/080,433, filed Feb. 21, 2002, now U.S. Pat. No. 6,845,256, which is a division of U.S. application Ser. No. 09/348,437, filed Jul. 7, 1999, now U.S. Pat. No. 6,374,129, which is a division of U.S. application Ser. No. 08/722,443, filed Oct. 10, 1996, now U.S. Pat. No. 6,018,673, which disclosures are incorporated by reference for all purposes.

BACKGROUND OF THE INVENTION

The present invention relates to optical sensors for non-invasive determination of physiological characteristics, and in particular to sensors for making such determinations in the presence of motion.

Many types of optical sensors are used to measure physiological characteristics of a patient. Typically, an optical sensor provides emitted light which is then scattered through tissue and detected. Various characteristics of a patient can be determined from analyzing such light, such as oxygen saturation, pulse rate, pH, etc.

Pulse oximetry is typically used to measure various blood characteristics including, but not limited to, the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and the rate of blood pulsations corresponding to each heartbeat of a patient. Measurement of these characteristics has been accomplished by use of a non-invasive sensor which scatters light through a portion of the patient's tissue where blood perfuses the tissue, and photoelectrically senses the absorption of light in such tissue. The amount of light absorbed is then used to calculate the amount of blood constituent being measured.

The light scattered through the tissue is selected to be of one or more wavelengths that are absorbed by the blood in an amount representative of the amount of the blood constituent present in the blood. The amount of transmitted light scattered through the tissue will vary in accordance with the changing amount of blood constituent in the tissue and the related light absorption. For measuring blood oxygen level, such sensors have typically been provided with a light source that is adapted to generate light of at least two different wavelengths, and with photodetectors sensitive to both of those wavelengths, in accordance with known techniques for measuring blood oxygen saturation.

Known non-invasive sensors include devices that are secured to a portion of the body, such as a finger, an ear or the scalp. In animals and humans, the tissue of these body portions is perfused with blood and the tissue surface is readily accessible to the sensor. A photoelectric pulse transducer from World Precision Instruments is described as even recording signals through the fingernail.

Optical sensors are typically either reflective or transmissive. Transmissive sensors have the emitter and detector on opposite sides of a finger, toe, nose or other tissue. They measure light transmitted through the tissue from one side to the other. Reflectance sensors, on the other hand, have the emitter and detector side-by-side, such as placement on the forehead, or on a fetus where it is difficult to position a sensor over a finger, etc. Reflectance sensors detect light which is scattered back to the same surface.

In pulse oximetry, the goal is to determine the amount of oxygen in arterial blood, as distinguished from venous blood or the tissue itself. The light emitted can be absorbed by all three, however, and they need to be distinguished among. FIG. **1** illustrates a plot of the logarithm of the detected intensity signal versus time. Solid line **10** is the detected infrared signal in a pulse oximeter, shown varying with time. Dotted line **12** is the detected red wavelength signal. As can be seen, the value moves up and down with the heartbeat frequency, due to the pulsing of the blood through the arteries. The portion of the signal below line **14** is representative of light absorbed by the tissue, venous blood, and a baseline component of the arterial blood.

Using appropriate signal analysis, the DC portion can be eliminated, leaving an extracted AC portion which is due to absorption by arterial blood. As can be seen in FIG. **1**, and more clearly in FIG. **2**, the red and infrared signals, although varying by different amounts, are in phase. FIG. **2** illustrates a plot over an epoch of time of the red logarithmic signal versus the infrared logarithmic signal, and is commonly referred to as a Lissajous plot. As can be seen, a line is formed, indicating they are in phase.

This characteristic of the red and infrared signals allows the determination of oxygen saturation through two methods. In a first method, the "ratio of ratios" is calculated, which is the ratio, between red and infrared, of the logarithms of the quotients obtained by dividing the maximum signal intensity and the subsequent minimum signal intensity. This ratio-of-ratios is then used in a predetermined formula to calculate arterial oxygen saturation. This is described more fully in U.S. Pat. No. 4,653,498.

