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**LeBoeuf**

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(54) **APPARATUS AND METHODS FOR ESTIMATING TIME-STATE PHYSIOLOGICAL PARAMETERS**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,595,219 A 7/1971 Friedlander et al.  
4,240,882 A 12/1980 Ang et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE 3910749 A1 10/1990  
EP 1 480 278 A2 11/2004

(Continued)

OTHER PUBLICATIONS

Edmison et al., "E-Textile Based Automatic Activity Diary for Medical Annotation and Analysis," Proc. BSN 2006 Int. Workshop Wearable Implantable Body Sensor Netw. (2006), pp. 131-145, Apr. 3-5, 2006.

(Continued)

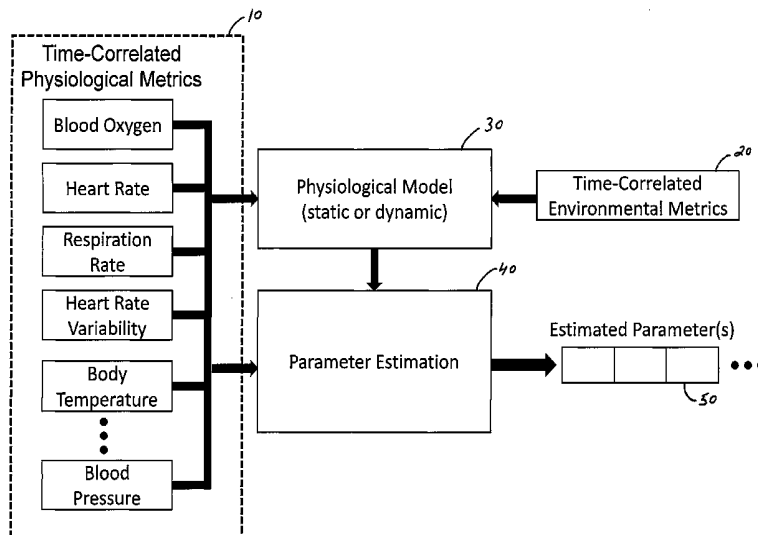
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(57) **ABSTRACT**

A method of determining a value of a physiological parameter for a subject at a selected state includes obtaining, via a device attached to the subject, a value of the physiological parameter of the subject at a particular time-of-day, and applying a time-dependent relationship function to the obtained physiological parameter value via a processor to determine a value of the physiological parameter at the selected state.

**22 Claims, 11 Drawing Sheets**



(56)

## References Cited

## U.S. PATENT DOCUMENTS

4,331,154	A	5/1982	Broadwater et al.	6,605,038	B1	8/2003	Teller et al.
4,438,772	A	3/1984	Slavin	6,616,613	B1	9/2003	Goodman
4,491,760	A	1/1985	Linville	6,631,196	B1	10/2003	Taenzer et al.
4,521,499	A	6/1985	Switzer	6,647,378	B2	11/2003	Kindo
4,541,905	A	9/1985	Kuwana et al.	6,656,116	B2	12/2003	Kim et al.
4,592,807	A	6/1986	Switzer	6,694,180	B1	2/2004	Boesen
4,655,225	A	4/1987	Dahne et al.	6,760,610	B2	7/2004	Tschupp et al.
4,882,492	A	11/1989	Schlager	6,783,501	B2	8/2004	Takahashi et al.
4,896,676	A	1/1990	Sasaki	6,808,473	B2	10/2004	Hisano et al.
4,928,704	A	5/1990	Hardt	6,859,658	B1	2/2005	Krug
4,957,109	A	9/1990	Groeger et al.	6,893,396	B2	5/2005	Schulze et al.
5,002,060	A	3/1991	Nedivi	6,941,239	B2	9/2005	Unuma et al.
5,022,970	A	6/1991	Cook et al.	6,953,435	B2	10/2005	Kondo et al.
5,079,421	A	1/1992	Knudson et al.	6,996,427	B2	2/2006	Ali et al.
5,086,229	A	2/1992	Rosenthal et al.	6,997,879	B1	2/2006	Turcott
5,143,078	A	9/1992	Mather et al.	7,018,338	B2	3/2006	Vetter et al.
5,226,417	A	7/1993	Swedlow et al.	7,024,369	B1	4/2006	Brown et al.
5,348,002	A	9/1994	Caro	7,041,062	B2	5/2006	Friedrichs et al.
5,377,100	A	12/1994	Pope et al.	7,043,287	B1	5/2006	Khalil et al.
5,482,036	A	1/1996	Diab et al.	7,054,674	B2	5/2006	Cane et al.
5,492,129	A	2/1996	Greenberger	7,088,234	B2	8/2006	Naito et al.
5,499,301	A	3/1996	Sudo et al.	7,107,088	B2	9/2006	Aceti
5,581,648	A	12/1996	Sahagen	7,113,815	B2	9/2006	O'Neil et al.
5,596,987	A	1/1997	Chance	7,117,032	B2	10/2006	Childre et al.
5,662,117	A	9/1997	Bittman	7,163,512	B1	1/2007	Childre et al.
5,673,692	A	10/1997	Schulze et al.	7,175,601	B2	2/2007	Verjus et al.
5,697,374	A	12/1997	Odagiri et al.	7,209,775	B2	4/2007	Bae et al.
5,711,308	A	1/1998	Singer	7,252,639	B2	8/2007	Kimura et al.
5,725,480	A	3/1998	Oosta et al.	7,263,396	B2	8/2007	Chen et al.
5,743,260	A	4/1998	Chung et al.	7,336,982	B2	2/2008	Yoo et al.
5,779,631	A	7/1998	Chance	7,341,559	B2	3/2008	Schulz et al.
5,807,114	A	9/1998	Hodges et al.	7,376,451	B2	5/2008	Mahony et al.
5,807,267	A	9/1998	Bryars et al.	7,470,234	B1	12/2008	Elhag et al.
5,853,005	A	12/1998	Scanlon	7,483,730	B2	1/2009	Diab et al.
5,904,654	A	5/1999	Wohltmann et al.	7,486,988	B2	2/2009	Goodall et al.
5,938,593	A	8/1999	Quellette	7,519,327	B2	4/2009	White
5,964,701	A	10/1999	Asada et al.	7,583,994	B2	9/2009	Scholz
5,971,931	A	10/1999	Raff	7,625,285	B2	12/2009	Breving
5,974,338	A	10/1999	Asano et al.	7,652,569	B2	1/2010	Kiff et al.
5,995,858	A	11/1999	Kinast	7,689,437	B1	3/2010	Teller et al.
6,004,274	A	12/1999	Nolan et al.	7,695,440	B2	4/2010	Kondo et al.
6,013,007	A	1/2000	Root et al.	7,725,147	B2	5/2010	Li et al.
6,023,541	A	2/2000	Merchant et al.	7,756,559	B2	7/2010	Abreu
6,045,511	A	4/2000	Ott et al.	7,843,325	B2	11/2010	Otto
6,067,006	A	5/2000	O'Brien	7,894,869	B2	2/2011	Hoarau
6,070,093	A	5/2000	Oosta et al.	7,914,468	B2	3/2011	Shalon et al.
6,078,829	A	6/2000	Uchida et al.	7,991,448	B2	8/2011	Edgar et al.
6,080,110	A	6/2000	Thorgersen	8,050,728	B2	11/2011	Al-Ali et al.
6,186,145	B1	2/2001	Brown	8,055,319	B2	11/2011	Oh et al.
6,198,394	B1	3/2001	Jacobsen et al.	8,059,924	B1	11/2011	Letant et al.
6,198,951	B1	3/2001	Kosuda et al.	8,130,105	B2	3/2012	Al-Ali et al.
6,205,354	B1	3/2001	Gellermann et al.	8,137,270	B2	3/2012	Keenan et al.
6,231,519	B1	5/2001	Blants et al.	8,172,459	B2	5/2012	Abreu
6,283,915	B1	9/2001	Aceti et al.	8,175,670	B2	5/2012	Baker, Jr. et al.
6,285,816	B1	9/2001	Anderson et al.	8,251,903	B2	8/2012	LeBoeuf et al.
6,289,230	B1	9/2001	Chaiken et al.	8,255,027	B2	8/2012	Al-Ali et al.
6,298,314	B1	10/2001	Blackadar et al.	8,328,420	B2	12/2012	Abreu
6,332,868	B1	12/2001	Sato et al.	8,416,959	B2	4/2013	Lott et al.
6,358,216	B1	3/2002	Kraus et al.	8,491,492	B2 *	7/2013	Shinar ..... A61B 5/0205 600/16
6,361,660	B1	3/2002	Goldstein	8,504,679	B2	8/2013	Spire et al.
6,371,925	B1	4/2002	Imai et al.	8,506,524	B2	8/2013	Graskov et al.
6,374,129	B1	4/2002	Chin et al.	8,512,242	B2	8/2013	LeBoeuf et al.
6,415,167	B1	7/2002	Blank et al.	8,730,048	B2	5/2014	Shen et al.
6,443,890	B1	9/2002	Schulze et al.	9,005,129	B2	4/2015	Venkatraman et al.
6,444,474	B1	9/2002	Thomas et al.	2001/0049471	A1	12/2001	Suzuki et al.
6,454,718	B1	9/2002	Clift	2002/0143242	A1	10/2002	Nemirovski
6,458,080	B1	10/2002	Brown et al.	2002/0156386	A1	10/2002	Dardik et al.
6,470,893	B1	10/2002	Boesen	2002/0156654	A1	10/2002	Roe et al.
6,514,278	B1	2/2003	Hibst et al.	2002/0186137	A1	12/2002	Skardon
6,527,711	B1	3/2003	Stivoric et al.	2002/0194002	A1	12/2002	Petrushin
6,527,712	B1	3/2003	Brown et al.	2003/0002705	A1	1/2003	Boesen
6,534,012	B1	3/2003	Hazen et al.	2003/0007631	A1	1/2003	Bolognesi et al.
6,556,852	B1	4/2003	Schulze et al.	2003/0045785	A1	3/2003	Diab et al.
6,569,094	B2	5/2003	Suzuki et al.	2003/0050563	A1	3/2003	Suribhotla et al.
6,571,117	B1	5/2003	Marbach	2003/0064712	A1	4/2003	Gaston et al.
				2003/0083583	A1	5/2003	Kovtun et al.
				2003/0109030	A1	6/2003	Uchida et al.
				2003/0181795	A1	9/2003	Suzuki et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