In a second method, referred to here as "least squares," a least squares regression analysis is performed on the above-mentioned Lissajous plot to determine the slope of the ensemble of data points taken during an epoch of time. This slope is then used in a predetermined formula to determine arterial oxygen saturation. Other techniques are set forth in a co-pending application entitled "Method and Apparatus for Estimating Physiological Parameters Using Model-Based Adaptive filtering," filed Jun. 7, 1996, Ser. No. 08/660,510, the disclosure of which is hereby incorporated by reference.

In some cases, it is desirable to measure the oxygen saturation of the venous blood in order to get an indication of how much oxygen is being used by the body. The arterial blood, on the other hand, gives an indication of how much oxygen is being delivered to the body. In Shiga U.S. Pat. No. 4,927,264, the oxygen saturation in venous blood is determined by inducing a venous pressure with a pressure cuff. This effectively varies line **14** of FIG. **1** at a frequency different from the heart rate, so that it can be separately filtered and isolated and compared to the arterial pulse. The non-varying portion is then assumed to be the tissue absorption and can be distinguished from the slowly varying pressure induced venous blood absorption. An alternate approach can be used in extracorporeal monitoring where the blood is actually pumped out of the body and then back in. Such a technique is set forth in an article by Odell et al., entitled "Use of Pulse Oximetry to Monitor Venous Saturation During Extracorporeal Life Support" Critical Care Medicine, vol. 22, no. 4 (Apr. 4, 1994). In Odell, the venous blood being pumped out of the body passes the sensor, and the pumping mechanism provides an artificial pulse allowing the use of pulse oximetry techniques.

Motion artifact can degrade a pulse oximetry signal relied upon by a physician, without the physician's awareness. This

is especially true if the monitoring of the patient is remote, the motion is too small to be observed, or the doctor is watching the instrument or other parts of the patient, and not the sensor site. Thus, typically techniques are employed to reduce the effects of motion or compensate for motion.

In one oximeter system described in U.S. Pat. No. 5,025,791, an accelerometer is used to detect motion. When motion is detected, readings influenced by motion are either eliminated or indicated as being corrupted. In a typical oximeter, measurements taken at the peaks and valleys of the blood pulse signal are used to calculate the desired characteristic. Motion can cause a false signal peak and valley, resulting in a measurement having an inaccurate value and one which is recorded at the wrong time. In U.S. Pat. No. 4,802,486, assigned to Nellcor Puritan Bennett, the assignee of the present invention, an EKG signal is monitored and correlated to the oximeter reading to provide synchronization to limit the effect of noise and motion artifact pulses on the oximeter readings. This reduces the chances of the oximeter locking onto a periodic motion signal. Still other systems, such as the one described in U.S. Pat. No. 5,078,136, assigned to Nellcor Puritan Bennett, use signal processing in an attempt to limit the effect of noise and motion artifact. The '136 patent, for instance, uses linear interpolation and rate of change techniques to analyze the oximeter signal. U.S. Pat. No. 5,337,744 sets forth sensor modifications used to improve the immunity of the signal from motion artifacts.

The motion signal impedes the measurement because it obscures the cardiac signal. The motion signal can have many components, such as, for example, the emitter or detector physically moving away from the body, or a volume of venous and arterial blood sloshing around in response to the motion, or the signal path being shortened or lengthened by expansion or compression of the tissue due to motion.