2003/0212336	A1	11/2003	Lee et al.	2006/0252999	A1	11/2006	Devaul et al.
2003/0220584	A1	11/2003	Honeyager et al.	2006/0264730	A1	11/2006	Stivoric et al.
2003/0222268	A1	12/2003	Yocom et al.	2006/0292533	A1	12/2006	Selod
2004/0004547	A1	1/2004	Appelt et al.	2007/0004449	A1	1/2007	Sham
2004/0022700	A1	2/2004	Kim et al.	2007/0004969	A1	1/2007	Kong et al.
2004/0030581	A1	2/2004	Leven	2007/0015992	A1	1/2007	Filkins et al.
2004/0034289	A1	2/2004	Teller et al.	2007/0021206	A1	1/2007	Sunnen
2004/0034293	A1	2/2004	Kimball	2007/0027367	A1	2/2007	Oliver et al.
2004/0054291	A1	3/2004	Schulz et al.	2007/0036383	A1	2/2007	Romero
2004/0075677	A1	4/2004	Loyall et al.	2007/0060800	A1	3/2007	Drinan et al.
2004/0077934	A1	4/2004	Massad	2007/0063850	A1	3/2007	Devaul et al.
2004/0103146	A1	5/2004	Park	2007/0082789	A1	4/2007	Nissila et al.
2004/0117204	A1	6/2004	Mazar et al.	2007/0083092	A1	4/2007	Rippo et al.
2004/0120844	A1	6/2004	Tribelsky et al.	2007/0083095	A1	4/2007	Rippo et al.
2004/0122294	A1	6/2004	Hatlestad et al.	2007/0088221	A1	4/2007	Stahmann
2004/0122702	A1	6/2004	Sabol et al.	2007/0106167	A1	5/2007	Kinast
2004/0133123	A1	7/2004	Leonhardt et al.	2007/0112598	A1	5/2007	Heckerman et al.
2004/0135571	A1	7/2004	Uutela et al.	2007/0116314	A1	5/2007	Grilliot et al.
2004/0138578	A1	7/2004	Pineda et al.	2007/0118054	A1	5/2007	Pinhas et al.
2004/0186390	A1	9/2004	Ross et al.	2007/0165872	A1	7/2007	Bridger et al.
2004/0219056	A1	11/2004	Tribelsky et al.	2007/0167850	A1	7/2007	Russell et al.
2004/0220488	A1	11/2004	Vyshedskiy et al.	2007/0197881	A1	8/2007	Wolf et al.
2004/0225207	A1	11/2004	Bae et al.	2007/0213020	A1	9/2007	Novac
2004/0228494	A1	11/2004	Smith	2007/0233403	A1	10/2007	Alwan et al.
2004/0242976	A1	12/2004	Abreu	2007/0265097	A1	11/2007	Havukainen
2005/0004458	A1	1/2005	Kanayama et al.	2007/0270667	A1	11/2007	Coppi et al.
2005/0027216	A1	2/2005	Guillemaud et al.	2007/0270671	A1	11/2007	Gal
2005/0030540	A1	2/2005	Thornton	2007/0293781	A1	12/2007	Sims et al.
2005/0033200	A1	2/2005	Soehren et al.	2008/0004536	A1	1/2008	Baxi et al.
2005/0038349	A1	2/2005	Choi et al.	2008/0039731	A1	2/2008	McCombie et al.
2005/0043600	A1	2/2005	Diab et al.	2008/0076972	A1	3/2008	Dorogusker et al.
2005/0043630	A1	2/2005	Buchert	2008/0081963	A1	4/2008	Naghavi et al.
2005/0058456	A1	3/2005	Yoo	2008/0096726	A1	4/2008	Riley et al.
2005/0059870	A1	3/2005	Aceti	2008/0114220	A1	5/2008	Banet et al.
2005/0101845	A1	5/2005	Nihtila	2008/0132798	A1	6/2008	Hong et al.
2005/0101872	A1	5/2005	Sattler et al.	2008/0141301	A1	6/2008	Azzaro et al.
2005/0113167	A1	5/2005	Buchner et al.	2008/0146890	A1	6/2008	LeBoeuf et al.
2005/0113656	A1	5/2005	Chance	2008/0146892	A1	6/2008	LeBoeuf et al.
2005/0113703	A1	5/2005	Farringdon et al.	2008/0154098	A1	6/2008	Morris et al.
2005/0116820	A1	6/2005	Goldreich	2008/0154105	A1	6/2008	Lemay
2005/0119833	A1	6/2005	Nanikashvili	2008/0165017	A1	7/2008	Schwartz
2005/0148883	A1	7/2005	Boesen	2008/0170600	A1	7/2008	Sattler et al.
2005/0154264	A1	7/2005	Lecompte et al.	2008/0171945	A1	7/2008	Dotter
2005/0177034	A1	8/2005	Beaumont	2008/0177162	A1	7/2008	Bae et al.
2005/0187448	A1	8/2005	Petersen et al.	2008/0200774	A1	8/2008	Luo
2005/0187453	A1	8/2005	Petersen et al.	2008/0203144	A1	8/2008	Kim
2005/0192515	A1	9/2005	Givens et al.	2008/0249594	A1	10/2008	Dietrich
2005/0196009	A1	9/2005	Boesen	2008/0287752	A1	11/2008	Stroetz et al.
2005/0203349	A1	9/2005	Nanikashvili	2009/0005662	A1	1/2009	Petersen et al.
2005/0203357	A1	9/2005	Debreczeny et al.	2009/0006457	A1	1/2009	Stivoric et al.
2005/0209516	A1	9/2005	Fraden	2009/0010461	A1	1/2009	Klinghult et al.
2005/0222487	A1	10/2005	Miller et al.	2009/0030350	A1	1/2009	Yang et al.
2005/0222903	A1	10/2005	Buchheit et al.	2009/0054752	A1	2/2009	Jonnalagadda et al.
2005/0228244	A1	10/2005	Banet	2009/0069645	A1	3/2009	Nielsen et al.
2005/0228299	A1	10/2005	Banet	2009/0082994	A1	3/2009	Schuler et al.
2005/0240087	A1	10/2005	Keenan et al.	2009/0088611	A1	4/2009	Buschmann
2005/0258816	A1	11/2005	Zen et al.	2009/0093687	A1	4/2009	Telfort et al.
2005/0259811	A1	11/2005	Kimm et al.	2009/0105548	A1	4/2009	Bart
2006/0009685	A1	1/2006	Finarov et al.	2009/0105556	A1	4/2009	Fricke et al.
2006/0063993	A1	3/2006	Yu et al.	2009/0112071	A1	4/2009	LeBoeuf et al.
2006/0064037	A1	3/2006	Shalon et al.	2009/0131761	A1	5/2009	Moroney, III et al.
2006/0084878	A1	4/2006	Banet et al.	2009/0131764	A1	5/2009	Lee et al.
2006/0122520	A1	6/2006	Banet et al.	2009/0175456	A1	7/2009	Johnson
2006/0123885	A1	6/2006	Yates et al.	2009/0177097	A1	7/2009	Ma et al.
2006/0142665	A1	6/2006	Garay et al.	2009/0214060	A1	8/2009	Chuang et al.
2006/0202816	A1	9/2006	Crump et al.	2009/0221888	A1	9/2009	Wijesiriwardana
2006/0205083	A1	9/2006	Zhao	2009/0227853	A1	9/2009	Wijesiriwardana
2006/0210058	A1	9/2006	Kock et al.	2009/0240125	A1	9/2009	Such et al.
2006/0211922	A1	9/2006	Al-Ali et al.	2009/0253992	A1	10/2009	Van Der Loo
2006/0211924	A1	9/2006	Dalke et al.	2009/0253996	A1	10/2009	Lee et al.
2006/0217598	A1	9/2006	Miyajima et al.	2009/0264711	A1	10/2009	Schuler et al.
2006/0224059	A1	10/2006	Swedlow et al.	2009/0270698	A1	10/2009	Shioi et al.
2006/0240558	A1	10/2006	Zhao	2009/0287067	A1	11/2009	Dorogusker et al.
2006/0246342	A1	11/2006	MacPhee	2009/0299215	A1	12/2009	Zhang
2006/0251334	A1	11/2006	Oba et al.	2010/0004517	A1	1/2010	Bryenton et al.
				2010/0045663	A1	2/2010	Chen et al.
				2010/0100013	A1	4/2010	Hu et al.
				2010/0113948	A1	5/2010	Yang et al.
				2010/0168531	A1	7/2010	Shaltis et al.

(56)

## References Cited

## U.S. PATENT DOCUMENTS

2010/0172522	A1	7/2010	Mooring et al.
2010/0179389	A1	7/2010	Moroney et al.
2010/0185105	A1	7/2010	Baldinger
2010/0217099	A1*	8/2010	LeBoeuf ..... A61B 5/00 600/301
2010/0217102	A1	8/2010	LeBoeuf et al.
2010/0217103	A1	8/2010	Abdul-Hafiz et al.
2010/0222655	A1	9/2010	Starr et al.
2010/0228315	A1	9/2010	Nielsen
2010/0234714	A1	9/2010	Mercier et al.
2010/0268056	A1	10/2010	Picard et al.
2010/0274100	A1	10/2010	Behar et al.
2010/0274109	A1	10/2010	Hu et al.
2010/0292589	A1	11/2010	Goodman
2010/0298653	A1	11/2010	McCombie et al.
2011/0028810	A1	2/2011	Van Slyke et al.
2011/0028813	A1	2/2011	Watson et al.
2011/0081037	A1	4/2011	Oh et al.
2011/0105869	A1	5/2011	Wilson et al.
2011/0112382	A1	5/2011	Li et al.
2011/0130638	A1	6/2011	Raridan, Jr.
2011/0142371	A1	6/2011	King et al.
2011/0288379	A1	11/2011	Wu
2012/0030547	A1	2/2012	Raptis et al.
2012/0095303	A1	4/2012	He
2012/0156933	A1	6/2012	Kreger et al.
2012/0179011	A1	7/2012	Moon et al.
2012/0197093	A1	8/2012	LeBoeuf et al.
2012/0277548	A1	11/2012	Burton
2013/0053661	A1	2/2013	Alberth et al.
2013/0072765	A1	3/2013	Kahn et al.
2013/0131519	A1	5/2013	LeBoeuf et al.
2013/0245387	A1	9/2013	Patel
2013/0336495	A1	12/2013	Burgett et al.
2014/0051940	A1	2/2014	Messerschmidt
2014/0052567	A1	2/2014	Bhardwaj et al.
2014/0073486	A1	3/2014	Ahmed et al.
2014/0100432	A1	4/2014	Golda et al.
2014/0127996	A1	5/2014	Park et al.
2014/0219467	A1	8/2014	Kurtz
2014/0236531	A1	8/2014	Carter
2014/0275852	A1	9/2014	Hong et al.
2014/0323880	A1	10/2014	Ahmed et al.
2014/0378844	A1	12/2014	Fei

## FOREIGN PATENT DOCUMENTS

EP	2 077 091	A2	7/2009
EP	2 182 839	B1	10/2011
GB	2 408 209	A	5/2005
GB	2 411 719	A	9/2005
JP	7-241279		9/1995
JP	9-253062		9/1997
JP	9-299342		11/1997
JP	2000-116611		4/2000
JP	2001-025462		1/2001
JP	2003-159221		6/2003
JP	2004-513750	A	5/2004
JP	2004-283523		10/2004
JP	2007-044203		2/2007
JP	2007-185348		7/2007
JP	2008-136556	A	6/2008
JP	2008-279061	A	11/2008
JP	2009-153664	A	7/2009
JP	2010-526646		8/2010
JP	2014-068733	A	4/2014
KR	20-0204510	Y1	11/2000
WO	WO 00/24064		4/2000
WO	WO 00/47108	A1	8/2000
WO	WO 01/08552	A1	2/2001
WO	WO 02/17782	A2	3/2002
WO	WO 2005/010568	A2	2/2005
WO	WO 2005/020121	A1	3/2005
WO	WO 2005/110238	A1	11/2005
WO	WO 2006/009830	A2	1/2006

WO	WO 2006/067690	A2	6/2006
WO	WO 2007/012931	A2	2/2007
WO	WO 2007/053146	A1	5/2007
WO	WO 2008141306	A2	11/2008
WO	WO 2013/038296	A1	3/2013
WO	WO 2014/092932	A1	6/2014

## OTHER PUBLICATIONS

European Search Report, EP Application No. 13863449.8, Oct. 19, 2015, 3 pages.

European Search Report, EP Application No. 14743615.8, Oct. 12, 2015, 3 pages.

European Search Report, EP Application No. 14743839.4, Oct. 12, 2015, 3 pages.

Gibbs et al., "Reducing Motion Artifact in Wearable Bio-Sensors Using MEMS Accelerometers for Active Noise Cancellation," 2005 American Control Conference, Jun. 8-10, 2005, Portland, OR, USA, pp. 1581-1586.

International Preliminary Report on Patentability, PCT/US2014/012940, Jun. 17, 2015, 23 pages.

International Search Report and Written Opinion of the International Searching Authority, corresponding to International Patent Application No. PCT/US2014/012940, Date of Mailing: Oct. 16, 2014, 13 pages.

International Search Report corresponding to International Patent Application No. PCT/US2014/012909, Date of Mailing: May 13, 2014, 3 pages.