Contrary to conventional practice, signal analysis might be able to directly use the time-varying motion signal to calculate oxygen saturation. Under some conditions, the ratio-of-ratios (or least squares) resulting from a motion-induced signal has the same value as the ratio-of-ratios (or least squares) for the cardiac induced signal. The red and infrared intensity signals are often not in phase, and can limit the use of the motion signal for calculating oxygen saturation. One of the factors that may cause this is illustrated in FIG. **3**. As FIG. **3** illustrates, light from emitter **28** can pass through skin **13**, fat **15**, muscle **16**, and bone **18**, on its way to a detector **30**. Light of one wavelength may, on average, take path **32**, while light of another wavelength may penetrate deeper and take path **34**. Motion will cause disproportionate variances in the path lengths of the two wavelengths of light, resulting in out-of-phase signals of the detector.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a non-invasive optical sensor which uses the motion signal to calculate the physiological characteristic being measured. For pulse oximetry, a least squares or a ratio-of-ratios technique can be applied to the slope of the motion signal itself. This is made possible by selecting a site on the patient where motion produces signals at two wavelengths which are adequately correlated with each other. Adequately correlated signals have a "closed" or "nearly closed" Lissajous. In particular, it has been determined that a sensor placed on a nail, in particular a thumbnail, exhibits the characteristics of having the red and infrared signals in phase when used for pulse oximetry.

The present invention also provides an optical sensor which fits entirely on a nail. No adhesive or other securing mechanism around the rest of the finger is necessary, resulting in the entire sensor moving with the nail. The use of the nail site reduces the likelihood of out-of-phase motion signals for red and infrared wavelengths, and takes advantage of the predominantly arterial blood saturation characteristic of the blood present beneath the nail. In addition, the nail is an advantageous surface for adhering the sensor to, and at this location the method of attachment allows a low profile, low mass sensor to be used which further limits differential phase errors due to motion.

Preferably, the sensor on a nail of the present invention is a reflectance-type sensor. In one embodiment, a closer spacing is used than in typical prior art sensors, preferably less than 5 mm, more preferably approximately 4 mm. It has been empirically determined that the physiological characteristics at a nail site produce an improved signal with closer spacing. In addition, the sensor preferably has a curvature which conforms to the shape of the nail, and is attached with an adhesive.

In alternate embodiments of the invention, artificial motion may be induced with an air bag or otherwise to produce a motion signal which can be used with the sensor of the invention. In particular, this could be used for patients with low perfusion, a weak heartbeat or no heartbeat such as is the case during heart bypass surgery.

For a further understanding of the nature and advantages of the invention, reference should be made to the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a graph of the log of the infrared and red intensity signals for pulse oximeters.

FIG. **2** is a graph of the red and IR signals showing correlation.

FIG. **3** is a diagram of the different average paths of different wavelength light through a patient.

FIG. **4** is a perspective view of a nail sensor according to the present invention on a thumb.

FIG. **5** is a cross-sectional, cutaway view of a thumb showing its components.

FIG. **6** is a end, cutaway view of one embodiment of a conformable nail sensor according to the present invention.

FIG. **7** is a diagram of a sensor according to the present invention placed longitudinally to span the lunula of the nail.

FIGS. **8**A-**8**D are Lissajous plots of the output of a sensor according to the invention with and without motion, and at low and high saturation.

FIG. **9**A is a plot of the red and infrared frequency distribution (FFT of time signals) showing experimental results from a thumbnail sensor according to the invention.

FIG. **9**B is a plot of the Lissajous for the results of FIG. **9**A.

FIG. **10** is a graph showing a plot of oxygen saturation readings of a sensor according to the present invention compared to a standard prior art sensor.

FIGS. **11**A and **11**B compare the prior art sensor and the present invention. The output waveforms and Lissajous plot are shown for each.

FIG. **12** is a diagram of an alternate embodiment of the invention showing a combination reflective and transmissive sensor.

FIG. **13** is a diagram of an alternate embodiment of the invention showing a self-contained nail sensor with its own display.

FIG. **14** is a diagram of a nail sensor with a motion inducing mechanism according to the present invention.

FIGS. **15** and **16** are top and side views of the motion stimulating mechanism of FIG. **14**.

FIG. **17** is a flowchart of one embodiment of a program for responding to whether motion or a cardiac pulse is used for calculating saturation.

FIG. **18** is a block diagram of one embodiment of portions of an oximeter using controlled generation of motion.

FIG. **19** is a diagram of an embodiment of the sensor using a cylindrical lens and a tinted adhesive.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **4** illustrates a sensor **40** according to the present invention preferably mounted on a nail **42** (a thumbnail or any other digit may be used). The sensor is held on with adhesive, and has an emitter **44** and a detector **46**. A flexible circuit **48** provides the electrical connections to the emitter and detector, and may be accordion-shaped between the sensor and a securing band **50** to provide additional strain relief. This isolates the sensor from tugging or pulling on the electrical connection cord from either the sensor side or the other direction. Band **50** may be, for instance, an elastic band, cloth wrap secured with Velcro™, or another device. Flexible circuit **48** could be electrical wires or fiber optic cables. The different **25** wavelength light could be premixed using the fiber optic cable.

The placement on the top of the nail allows the cable to extend along the top of the finger or other digit, without the sensor or the cable being on the palmar side of the digit where it would interfere with grasping or other functionality of the hand.

As can be seen, the emitter **44** and detector **46** are arranged laterally across the width of the nail. However, a longitudinal arrangement (discussed more fully below) or any other arrangement on a nail is possible. The spacing of the emitter and detector may be varied, but an optimum spacing was experimentally found to be less than 10 mm, preferably less than 5 mm, more preferably approximately 4 mm.

The nailbed makes a good site for the sensor because it has been observed that motion generates artifact signals for the red and infrared wavelengths that are largely correlated to one another. The inventors have observed that this results in a ratio-of-ratios (or least squares) which correlates well with the arterial oxygen saturation.

Referring to FIG. **5**, a cross-sectional view of the thumb is shown. As can be seen, the thumb includes a bone **52** with a thin layer of connective tissue **54** between the bone and thumbnail **56**. A number of characteristics may contribute to the improved signal and the motion induced artifact being in phase. The different wavelength paths illustrated in FIG. **3** may be limited by the presence of bone **52**, preventing one of the wavelengths from going deeper into tissue and having a different distance to travel. This effect is provided by the selection of the thumbnail as a site, and the use of reflectance oximeter sensor as opposed to a transmissive sensor. In a transmissive sensor, light would have to travel around the bone deep through the tissue, and the red and infrared may travel different lengths and be affected differently by motion.

Connective tissue layer **54** is thin and apparently strongly connective. Thus, the expansion and compression of tissues, particularly fatty tissues, which may cause out of phase motion artifacts for other sites and types of sensors, is apparently greatly reduced here. Because the thumbnail **56** itself provides a strong mounting platform, the sensor can be securely attached to it with adhesive, avoiding the emitter and detector from separating from the patient and causing gaps that may cause corrupt ratio-of-ratio values.

The region beneath nail **56** also provides a region which appears to be concentrated with oxygen saturated blood similar to the saturation of arterial blood. Oxygen consumption beneath the nail appears to be small relative to the circulation there, or the relative volume of venous blood may be negligibly small.

The presence of many small capillaries, rather than large vessels, makes the region more homogeneous, and thus lessens the likelihood that two different light wavelengths would be affected differently by passing through differing regions. In the absence of motion, the high perfusion allows a normal pulse oximetry reading to be made. During the occurrence of motion, the large amount of blood present allows a strong motion signal to be obtained, since a lot of blood is moved around by the motion. In experiments conducted by the inventors, motion artifact signals greater than 50 times that of a normal pulsatile plethysmograrn signal have been observed. The nail site also appears to have a nailbed-tissue boundary that is optically phase-matched for the wavelengths of the sensor.

In addition to measuring oxygen saturation, the nailbed is a good site for other optical sensors. For example, glucose detection which requires the use of a near infrared wavelength could be used. Among the blood properties or constituents that can be measured are blood gases (CO_2, O_2), pH, glucose, drug concentrations, or other analytes (THb, Hct, lactate, K^+, Na^+, Ca_2^+, etc.).