Notification Concerning Transmittal of International Preliminary Report on Patentability, PCT/US2014/012909, Jul. 28, 2015.

Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2015/014562, Oct. 28, 2015.

Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2015/042636, Oct. 29, 2015.

Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2015/042015, Oct. 29, 2015.

Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2015/042035, Oct. 29, 2015.

Wood et al., "Active Motion Artifact Reduction for Wearable Sensors Using Laguerre Expansion and Signal Separation," Proceedings of the 2005 IEEE Engineering in Medicine and Biology, 27<sup>th</sup> Annual Conference, Shanghai, China, Sep. 1-4, 2005, pp. 3571-3574.

"U.S. Army Fitness Training Handbook" by the Department of the Army, 2003, The Lyons Press. p. 17.

"Warfighter Physiological and Environmental Monitoring: A Study for the U.S. Army Research Institute in Environmental Medicine and the Soldier Systems Center", Massachusetts Institute of Technology Lincoln Laboratory, Final Report, Nov. 1, 2004, prepared for the U.S. Army under Air Force Contract F19628-00-C-0002; approved for public release.

Anpo et al. "Photocatalytic Reduction of CO<sub>2</sub> With H<sub>2</sub>O on Titanium Oxides Anchored within Micropores of Zeolites: Effects of the Structure of the Active Sites and the Addition of Pt" *J. Phys. Chem. B*, 101:2632-2632 (1997).

Bársan et al. "Understanding the fundamental principles of metal oxide based gas sensors; the example of CO sensing with SnO<sub>2</sub> sensors in the presence of humidity" *Journal of Physics: Condensed Matter* 15:R813-R839 (2003).

Bott "Electrochemistry of Semiconductors" *Current Separations* 17(3):87-91 (1998).

Colligan, M. J. et al. in "The psychological effects of indoor air pollution", *Bulletin of the New York Academy of Medicine*, vol. 57, No. 10, Dec. 1981, p. 1014-1026.

de Paula Santos, U. et al. in "Effects of air pollution on blood pressure and heart rate variability: a panel study of vehicular traffic controllers in the city of Sao Paulo, Brazil", *European Heart Journal* (2005) 26, 193-200.

(56)

## References Cited

## OTHER PUBLICATIONS

- Ebert, T et al., "Influence of Hydration Status on Thermoregulation and Cycling Hill Climbing," *Med. Sci. Sport Exerc.* vol. 39, No. 2, pp. 323-329, 2007.
- European Search Report corresponding to European Application No. 07862660.3 dated Apr. 25, 2012; 7 pages.
- Falkner et al., "Cardiovascular response to mental stress in normal adolescents with hypertensive parents. Hemodynamics and mental stress in adolescents," *Hypertension* 1:23-30.
- FitTrainer "The Only Trainer You Need"; <http://itami.com>; Downloaded Feb. 26, 2010; © 2008 FitTrainer™; 2 pages.
- Fleming et al., "A Comparison of Signal Processing Techniques for the Extraction of Breathing Rate from the Photoplethysmogram," *World Academy of Science, Engineering and Technology*, vol. 30, Oct. 2007, pp. 276-280.
- Geladas et al., "Effect of cold air inhalation on core temperature in exercising subjects under stress," *The American Physiological Society*, pp. 2381-2387, 1988.
- Gold, D.R. et al. in "Ambient Pollution and Heart Rate Variability", *Circulation* 2000, 101:1267-1273.
- International Search Report and Written Opinion of the International Searching Authority, corresponding to PCT/US2012/0948079, mailed Oct. 9, 2012.
- International Search Report and Written Opinion of the International Searching Authority, corresponding to PCT/US2007/025114, mailed May 13, 2008.
- International Search Report Corresponding to International Application No. PCT/US2012/022634, Date of Mailing: Aug. 22, 2012, 9 pages.
- Maomao et al., "Mobile Context-Aware Game for the Next Generation," 2<sup>nd</sup> International Conference on Application and Development of Computer Games ADCOG 2003, p. 78-81.
- Martins et al. "Zinc oxide as an ozone sensor" *Journal of Applied Physics* 96(3):1398-1408.
- Maughan, R.J., "Impact of mild dehydration on wellness and on exercise performance," *European Journal of Clinical Nutrition*, 57, Suppl. 2, pp. S19-S23, 2003.
- Maughan et al., "Exercise, Heat, Hydration and the Brain," *Journal of the American College of Nutrition*, vol. 26, No. 5, pp. 604S-612S, 2007.
- Mostardi, R., et al., "The effect of increased body temperature due to exercise on the heart rate and the maximal aerobic power," *Europ. J. Appl. Physiol*, 33, pp. 237-245, 1974.
- Nakajima et al., "Monitoring of heart and respiratory rates by photoplethysmography using a digital filtering technique," *Med. Eng. Phys.*, vol. 18, No. 5, Jul. 1996, pp. 365-372.
- Notification of Transmittal of the International Search Report and Written Opinion of the International Search Authority issued Jul. 30, 2010 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2010/021936.
- Notification of Transmittal of the International Search Report and Written Opinion of the International Search Authority issued Aug. 26, 2010 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2010/021629.
- Notification of Transmittal of the International Search Report and the Written Opinion of the International Search Authority issued Sep. 16, 2010 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2010/024922.
- Notification of Transmittal of the International Search Report and the Written Opinion of the International Search Authority issued Sep. 27, 2010 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2010/025216.
- Notification of Transmittal of The International Search Report and The Written Opinion of the International Searching Authority, or the Declaration corresponding to International Application No. PCT/US2013/070271; Date of Mailing: Feb. 26, 2014; 13 pages.
- Saladin et al. "Photosynthesis of CH<sub>4</sub> at a TiO<sub>2</sub> Surface from Gaseous H<sub>2</sub>O and CO<sub>2</sub>" *J Chem. Soc., Chem. Commun.* 533-534 (1995).
- Shorten et al., "Acute effect of environmental temperature during exercise on subsequent energy intake in active men," *Am. J. Clin. Nutr.* 90, pp. 1215-1221, 2009.
- Skubal et al. "Detection and identification of gaseous organics using a TiO<sub>2</sub> sensor" *Journal of Photochemistry and Photobiology A: Chemistry* 148:103-108 (2002).
- Skubal et al. "Monitoring the Electrical Response of Photoinduced Organic Oxidation on TiO<sub>2</sub> Surfaces" Manuscript submitted Oct. 2000 to SPIE Intl. Symposium on Environment & Industrial Sensing, Boston, MA, Nov. 5-8, 2000, sponsored by SPIE, 10 pp.
- Thompson, M.W., "Cardiovascular drift and critical core temperature: factors limiting endurance performance in the heat?" *J. Exerc. Sci. Fit*, vol. 4, No. 1, pp. 15-24, 2006.
- Zhang et al. "Development of Chemical Oxygen Demand On-Line Monitoring System Based on a Photoelectrochemical Degradation Principle" *Environ. Sci. Technol.*, 40(7):2363-2368 (2006).
- Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2015/046079, Dec. 29, 2015.
- Communication pursuant to Article 94(3) EPC, European Patent Application No. 13863449.8, Nov. 5, 2015, 7 pages.
- Communication pursuant to Article 94(3) EPC, European Patent Application No. 14743615.8, Dec. 23, 2015, 7 pages.
- Communication pursuant to Article 94(3) EPC, European Patent Application No. 14743839.4, Dec. 23, 2015, 6 pages.
- International Search Report corresponding to International Patent Application No. PCT/US2012/046446; Date of Mailing: Jan. 14, 2013; 3 pages.
- Communication pursuant to Article 94(3) EPC, European Patent Application No. 12820308.0, Feb. 3, 2016, 5 pages.
- Notification of Transmittal of the International Search Report and Written Opinion of the International Search Authority issued May 26, 2016 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2016/019126.
- Notification of Transmittal of the International Search Report and Written Opinion of the International Search Authority issued May 26, 2016 by the Korean Intellectual Property Office for corresponding International Application No. PCT/US2016/019132.