FIG. **6** is an end, cutaway view of one embodiment of a sensor **40** according to the present invention. Emitter **44** and detector **46** are shown mounted on a flexible circuit board **60**. An electrical cord **62** provides the connection to the electrical components of circuit board **60**. The body of the sensor is preferably a semi-rigid piece of black poron foam. A metal strip could be imbedded to give extra rigidity. An adhesive is attached to underside **64** of the sensor to attach it securely to the nail. The underside is also curved to conform to the shape of the nail, but is slightly flexible to allow adaptation to differing nail shapes. Different curvature sensors could be provided for different sizes and shapes of nails to provide optimum fit, or the bottom surface could be fabricated from a softer, more conforming material.

One characteristic of the nail as a site is that the nail itself could act as a light pipe, shunting light between the emitter and the detector. Preferably, the light travels through the tissue beneath the nail along a path **66**. However, some light could bounce back and forth through the nail itself on a path **68** between the emitter and detector in a manner not unlike a waveguide. To limit this shunting, the sensor body is made to absorb light, or at least the region between the emitter and detector is made at least partially absorbing to the wavelengths of interest. In this way, each time light strikes the side of the nail adjacent the absorbing layer, it will be absorbed, rather than propagating along the nail.

Shunting can also be limited by recessing the emitter and detector and providing a narrow numerical aperture. Because of the rigidity of the sensor body, recessing will not produce variations in distance during motion. By limiting the numerical aperture of the emitter and detector to values less than 0.9, preferably to values less than 0.5, the emitter will not directly launch light into the nail "waveguide," and light which does potentially travel path **68** will be outside the acceptance angle of the detector.

The nail also provides advantages for adhering the sensor to the patient since the nail does not have the quantity of oils or sweat as present on the skin.

FIG. **7** is a diagram of a sensor **700** arranged longitudinally along a nail **706**. The sensor has an emitter **702** and a detector

704 which are not both on the lunula of the nail. The lunula is the light colored area of the nail below line 708 in FIG. 7. It is believed that if both the emitter and detector are located on the lunula, more undesirable shunting of light will occur.

FIG. 8 has FIGS. 8A-8D which show the Lissajous plots and calculated saturations for a sensor according to the present invention during four conditions: motion and no motion at high and low saturation. As can be seen in FIGS. 8A and 8B at high saturation, the calculated saturation 100% is equivalent with or without motion. In FIG. 8B, the motion signal is seen to be more than 10 times larger than the cardiac signal of FIG. 8A (FIGS. 8A and 8C are magnified by 10). Similar results occur at low saturation as seen in FIGS. 8C and 8D where the saturation values are calculated to be 70% under both conditions.

FIG. 9A is a graph of the frequency distribution of the detected red and infrared signals for a sensor of the present invention in an experiment with an 8 Hz artificial motion pulse applied. The cardiac signature can be seen at the lower frequencies below 5 Hz, while the 8 Hz driven motion signal is also visible. FIG. 9B is a graph of the red versus infrared intensity signals for the experiment illustrating that both signals are correlated and representative of the same saturation.

FIG. 10 illustrates the oxygen saturation readings of a sensor according to the present invention in experimental tests without motion comparing it with a standard prior art transmissive sensor at another site. A close agreement was noted, indicating the calibration of this sensor on the nailbed site is similar to a conventional transmission sensor.

FIGS. 11A and 11B show a comparison of the output waveform and Lissajous, in the presence of motion, of a sensor according to the present invention (FIG. 11B) with a standard prior art transmissive sensor at another site (FIG. 11A).

FIG. 12 illustrates an alternate embodiment of the present invention in which a nail sensor 70 according to the present invention is attached via a flexible circuit 72 to a transmissive sensor 74 which wraps around the finger and has an emitter 76 and detector 78 positioned on top and on the bottom of the finger. Such a combination sensor could allow the oximeter monitor with its program to choose between the sensors depending upon motion conditions. When motion is present, nail sensor 70 could be used, and when motion is not present, sensor 74, which may be more sensitive to the cardiac pulse signal, could be used. Alternately, a single pair of red and infrared emitters could be used, with a reflectance detector on the nail, and a transmissive detector off the nail. Depending on the mode, a switch in the sensor, or in an intermediate amplifier module, or in the oximeter monitor could select between the detectors. In another embodiment, a single detector is used, with one pair of emitters on the nail, and another pair of emitters off the nail. Alternately, a completely separate transmissive sensor could be used.

In some patients, in particular those with low blood perfusion, it may be difficult to lock onto a pulse waveform. The additional transmissive sensor could be used to enable locking on for such patients. In addition, a transmissive sensor could be used to calibrate the nail sensor "on-the-fly." Because of shunting and other unique aspects of the nail site, a predetermined calibration may be off. A measurement of saturation using the transmissive and the nail reflectance sensors could be done in the absence of motion, with a correction factor applied to the reflectance sensor. The correction could be a constant which is added or a multiplicative factor, or both. If measurements are done at different saturations, a calibration line or curve could be determined by the oximeter to allow adjustments anywhere along the calculated curve. Subsequently, in the presence of motion, the nail sensor will be more accurately calibrated.

FIG. 13 illustrates an alternate embodiment of the invention in which a self-contained sensor 80 according to the present invention includes the processing circuitry on one or more semiconductor chips inside, and has its own display 82, which may be a liquid crystal display, for instance. In one embodiment, a button 84 allows switching between modes, such as between displaying a pulse and oxygen saturation. In an alternate embodiment, a flex connection 86 to a module 88 attached on a band 90 may be used. Module 88 might contain the battery, or alternately the processing circuitry, or the display. Additionally, either embodiment could be used for a wireless transmission to an oximeter, with the transmitting circuit either being in module 88 or sensor body 80.

FIG. 14 illustrates another embodiment of the present invention in which a stimulator is used to generate an artificial pulse. A stimulator could electrically stimulate the nerves to cause motion of an appendage, or could use a pneumatic pressure cuff to stimulate an artificial pulse; or use electromechanical stimulation or any other mechanism which generates a pulse characteristically different (e.g., amplitude, frequency, shape, etc.) than the cardiac pulse so that the cardiac pulse need not be used. Such an apparatus would be particularly advantageous for patients with low blood perfusion or a weak heartbeat. FIG. 14 is one embodiment showing a sensor 92 mounted on a thumbnail, with an airbag 94 mounted to the bottom of the thumb and held in place with a band 96. A hose 98 to the airbag periodically inflates and deflates it, causing a pressure wave through the thumb, giving artificially induced motion. This pressure induced motion provides the variation needed for sensor 92 to measure the oxygen saturation using either the ratio-of-ratios or a least squares technique. If the motion is in the frequency range of a heartbeat, the sensor can be backward compatible with existing oximeter monitors, even those that look for a cardiac signal.

FIG. 15 illustrates airbag 94 in a top view, showing hose 98 connected to a diaphragm pump 100. FIG. 16 shows a side view of the airbag 94 of FIG. 15, showing that it is wide but flat.

FIG. 17 is a flowchart of one embodiment of a portion of a program for operating an oximeter so that either cardiac pulses or motion pulses can be used to calculate oxygen saturation. The oxygen saturation is calculated in a known manner (step A). In a first alternative, the signal is analyzed to determine if it is a cardiac pulse or a motion pulse (step B). This can be done using any of the pulse qualification or motion detection techniques known to those of skill in the art. If a motion signal is present and used for the oxygen saturation calculation, then in step C only the oxygen saturation signal is displayed, and not a pulse rate (which would be a motion pulse rate, and not the patient's heart rate). If a cardiac pulse is used, the pulse rate is also displayed (step D).