\* cited by examiner

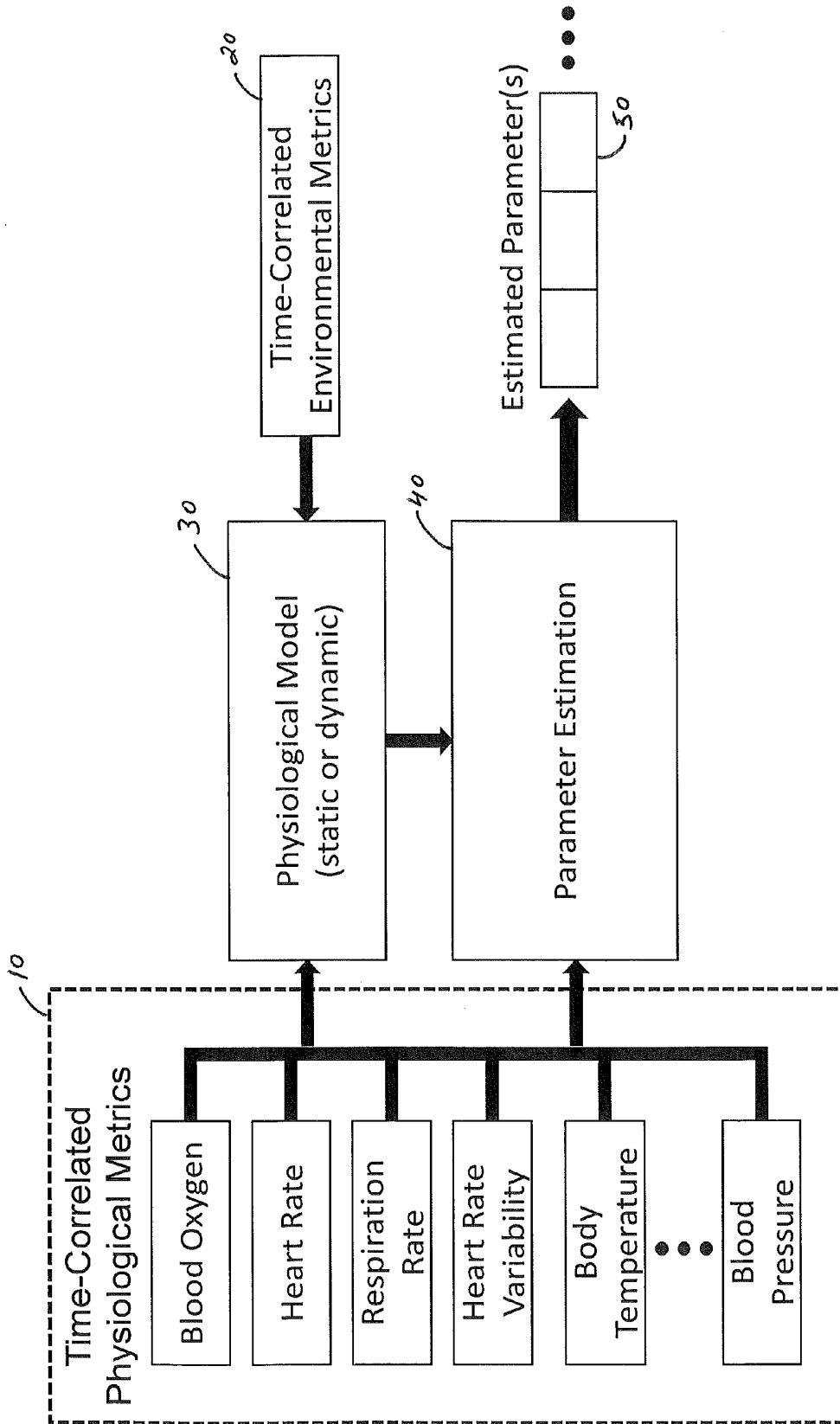


Figure 1

Average Core Body Temperature vs. Time  
For average human over average day

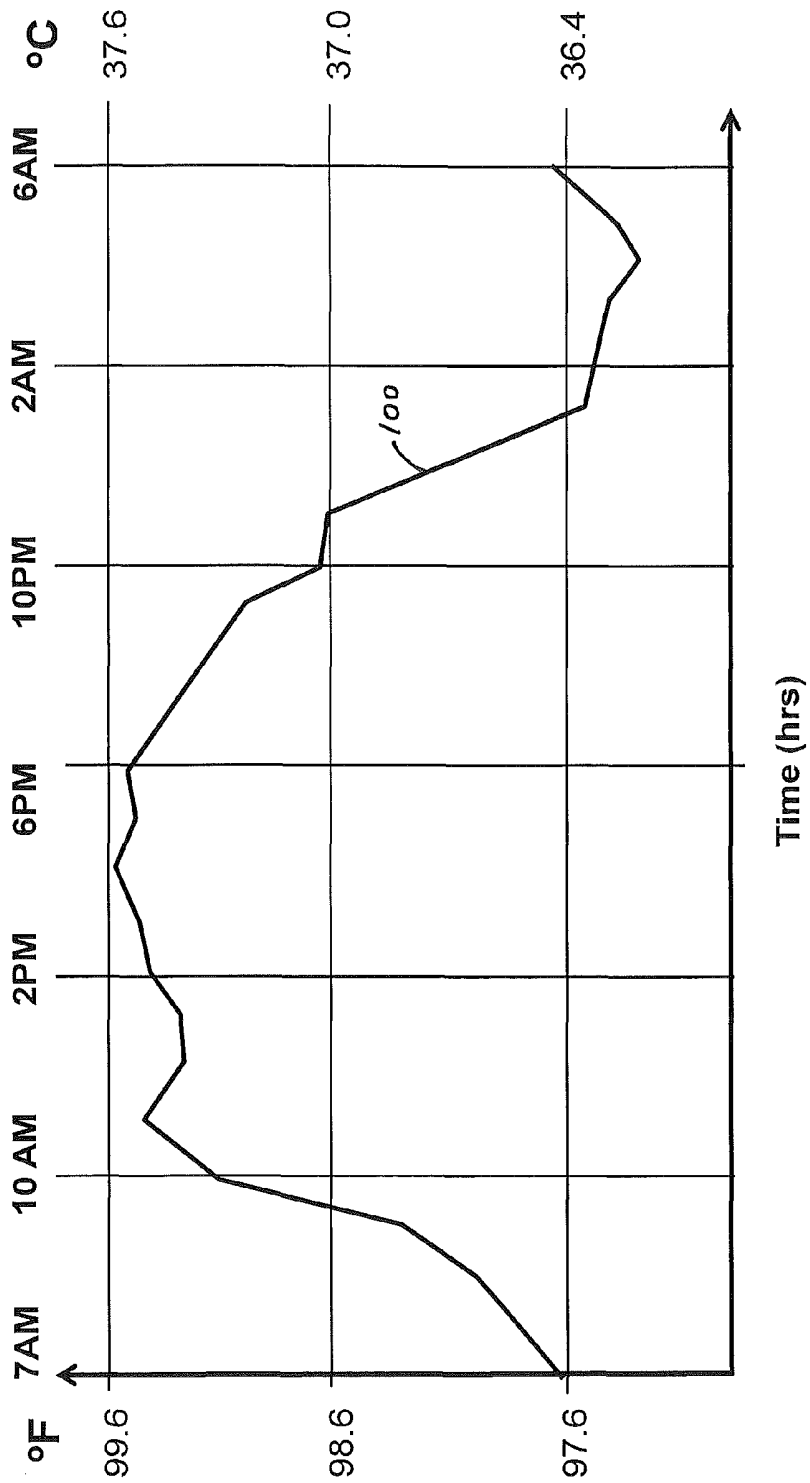


Figure 2

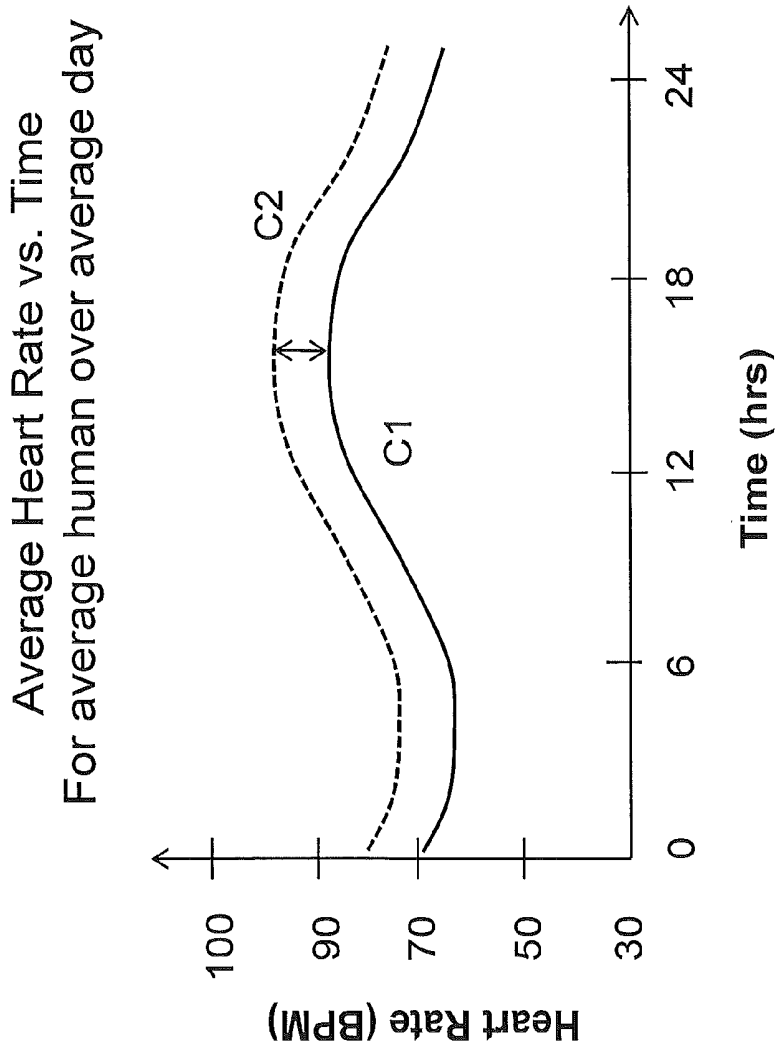


Figure 3

Average HF Heart Rate Variability vs. Time  
For average human over average day

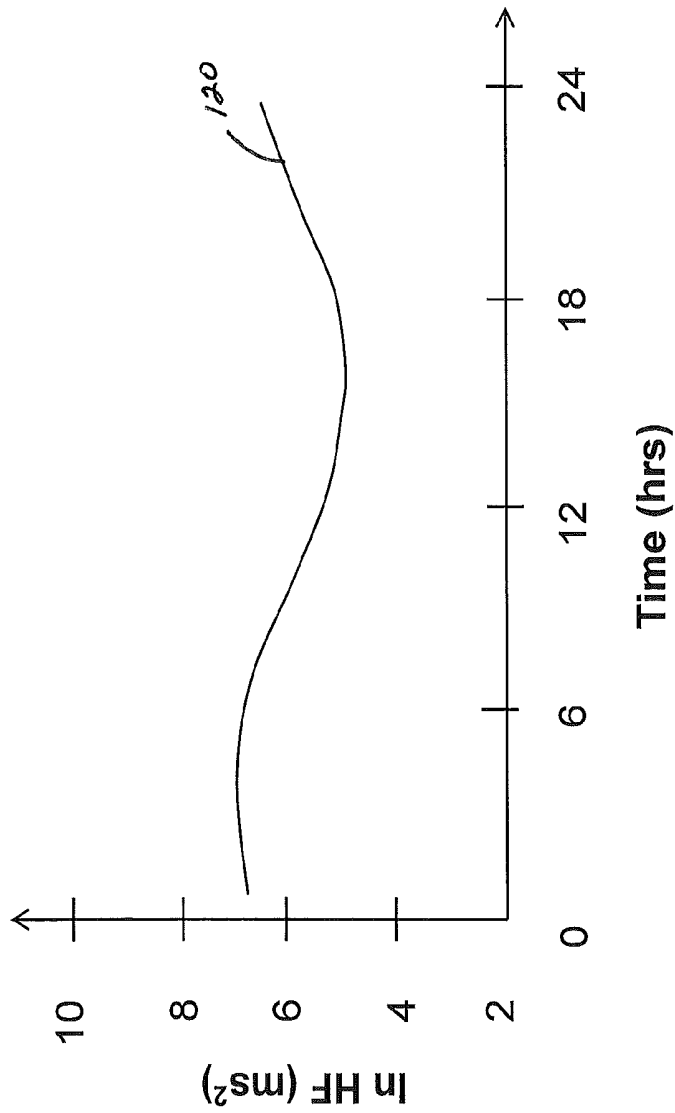


Figure 4

Exemplary Relationship between Heart Rate & Activity  
for Average Human Wearing Accelerometer(s)