Alternately, a pulse determination step E could be used where the sensor includes both a reflectance sensor and a transmittance sensor. If motion is present above a predetermined threshold (such as at least twice the arterial pulse signal), the reflectance sensor is used, which uses the motion signal, and alters any motion filtering or motion reduction techniques (step F). If the motion signal is below the threshold, the transmittance sensor is used (step G), with standard motion reduction techniques being employed (either hardware or software or both).

Both sensors could be energized in an ongoing manner, and the saturation and rate could be chosen to come from the sensor considered most reliable, depending on the instru-

ment's assessment of motion. Simultaneous computation may further allow improved processed signal estimates of cardiac rate in the presence of motion given knowledge of estimated saturation.

FIG. **18** is a block diagram of a portion of a pulse oximeter monitor used in conjunction with an artificial pulse generator, such as shown in FIGS. **14-16**. A frequency generator **110** produces a desired frequency for the motion pulse. This could be varied to give a frequency which is not interfered with by other noise, or frequency hopping could be used to isolate the signal from other sources of motion or noise. A pump controller **112** activates a pump or motor **100** (FIG. **12**) at the generated frequency. Since the driven frequency is known, optionally other frequencies could be filtered out to reduce noise. After a signal is captured and converted to digital form by a circuit **114**, a bandpass filter **116** is used to reduce other frequency signals. A control signal from frequency generator **110** could vary the bandpass frequency. A circuit or processor **118** then calculates the oxygen saturation. A central controller **120** controls the rest of the circuitry, including a sensor driver circuit **122**, which could selectively activate different reflectance and transmittance emitters in one embodiment. Controller **120** could also analyze the signals for the presence of motion to alternate between motion and cardiac pulse modes in one embodiment. Alternately, a separate motion sensor could provide an input to controller **120**. Note that other physical implementations are possible, such as using a single processor to do the filtering, the frequency generation and the oxygen saturation calculation.

A calibration resistor (or other active or passive element) **115** encodes the mean wavelength of at least one LED, and provides it to a calibration reader circuit or CPU **120**. The wavelength indicated is used to select coefficients stored in the monitor. Such a calibration technique is described in more detail in U.S. Pat. No. 4,621,643, the disclosure of which is incorporated herein by reference.

FIG. **19** is a cut-away view of an embodiment of a sensor **130** according to the invention. An emitter **132** is mounted on a circuit **134** inside the sensor housing. A cylindrical lens **136** is mounted in an aperture **138**. The lens directs the light down through the nail, minimizing the light which hits the nail at an angle and can be shunted to the detector. An aperture itself can perform the same function, but the lens insures that more of the light is used, maintaining a higher intensity at a given power, or allowing less power to be used. Detector **140** is recessed in an aperture **142** to avoid shunted light on the receiving end.

The sensor is secured to a nail **144** using an adhesive layer **146**. The adhesive layer can act as a shunt path itself. Accordingly, the adhesive layer may be tinted to be opaque to the wavelengths used, with preferably transparent windows **148** and **150** for the detector and emitter apertures.

As will be understood by those of skill in the art, the present invention could be embodied in other specific forms without departing from the spirit or essential characteristics thereof. For example, a sensor could be placed on a fingernail other than the thumb nail, and could be placed on toenails. Alternately, a sensor could be placed on the cuticle or the live nail fold skin extending over the beginning of the nail. The sensor could be attached with a clip-type sensor, or an elastic wrap, bandage or adhesive which encircles the appendage could be used. The sensor could be placed at locations other than the nailbed where signals at the multiple wavelengths in the presence of motion are still adequately correlated. The emitter in the sensor could be fabricated using an optical fiber to carry the light from a source remotely located, and equivalently the detector could be an optical light guide to pipe the light to a remote detector. Accordingly, reference should be made to the following claims which set forth the scope of the invention.