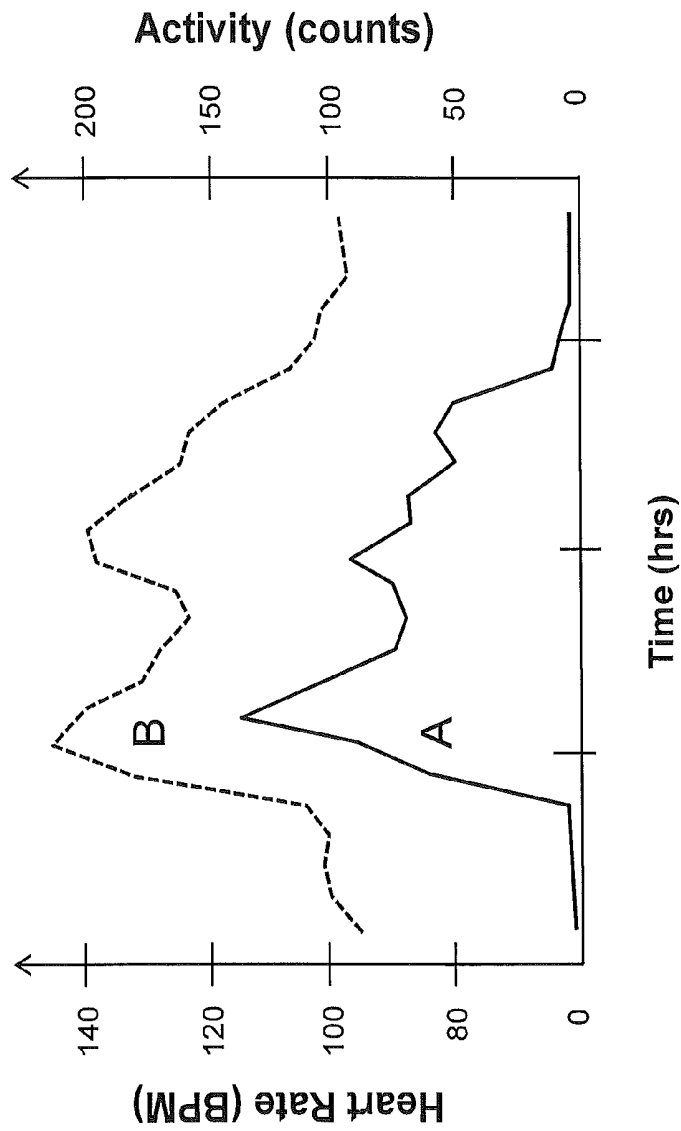


Figure 5

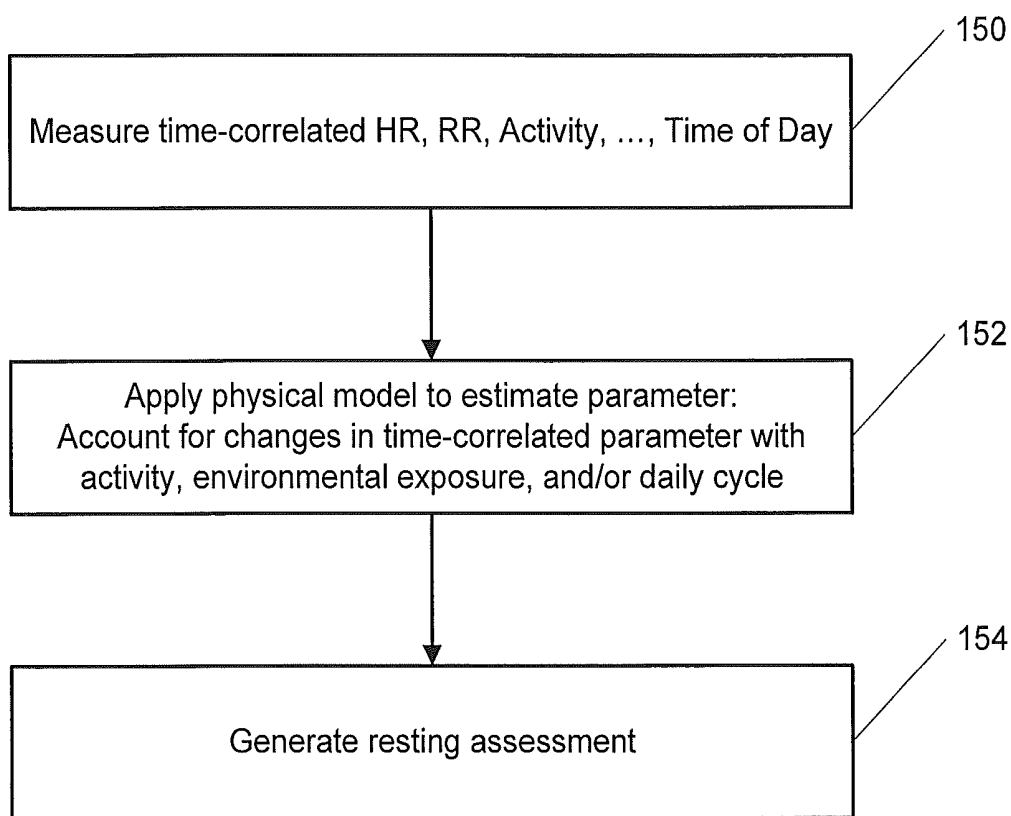


Figure 6

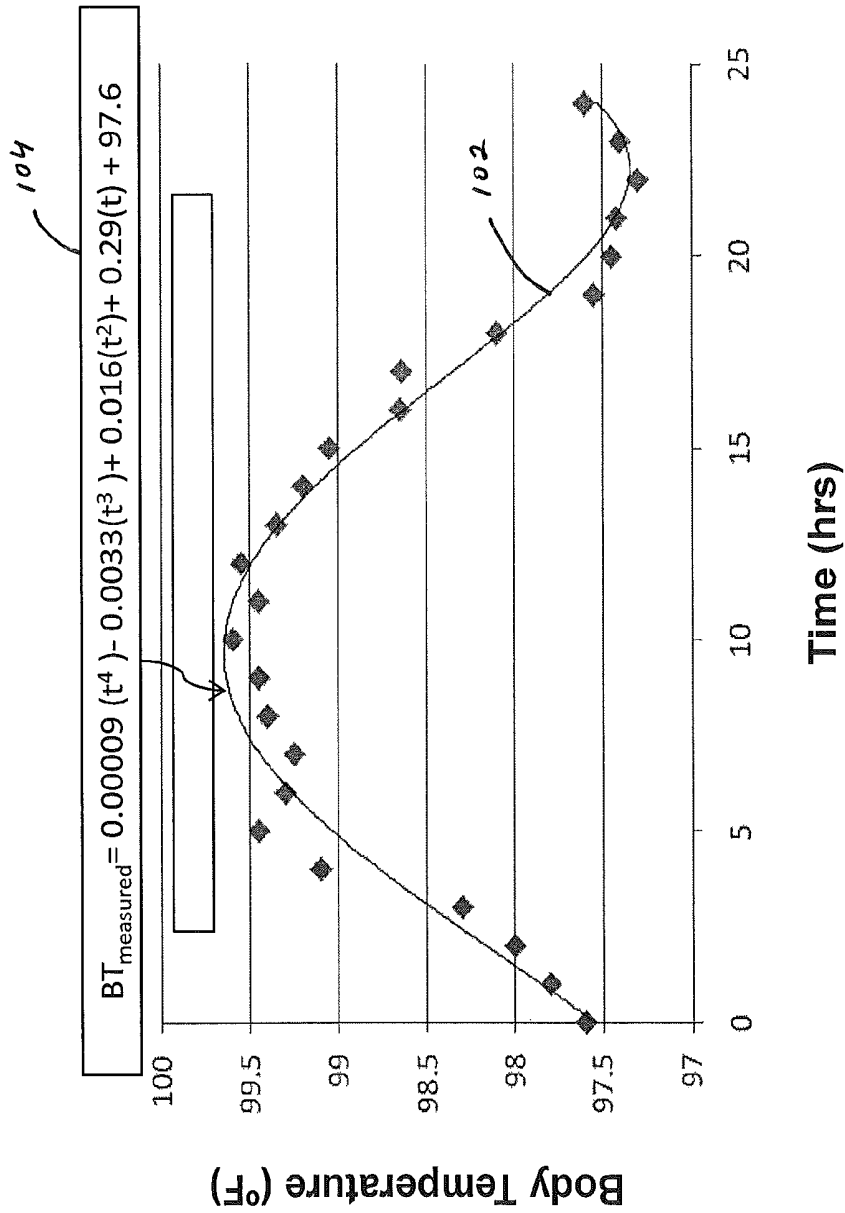


Figure 7

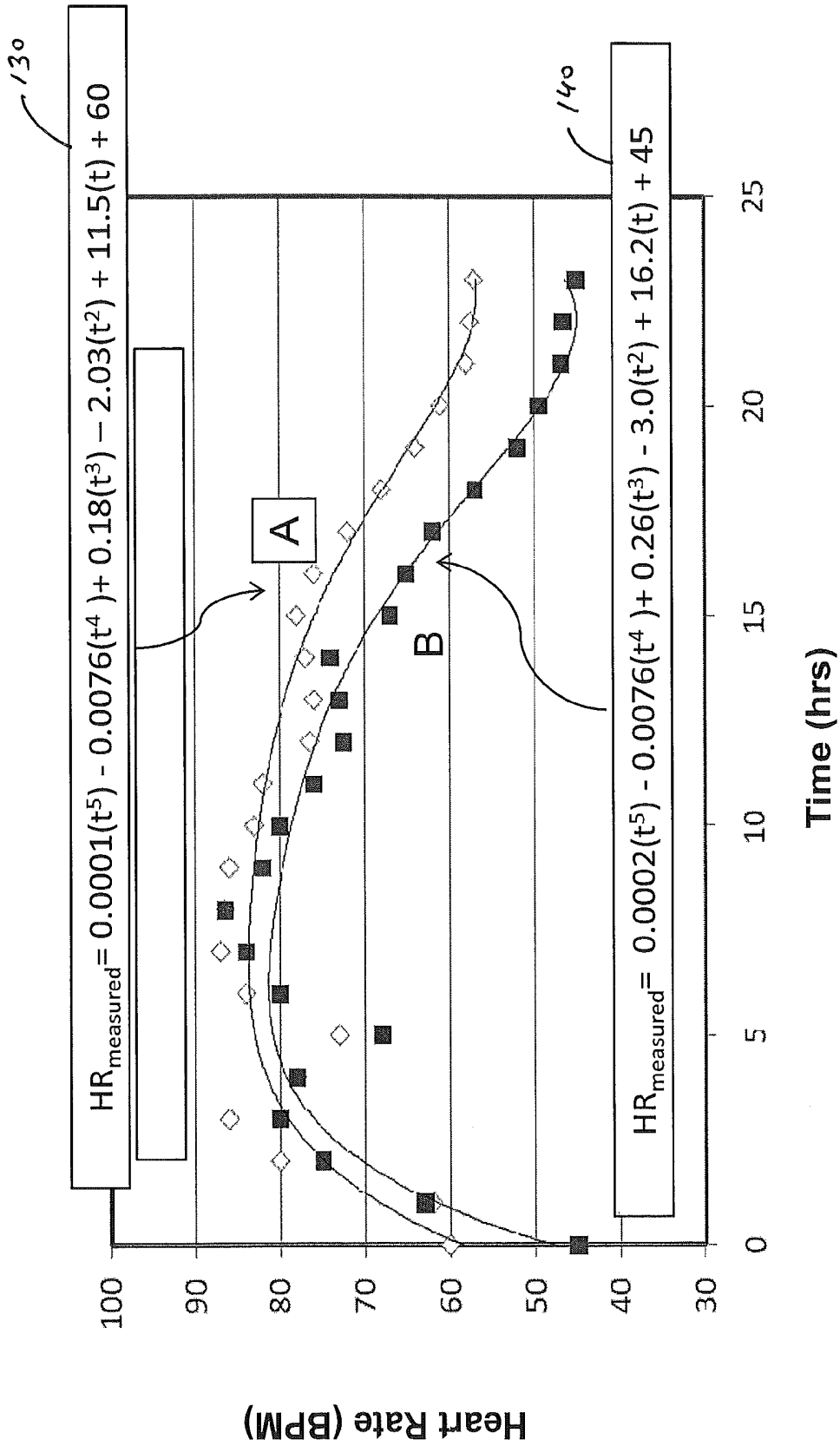
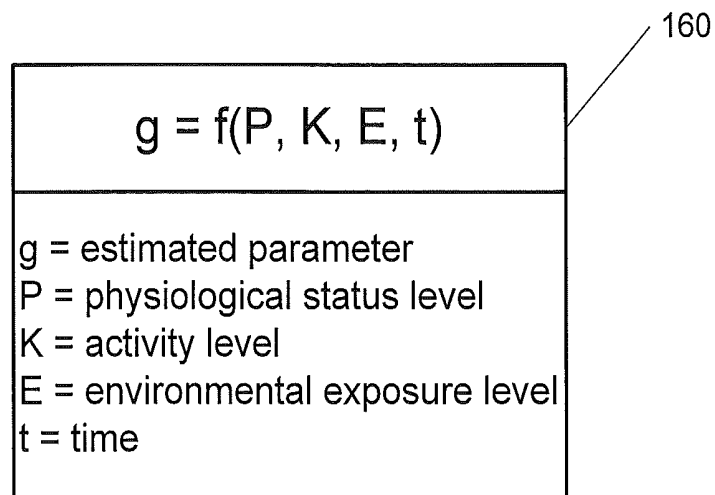


Figure 8



*Figure 9*

110

Time of Day	Measured Value	% Multiplier	Resting Estimation
7:00 AM		1	
9:00 AM		0.995918	
10:00 AM		0.992879	
12:00 PM		0.981398	
2:00 PM		0.983375	
4:00 PM		0.981398	
6:00 PM	99.5°F	0.981398	97.6°F
8:00 PM		0.982386	
10:00 PM		0.985361	
12:00 AM		0.989457	
2:00 AM		1.000513	
4:00 AM		1.001848	
6:00 AM		1.002053	

Figure 10

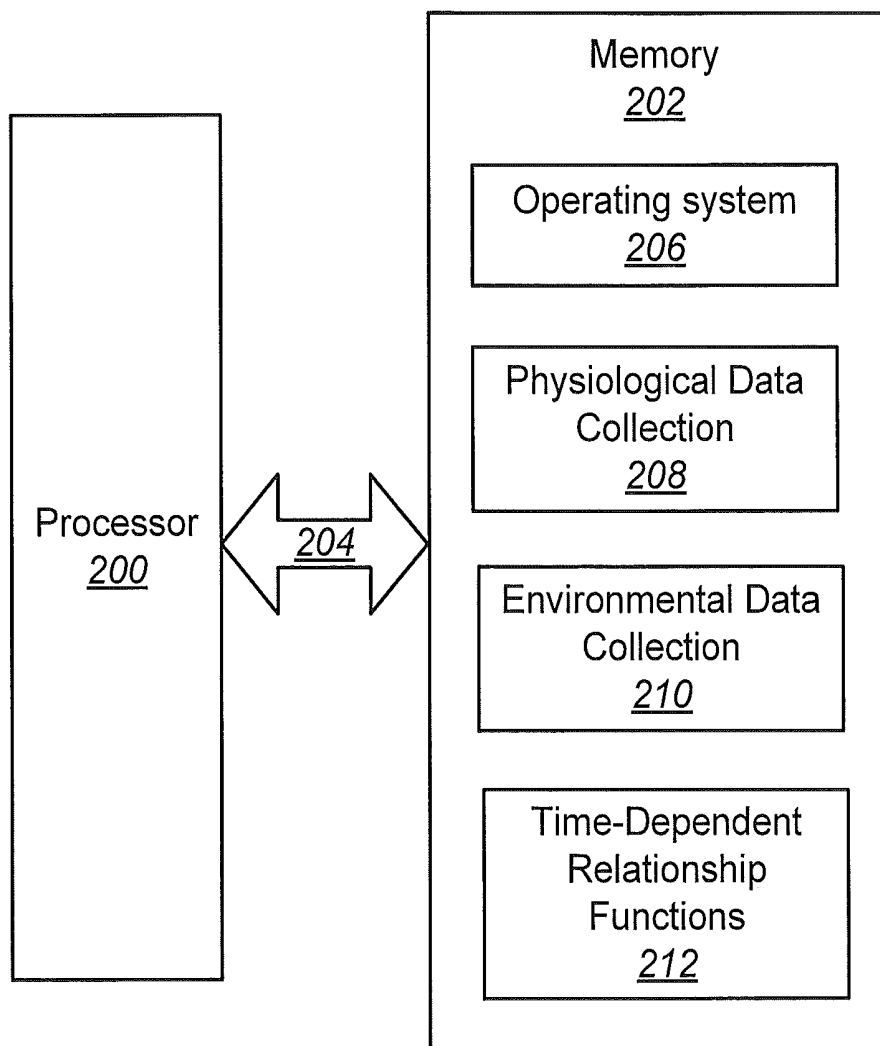


Figure 11

## APPARATUS AND METHODS FOR ESTIMATING TIME-STATE PHYSIOLOGICAL PARAMETERS

### RELATED APPLICATION

This application is a 35 U.S.C. §371 national stage application of PCT Application No. PCT/US2012/046446, filed on Jul. 12, 2012, which claims the benefit of and priority to U.S. Provisional Patent Application No. 61/511,238 filed Jul. 25, 2011, the disclosures of which are incorporated herein by reference as if set forth in their entireties. The above-referenced PCT International Application was published in the English language as International Publication No. WO 2013/016007 on Jan. 31, 2013.

### FIELD OF THE INVENTION

The present invention relates generally to monitoring apparatus and methods and, more particularly, to physiological monitoring apparatus and methods.

### BACKGROUND OF THE INVENTION

Physiological parameters for living beings are typically a function of one or more of the following: the time-of-day, environmental conditions to which a being is exposed, activity level of a being, and various other physiological parameters. Many of these are related. For example, the average change in heart rate, body temperature, and heart rate variability (HRV) with the time-of-day are generally known based on human and animal studies of the circadian cycle.

### SUMMARY

It should be appreciated that this Summary is provided to introduce a selection of concepts in a simplified form, the concepts being further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of this disclosure, nor is it intended to limit the scope of the invention.

According to some embodiments of the present invention, a method of determining a value of a physiological parameter for a subject at a selected state (e.g., state of peak metabolism, state of lowered metabolism, state of rest, etc.), includes obtaining, via a device attached to the subject, a value of the physiological parameter of the subject at a particular time-of-day, and applying a time-dependent relationship function to the obtained physiological parameter value via at least one processor to determine a value of the physiological parameter at the selected state. Exemplary physiological parameters include, but are not limited to, subject body temperature, subject heart rate, subject heart rate variability, subject blood gas levels, subject metabolic rate, subject respiration rate, subject blood analyte levels, subject blood pressure, subject pulse pressure, etc. In some embodiments of the present invention, the time-dependent relationship function is derived from a circadian rhythm for the subject. In some embodiments of the present invention, the time-dependent relationship function is a lookup table.

In some embodiments of the present invention, determining a value of the physiological parameter of the subject at a selected state may include obtaining the value of the physiological parameter at the same time-of-day for multiple days and determining an average value for the multiple obtained values. Applying the time-dependent relationship

function to the obtained physiological parameter value may include applying the time-dependent relationship function to the average value.

In some embodiments of the present invention, determining a value of a physiological parameter for a subject at a selected state may further include determining if the subject is in a condition of heightened activity at the selected time-of-day by determining via the device if at least one obtained physiological parameter value is at a level associated with the heightened activity condition. The time-dependent relationship function is adjusted for the heightened activity condition of the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, prior to obtaining a value of the physiological parameter of the subject at a particular time-of-day, values of the physiological parameter of the subject are obtained at multiple times during at least one previous day. A personalized time-dependent relationship function between at least one obtained value of the physiological parameter and a value of the physiological parameter at a time when the subject is at the selected state is generated for the subject using the obtained values from the at least one previous day. Applying the time-dependent relationship function to the obtained physiological parameter value includes applying the personalized time-dependent relationship function to the obtained physiological parameter value via at least one processor to determine a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for calories consumed by the subject prior to determining a value of the physiological parameter at a time when the subject is at the selected state.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for blood oxygen level of the subject prior to determining a value of the physiological parameter at a time when the subject is at the selected state.

In some embodiments of the present invention, the device includes at least one physiological sensor that is configured to detect and/or measure physiological information from the subject to which the device is attached.

In some embodiments of the present invention, the device includes at least one environmental sensor that detects and/or measures environmental condition information in a vicinity of the subject. Determining a value of a physiological parameter for a subject at a selected state, according to some embodiments of the present invention, further comprises obtaining, via the device, a value of an environmental parameter in a vicinity of the subject at the particular time-of-day. Applying the time-dependent relationship function to the obtained physiological parameter value comprises applying the time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value via the at least one processor to determine a value of the physiological parameter at a time when the subject is at the selected state.

Devices according to embodiments of the present invention may be configured to be attached to various portions of the body of a subject including, but not limited to, ear, arm, wrist, leg, hand, foot, finger, toe, chest, head, hair, nose, waist, trunk, shoulder, and neck. Devices according to embodiments of the present invention may also be configured to be embedded within clothing, foot apparel, and other wearable objects, without limitation. Additionally, devices according to embodiments of the present invention may be

worn outside the body so as to be noninvasive, may be worn inside the body so as to be invasive, or may be worn subdermally so as to be mildly invasive.

According to other embodiments of the present invention, a method of determining a value of a physiological parameter (e.g., subject body temperature, subject heart rate, subject heart rate variability, subject blood gas levels, subject metabolic rate, subject respiration rate, subject blood analyte levels, subject blood pressure, and subject pulse pressure, etc.) for a subject at rest comprises obtaining, via a device attached to the subject, a value of the physiological parameter of the subject at a particular time-of-day, and applying a time-dependent relationship function to the obtained physiological parameter value via at least one processor to determine a value of the physiological parameter at a time when the subject is at rest.

In some embodiments of the present invention, determining a value of the physiological parameter of the subject at rest comprises obtaining the value of the physiological parameter at the same time-of-day for multiple days and determining an average value for the multiple obtained values. Applying the time-dependent relationship function to the obtained physiological parameter value may include applying the time-dependent relationship function to the average value.

In some embodiments of the present invention, determining a value of a physiological parameter for a subject at rest may further include determining if the subject is in a condition of heightened activity at the time-of-day by determining via the device if at least one obtained physiological parameter value is at a level associated with heightened activity. The time-dependent relationship function is adjusted for the heightened activity condition of the subject prior to determining a value of the physiological parameter at a time when the subject is at rest.

In some embodiments of the present invention, prior to obtaining a value of the physiological parameter of the subject at the time-of-day, values of the physiological parameter of the subject are obtained at multiple times during at least one previous day. A personalized time-dependent relationship function between at least one obtained value of the physiological parameter and a value of the physiological parameter at a time when the subject is at rest is generated for the subject using the obtained values from the at least one previous day. Applying the time-dependent relationship function to the obtained physiological parameter value includes applying the personalized time-dependent relationship function to the obtained physiological parameter value via the processor to determine a value of the physiological parameter at a time when the subject is at rest.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for calories consumed by the subject prior to determining a value of the physiological parameter at a time when the subject is at rest.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for blood oxygen level of the subject prior to determining a value of the physiological parameter at a time when the subject is at rest.

In some embodiments of the present invention, the device includes at least one environmental sensor that detects and/or measures environmental condition information in a vicinity of the subject. Determining a value of a physiological parameter for a subject at rest, according to some embodiments of the present invention, further comprises obtaining, via the device, a value of an environmental parameter in a vicinity of the subject at a particular time-

of-day. Applying the time-dependent relationship function to the obtained physiological parameter value comprises applying the time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value via at least one processor to determine a value of the physiological parameter at a time when the subject is at rest.

According to other embodiments of the present invention, a method of determining a value of a physiological parameter for a subject at a selected state (e.g., state of peak metabolism, state of lowered metabolism, state of rest, etc.) includes obtaining, via a device attached to the subject, a value of the physiological parameter (e.g., subject body temperature, subject heart rate, subject heart rate variability, subject blood gas levels, subject metabolic rate, subject respiration rate, subject blood analyte levels, subject blood pressure, and subject pulse pressure, etc.) of the subject at a selected time-of-day; obtaining, via the device, a value of an environmental parameter in a vicinity of the subject at the selected time-of-day via the environmental sensor; determining if the subject is in a condition of heightened activity at the selected time-of-day by determining via the device if at least one obtained physiological parameter value is at a level associated with heightened activity; and applying a time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value via a processor to determine a value of the physiological parameter at the selected state, wherein the time-dependent relationship function is adjusted for the heightened activity condition of the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, obtaining a value of the physiological parameter of the subject at a particular time-of-day includes obtaining the value at the same time-of-day for multiple days and determining an average value for the multiple obtained values. Applying the time-dependent relationship function and the environmental-dependent relationship function to the obtained physiological parameter value includes applying the time-dependent relationship function and the environmental-dependent relationship function to the average value.

In some embodiments of the present invention, prior to obtaining a value of the physiological parameter of the subject at a particular time-of-day, values of the physiological parameter of the subject are obtained at multiple times during at least one previous day, and a personalized time-dependent relationship function between at least one obtained value of the physiological parameter and a value of the physiological parameter at the selected state is generated for the subject using the obtained values from the at least one previous day. Applying the time-dependent relationship function and the environmental-dependent relationship function to the obtained physiological parameter value includes applying the personalized time-dependent relationship function and the environmental-dependent relationship function to the obtained physiological parameter value via at least one processor to determine a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for calories consumed by the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the time-dependent relationship function is adjusted for blood oxygen level of the subject prior to determining a value of the physiological parameter at the selected state.

According to other embodiments of the present invention, an apparatus includes a housing configured to be attached to a subject and at least one physiological sensor attached to the housing, wherein the at least one physiological sensor detects and/or measures physiological information from the subject. At least one processor may be attached to the housing or may be located remotely from the housing. The at least one processor is in communication with the at least one physiological sensor and is configured to obtain from the at least one physiological sensor a value of a physiological parameter of the subject at a particular time-of-day, and to apply a time-dependent relationship function to the obtained physiological parameter value to determine a value of the physiological parameter at a selected state.