The invention claimed is:

1. An optical sensor comprising:

a sensor body configured to attach to a distal end portion of a patient's digit, the sensor body housing a light emitter and a light detector; and

a flexible circuit having a first portion operatively connected to the light emitter and to the light detector, having a second portion that is accordion-shaped and that extends over at least one joint of the patient's digit, and having a third portion configured to be secured to a proximal end portion of the patient's digit, wherein the accordion-shaped second portion is configured to move independently of the sensor body.

2. The optical sensor of claim **1**, wherein the sensor comprises a pulse oximetry sensor.

3. The optical sensor of claim **1**, wherein the light emitter is recessed in a first cavity of the sensor body, the light detector is recessed in a second cavity of the sensor body, and wherein the first cavity includes a lens between the light emitter and an edge of the sensor body, and the second cavity includes an empty space between the light detector and the edge of the sensor body.

4. The optical sensor of claim **1**, comprising a securing band for attaching the sensor body to the patient's digit.

5. The optical sensor of claim **4**, wherein the securing band comprises an elastic band and a hook and loop fastener.

6. The optical sensor of claim **1**, wherein the sensor body is configured to be attached to the patient's nail such that the light emitter and the light detector are positioned on the patient's nail.

7. The optical sensor defined in claim **1**, comprising a display disposed on the sensor for displaying at least one of a blood oxygen saturation value or a pulse rate.

8. The optical sensor defined in claim **7**, wherein the light emitter, the light detector, and the display are located in one housing of the sensor body.

9. The optical sensor defined in claim **7**, comprising a button or switch for alternating between displaying the pulse rate and the oxygen saturation value.

10. A method of reducing light shunting in an optical sensor, comprising:

emitting light into a tissue with a light emitter disposed in a sensor body, the sensor body configured to attach to a distal end portion of a patient's digit;

detecting the light from the tissue with the light detector disposed in the sensor body;

generating a signal based on the detected light; and

transmitting the signal to a monitor via a first portion of a flexible circuit operatively connected to the light emitter and to the light detector via a second portion of the flexible circuit that is accordion-shaped and that extends over at least one joint of the patient's digit and via a third portion of the flexible circuit configured to be secured to a proximal end portion of the patient's finger wherein the accordion-shaped second portion is configured to move independently of the sensor body.

11. The method of claim **10**, comprising determining a blood oxygen saturation value from the signal.

12. The method of claim **10**, comprising displaying the blood oxygen saturation value on a display located on the sensor body.

13. The method of claim **10**, wherein the light emitter is recessed in a first cavity of the sensor body having a lens, the light detector is recessed in a second cavity of the sensor body,

and wherein the second cavity includes an empty space between the light detector and a patient contacting surface of sensor body.

* * * * *

专利名称(译)	运动兼容传感器，用于非侵入式光学血液分析		
公开(公告)号	US8649839	公开(公告)日	2014-02-11
申请号	US12/822898	申请日	2010-06-24
[标]申请(专利权)人(译)	内尔科尔普里坦贝内特公司		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT LLC		
当前申请(专利权)人(译)	COVIDIEN LP		
[标]发明人	CHIN RODNEY MANNHEIMER PAUL D FLEWELLING ROSS		
发明人	CHIN, RODNEY MANNHEIMER, PAUL D FLEWELLING, ROSS		
IPC分类号	A61B5/1455 A61B5/1464 A61B5/00 A61B5/145 A61B5/1495		
CPC分类号	A61B5/6833 A61B5/14552 A61B5/7207 A61B5/6826 A61B5/6838		
其他公开文献	US20100261986A1		
外部链接	Espacenet USPTO		

摘要(译)

一种非侵入式光学传感器，其使用运动信号来计算被测量的生理特征。对于脉搏血氧测定法，可以将最小二乘法或比率比技术应用于运动信号本身。这可以通过选择患者的位置来实现，其中运动的变化产生两个充分相关的波长的信号。特别地，已经确定放置在指甲上的传感器，特别是缩略图，表现出当用于脉搏血氧测定时具有相关的红色和红外信号的特性，并且所得到的信号与动脉血氧饱和度相关。