In some embodiments of the present invention, the at least one processor is configured to obtain from the at least one physiological sensor the value of the physiological parameter at the same time-of-day for multiple days, determine an average value for the multiple obtained values, and apply the time-dependent relationship function to the average value.

In some embodiments of the present invention, the at least one processor is configured to determine if the subject is in a condition of heightened activity at the time-of-day by determining if at least one obtained physiological parameter value is at a level associated with heightened activity, and adjust the time-dependent relationship function for the heightened activity condition of the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the at least one processor is configured to obtain values of the physiological parameter of the subject at multiple times during at least one previous day, generate a personalized time-dependent relationship function between at least one obtained value of the physiological parameter and a value of the physiological parameter at the selected state using the obtained values from the at least one previous day, and apply the personalized time-dependent relationship function to the obtained physiological parameter value to determine a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the apparatus includes an environmental sensor that detects and/or measures environmental condition information in a vicinity of the subject. The at least one processor is configured to obtain a value of an environmental parameter in a vicinity of the subject at a particular time-of-day from the environmental sensor, and to apply the time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value to determine a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the at least one processor is configured to adjust the time-dependent relationship function for calories consumed by the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the at least one processor is configured to adjust the time-dependent relationship function for blood oxygen level of the subject prior to determining a value of the physiological parameter at the selected state.

In some embodiments of the present invention, the housing is configured to be attached to an ear of the subject. In other embodiments, the housing is configured to be attached to one or more of the following portions of a body of a subject: arm, wrist, leg, hand, foot, finger, toe, chest, head, hair, nose, waist, trunk, shoulder, and neck. In other embodi-

ments, the housing is configured to be embedded within clothing, foot apparel, and other wearable objects, without limitation.

Conventional methods and apparatus for studying the circadian cycle heretofore have not estimated resting state (or other) parameters of a being based on the current state of the being. There have been at least two major limitations preventing such an invention: 1) there has been no effort to estimate resting parameters based on what's already known about the relationships between resting state and current state and 2) there have been no apparatuses or methods for accurately and reliably measuring dynamically changing relationships between current and resting state parameters in everyday life activities.

It is noted that aspects of the invention described with respect to one embodiment may be incorporated in a different embodiment although not specifically described relative thereto. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination. Applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to be able to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner. These and other objects and/or aspects of the present invention are explained in detail below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which form a part of the specification, illustrate various embodiments of the present invention. The drawings and description together serve to fully explain embodiments of the present invention.

FIG. 1 is a block diagram of methods and apparatus for estimating physiological parameters of a being at a selected state, according to some embodiments of the present invention.

FIG. 2 is an exemplary plot of how tympanic or core body temperature may change with time-of-day for an average person.

FIG. 3 is an exemplary plot of how heart rate may change with time-of-day for an average person, wherein curve C1 represents a normal cycle and wherein curve C2 represents an elevated cycle.

FIG. 4 is an exemplary plot of how heart rate variability (HRV) may change with time-of-day for an average person.

FIG. 5 is an exemplary plot of how heart rate of a person may change with the person's activity level.

FIG. 6 is a flow chart for an algorithm for estimating resting parameters, according to some embodiments of the present invention.

FIG. 7 is a plot of average body temperature vs. time calculated using a polynomial equation for body vs. time-of-day, according to some embodiments of the present invention.

FIG. 8 is a plot of heart rate vs. time for an average person, wherein curve (A) represents heart rate vs. time before a lifestyle change, wherein curve (B) represents heart rate vs. time after a lifestyle change, and wherein curve (A) and (B) are generated via respective polynomial equations according to some embodiments of the present invention.

FIG. 9 illustrates a functional relationship between an estimated parameter and multiple time-dependent inputs, according to some embodiments of the present invention.

FIG. 10 is an exemplary lookup table for estimating resting body temperature, according to some embodiments of the present invention.

FIG. 11 is a block diagram that illustrates details of an exemplary processor and memory that may be used in accordance with embodiments of the present invention.

#### DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying figures, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Like numbers refer to like elements throughout. In the figures, certain layers, components or features may be exaggerated for clarity, and broken lines illustrate optional features or operations unless specified otherwise. In addition, the sequence of operations (or steps) is not limited to the order presented in the figures and/or claims unless specifically indicated otherwise. Features described with respect to one figure or embodiment can be associated with another embodiment or figure although not specifically described or shown as such.

It will be understood that when a feature or element is referred to as being “on” another feature or element, it can be directly on the other feature or element or intervening features and/or elements may also be present. In contrast, when a feature or element is referred to as being “directly on” another feature or element, there are no intervening features or elements present. It will also be understood that, when a feature or element is referred to as being “connected”, “attached” or “coupled” to another feature or element, it can be directly connected, attached or coupled to the other feature or element or intervening features or elements may be present. In contrast, when a feature or element is referred to as being “directly connected”, “directly attached” or “directly coupled” to another feature or element, there are no intervening features or elements present. Although described or shown with respect to one embodiment, the features and elements so described or shown can apply to other embodiments. It will also be appreciated by those of skill in the art that references to a structure or feature that is disposed “adjacent” another feature may have portions that overlap or underlie the adjacent feature.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

Spatially relative terms, such as “under”, “below”, “lower”, “over”, “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if a device in the figures is inverted, elements described as “under” or “beneath” other elements or features would then be oriented “over” the other elements or features. Thus, the exemplary term “under” can encompass both an orientation of over and

under. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly. Similarly, the terms “upwardly”, “downwardly”, “vertical”, “horizontal” and the like are used herein for the purpose of explanation only unless specifically indicated otherwise.

It will be understood that although the terms first and second are used herein to describe various features/elements, these features/elements should not be limited by these terms. These terms are only used to distinguish one feature/element from another feature/element. Thus, a first feature/element discussed below could be termed a second feature/element, and similarly, a second feature/element discussed below could be termed a first feature/element without departing from the teachings of the present invention.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the specification and relevant art and should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. Well-known functions or constructions may not be described in detail for brevity and/or clarity.

The term “housing”, as used herein, may refer to a physical structure for supporting and/or unifying one or more physical elements of the invention. For example, the housing of a wearable wrist sensor apparatus or headset sensor apparatus may comprise a structure to support the electronics, optics, and/or mechanical elements of the sensor. Two specific, non-limiting examples of a housing may be a “clamshell” of an earbud or one or more PCB boards for the sensor electronics. The structure may be composed of plastic, metal, polymer, ceramic, glass, composite material, or virtually any solid stable enough to support the physical elements of the apparatus.

The term “selected state”, as used herein, includes, but is not limited to, state of peak metabolism, state of lowered metabolism, state of rest, a state of one’s psychology or mental functioning or the body’s physiology or physiological functioning. Any example of mental functioning may include psychosocial stress, mental stress, mental acuity, brain activity, conscious state, state or phase of sleep, or the like. An example of physiological functioning may include the functioning of one or more organs individually or in unison. In addition, a selected state may refer to a particular time of day where a particular or noteworthy mental or physiological event may take place.

The term “heightened activity condition”, as used herein, includes, but is not limited to, elevated heart rate, elevated or lowered vital signs status, such as heart status (heart rate, ECG waveform intervals, cardiac output, cardiac stress or load, or the like), lung status (breathing rate, breathing volume, lung stress or load, or the like), blood pressure, blood oxygen level, heart rate variability, galvanic skin response, heat flux from the body, core body temperature, skin temperature, sympathetic or parasympathetic response, or the like.

The term “blood analyte” may refer to blood constituents, such as blood gases (blood oxygen, blood CO<sub>2</sub>, blood hemoglobin, and the like), blood glucose, blood cholesterol, blood lactic acid, blood bilirubin, dissolved species in the blood, and the like.

The term “headset” includes any type of device or earpiece that may be attached to or near the ear (or ears) of a user and may have various configurations, without limitation. Headsets as described herein may include mono headsets (one earbud) and stereo headsets (two earbuds), earbuds, hearing aids, ear jewelry, face masks, headbands, and the like.

The term “real-time” is used to describe a process of sensing, processing, or transmitting information in a time frame which is equal to or shorter than the minimum timescale at which the information is needed. For example, the real-time monitoring of pulse rate may result in a single average pulse-rate measurement every minute, averaged over 30 seconds, because an instantaneous pulse rate is often useless to the end user. Typically, averaged physiological and environmental information is more relevant than instantaneous changes. Thus, in the context of embodiments of the present invention, signals may sometimes be processed over several seconds, or even minutes, in order to generate a “real-time” response.

The term “monitoring” refers to the act of measuring, quantifying, qualifying, estimating, sensing, calculating, interpolating, extrapolating, inferring, deducing, or any combination of these actions. More generally, “monitoring” refers to a way of getting information via one or more sensing elements. For example, “blood health monitoring” includes monitoring blood gas levels, blood hydration, and metabolite/electrolyte levels.

The term “physiological” refers to matter or energy of or from the body of a creature/subject (e.g., humans, animals, etc.). In embodiments of the present invention, the term “physiological” is intended to be used broadly, covering both physical and psychological matter and energy of or from the body of a creature. However, in some cases, the term “psychological” is called-out separately to emphasize aspects of physiology that are more closely tied to conscious or subconscious brain activity rather than the activity of other organs, tissues, or cells. Embodiments of the present invention are not limited to use by only humans.

The term “body” refers to the body of a subject (human or animal) who may wear a headset incorporating embodiments of the present invention.

The terms “being”, “creature”, “subject”, and “organism”, as used herein, are interchangeable and include, but are not limited to, humans and animals.

The terms “circadian rhythm” and “circadian cycle”, as used herein, are interchangeable and refer to an endogenously driven, roughly 24-hour cycle in biochemical, physiological, or behavioral processes.

The term “processor” refers to a device that takes one form of information and converts this information into another form, typically having more usefulness than the original form. For example, in this invention, a signal processor may collect raw physiological and environmental data from various sensors and process this data into a meaningful assessment, such as pulse rate, blood pressure, or air quality. A variety of microprocessors or other processors may be used herein. The terms “signal processor”, “processor”, “controller”, and “microcontroller”, as used herein, are interchangeable.

Embodiments of the present invention provide methods and apparatus for estimating time-state physiological parameters/assessments, such as resting parameters, of a subject by factoring functional relationships between the time-dependent parameters and other measured factors. For example, current state parameters (such as vital signs, environmental exposures, time-of-day, and the like) are measured and a

physiological model is applied to generate an estimation of resting state parameters (or other particular states) of the subject. These relationships can be static relationships based on models that apply knowledge of how a current state of the subject relates to a resting state of the subject. These relationships can also be dynamic relationships based on personalized monitoring of a subject throughout various life activities.

Average body temperature, heart rate, heart rate variability for a subject, as well as many other vital parameters, change throughout the day on a regular schedule dependent on the time-of-day, consistent with normal circadian rhythms. Additionally, average values of vital signs will change throughout the day based on changes in a subject’s physical activity or metabolic rate. As shown in FIGS. 2 and 7, average body temperature for a human subject may change by  $\sim 2^\circ$  F. from early morning to mid-day. In FIG. 2, body temperature is plotted on the y-axis and time in hours is plotted on the x-axis. Curve 100 in FIG. 2 is a plot of average core body temperature vs. time for an average human over an average day. In FIG. 7, body temperature is plotted on the y-axis and time in hours is plotted on the x-axis. Polynomial equation 104 is used to calculate the plot 102.

Similarly, as shown in FIG. 3, average heart rate for a human subject may change by  $\sim 15$  BPM (beats per minute) during that same period. FIG. 3 illustrates how heart rate may change with time-of-day for an average person, wherein curve C1 represents a normal cycle and wherein curve C2 represents an elevated cycle. In FIG. 3, heart rate is plotted on the y-axis and time in hours is plotted on the x-axis. Thus, if average body temperature and average heart rate are being monitored throughout the day, estimating resting body temperature and resting heart rate for a subject may be derived by applying the respective relationships to the existing measured state.

For example, if the current state at mid-day shows a body temperature of  $99.6^\circ$  F. and heart rate of 80 BPM, the resting state values may be estimated as  $97.6^\circ$  F. and 65 BPM, by subtracting  $2^\circ$  F. from body temperature and 15 BPM from heart rate, respectively. Percent (%) change relationships for estimating resting state, as opposed to absolute value changes, may also be used to estimate resting state. For example, the change from current state to resting state in the aforementioned case is  $\sim 2\%$  and  $18\%$  for body temperature and resting heart rate, respectively. Thus, a lookup table (e.g., table 110, FIG. 10) may be generated with time-of-day in one column, measured value in a second column, and the associated percent multiplier in a third column, where the percent multiplier is the ratio between resting value and measured value. The estimation for resting value can then be generated by multiplying this time-of-day-dependent ratio by the measured vital parameter at the given time-of-day of the measurement.

A specific example for the case of body temperature is presented in FIG. 10, using the same relationships and data of FIG. 2, where a measurement of body temperature has been made at 6 PM, with a multiplier of  $\sim 0.981$ , yielding a resting body temp estimate of  $97.6^\circ$  F. A complimentary lookup table may replace the % multiplier column with a  $\pm$ add/subtract column, where the  $\pm$ number is the amount to add or subtract from the measured value to generate an estimate of the resting value.

It should also be noted that a formula, rather than a lookup table, may also be used to relate resting estimates to measured estimates, depending on the time-of-day. For example, a polynomial formula representing the table of FIG. 10 may

be: Estimated Resting Value=(Measured Value)\*(-0.29x<sup>4</sup>+0.79x<sup>3</sup>-0.63x<sup>2</sup>+0.13x+1.0), where x=time in hours, starting at x=0 for 7 AM. It is apparent from this formula that at 7 AM (x=0), the Estimated Resting Value=Measured Value, which is expected in the aforementioned formalism.

FIG. 7 shows an exemplary plot 102 of average human body temperature during a day, along with an approximate functional relationship for average body temperature vs. time. In the illustrated embodiment, the functional relationship is a polynomial equation 104 of order n=4. The a<sub>0</sub> term is 97.6° F., representing the resting body temperature, or BT<sub>resting</sub>=97.6° F. If a person's resting body temperature (BT<sub>resting</sub>) had started higher or lower than 97.6° F., the polynomial equation may still hold, with the only substantial difference being the a<sub>0</sub> term for BT<sub>resting</sub>. Thus, an equation for estimating BT<sub>resting</sub> vs. BT<sub>measured</sub> may be derived by rearranging terms such that a<sub>0</sub>=BT<sub>resting</sub>=BT<sub>measured</sub>-[9E-05(t<sup>4</sup>)-0.0033(t<sup>3</sup>)+0.0161(t<sup>2</sup>)+0.2868(t)]. More generally, a<sub>0</sub>=BT<sub>resting</sub>=BT<sub>measured</sub>-[a<sub>n</sub>(t<sup>n</sup>)+a<sub>n-1</sub>(t<sup>n-1</sup>)a<sub>n-2</sub>(t<sup>n-2</sup>)+ . . . a<sub>1</sub>(t)], where "n" is the order of the polynomial equation and where t=0 represents the value of BT at the resting state. The second term in the brackets may be related to body temperature changes due to circadian rhythms, such that BT<sub>resting</sub>=BT<sub>measured</sub>-ΔBT<sub>circadian</sub>. This same general relationship may be applied towards heart rate (HR) as shown in FIG. 3 and heart rate variability in FIG. 4. In FIG. 4, heart rate variability is plotted on the y-axis and time in hours is plotted on the x-axis. The units along the y-axis are milliseconds-squared. Plot 120 illustrates how heart rate variability (HRV) may change with time-of-day for an average person. For example, HR<sub>resting</sub>=HR<sub>measured</sub>-ΔHR<sub>circadian</sub> and HRV<sub>resting</sub>=HRV<sub>measured</sub>-HRV<sub>circadian</sub>. This formalism may be applied towards blood oxygen (SPO<sub>2</sub>), respiration rate (RR), blood pressure (BP), pulse pressure (PP), and other vital parameters (VP), that may change regularly throughout the day according to VP<sub>resting</sub>=VP<sub>measured</sub>-ΔVP<sub>circadian</sub>.

In some embodiments of the present invention, the general relationships illustrated in FIGS. 2, 3, and 7 may not enable a prediction of resting state (or other selected state) as accurately as desired. For example, a person engaging in heightened activity or personal variations may cause substantial departures from the general relationships. Fortunately, these differences may effectively average out if vital signs measurements are made over a period of time. For example, if a vital sign of interest is measured over several days at the same time-of-day, during different activity levels, the average value of the vital sign may be largely divorced of convolutions caused by heightened or acute activity. This average value of VP<sub>measured</sub> may then be used to estimate VP<sub>resting</sub>. However, it may be difficult to measure the vital parameter at the same time-of-day for multiple days, and a one-time measurement of a vital parameter taken during or following high activity may not be sufficient to support an accurate estimate of the resting value, using the general relationships alone.

To correct for conditions of high activity, a general relationship between changes in activity and changes in vital parameters may be used to correct an estimate of resting parameters, according to some embodiments of the present invention. For example, during activity, the heart rate of a subject may increase in a predictable fashion, as shown in FIG. 5. In FIG. 5, heart rate is plotted on the left y-axis, activity is plotted on the right y-axis, and time in hours is plotted on the x-axis. Curve A in FIG. 5 illustrates heart rate

and activity for a person at a first state, and curve B in FIG. 5 illustrates heart rate and activity for the person at a heightened activity state.

Generally, as illustrated in FIG. 5, heart rate will increase with activity, and the rate of increase with activity may be proportional to the physical fitness or aerobic capacity (VO<sub>2</sub>max) of the subject. Thus, if the relationship between heart rate and activity is known for a subject, then the differential increase in heart rate due to elevated activity, for a particular time-of-day, may be subtracted from the current heart rate measurement. Namely, the estimated resting heart rate can be defined as HR<sub>resting</sub>=HR<sub>measured</sub>-ΔHR<sub>circadian</sub>-ΔHR<sub>activity</sub>, where ΔHR<sub>activity</sub> is the change in heart rate with activity (either positive/negative for increases/decreases in heart rate with activity). For other vital parameters, the term ΔVP<sub>activity</sub> may be used instead.

Personal differences between individuals may cause deviations from the general, "universal" relationships previously described. For example, subjects having a higher metabolic rate change throughout a given day may have a larger total value or percent change in vital parameters between early morning and midday. Improving the accuracy of estimating resting parameters can be achieved by measuring vital parameters throughout the day, generating average time-dependent relationships based on these measured parameters, and deriving a personalized time-dependent relationship between measured and resting parameters. Once a personalized, functional, time-dependent relationship is generated between measured (current state) vital parameters and resting state vital parameters, this model may be used to estimate resting state parameters by inputting current state measurements into the model. For current state measurements taken at high activity, stored relationships between a subject's vital parameters and activity can be employed to subtract the change in vital parameter values with activity (ΔVP<sub>activity</sub>) as with the heart rate example described above.

Environmental exposures (i.e., environmental conditions to which a subject is exposed) may also affect the time-dependent relationship between measured and resting parameters. For example, sunlight exposure may elevate metabolism, resulting in an increase in heart rate, breathing, rate, other vital parameters, or the like. In such case, it may be insufficient to estimate resting parameters by simply measuring current resting parameters and inputting current parameters into the functional model. Rather, it may be more accurate to estimate resting vital parameters according to VP<sub>resting</sub>=VP<sub>measured</sub>-ΔVP<sub>circadian</sub>-ΔVP<sub>environmental exposure</sub> where ΔVP<sub>environmental exposure</sub> is the change (positive or negative) in the vital parameter value due to environmental exposure (e.g., sunlight exposure, etc.). A change in vital parameters may be caused by many different forms of environmental exposures such as, but not limited to, loud noises, strong wind, extreme temperatures, short wavelength light (e.g., light at wavelengths <470 nm), airborne pollution, mechanical stress, and the like.

It should be noted that multiple parameters may simultaneously affect the relationship between resting values and measured values. For example, if physical activity and environmental exposure both have an impact on instantaneous vital parameters, then a more general relationship for resting vital parameters may be: VP<sub>resting</sub>=VP<sub>measured</sub>-ΔVP<sub>circadian</sub>-ΔVP<sub>activity</sub>-ΔVP<sub>environmental exposure</sub>. Additional relationships, such as changes in a vital parameter with food intake (calories consumed), blood oxygen (SPO<sub>2</sub>), and the like may also be incorporated. These additional

relationships can be accommodated by  $\Delta VP_n$ , where the integer “n” represents an additional factor which may affect  $VP_{measured}$ .

The aforementioned models for estimating resting parameters have been presented as “static” models. A static model, once implemented or derived, stays fixed with time. However, models for determining a value of a physiological parameter for a subject at a selected state (e.g., at rest, etc.), according to some embodiments of the present invention, may also be dynamic, changing with time based on updated information about a particular person or group of people. For example, a person undergoing cardiac therapy, a new diet, drug therapy, or other lifestyle change may see an acute or chronic change in metabolism over time. In such case, static models may be insufficient for estimating resting parameters from current state measured parameters. Rather, it may be more accurate to measure vital parameters over a period of time and update the model based on updated relationships between resting and current state parameters.

FIG. 8 shows a specific example of a dynamic model for determining a value of a physiological parameter for a subject at a selected state (e.g., at rest, etc.) according to some embodiments of the present invention. FIG. 8 is a graph of heart rate vs. time-of-day for a twenty-four hour (24 hr) period. Curves A and B in FIG. 8 show the circadian change in average heart rate profile of an average person before and after a lifestyle change. Polynomial representations of these plots are also shown, with a polynomial order of  $n=5$ . Polynomial equation 130 is used to generate curve A in FIG. 8 and polynomial equation 140 is used to generate curve B in FIG. 8.

As illustrated in FIG. 8, after the lifestyle change, the average heart rate changes more dramatically as the time-of-day changes, as exemplified by the  $2\times$  increase in the 5th-power coefficient in the “B” curve when compared with the “A” curve. The resting heart rate for each case is the  $a_0$  terms of each, 60 and 45 BPM for curves A and B, respectively. Because the change in each model (for curves A and B) is not merely a scalar addition or subtraction, accurately estimating resting heart rate may require measuring average heart rate throughout the day, over the course of several days, modeling a relationship between resting and current state parameters, and then inputting current state parameters into the model. In one embodiment of the present invention, the model may be a polynomial equation fit to the measured data, as shown in FIG. 8. However, other models may be employed to improve accuracy or model simplicity, according to embodiments of the present invention.

FIG. 1 is a block diagram of methods and apparatus for generating estimated physiological parameters of a subject at a selected state based on current state measurements, according to some embodiments of the present invention. Time-correlated physiological metrics (Block 10) and/or time-correlated environmental metrics (Block 20) are collected and are input into a physiological model (static, dynamic, or a combination of both) (Block 30), and the desired parameters (such as resting state parameters) are estimated (Block 40) based on the metrics and physiological model. The estimated parameters are then reported in an organized fashion (Block 50).

An algorithm for estimating a resting parameter according to embodiments of the present invention is presented in the flow chart of FIG. 6. The algorithm includes measuring time-correlated heart rate (HR), respiration rate (RR), activity levels, etc., at a particular time of day (Block 150). A physical model is applied to estimate a parameter value that accounts for changes in the time-correlated parameter with

activity, environmental exposure, and/or daily cycle (Block 152). A resting assessment is then generated (Block 154).

FIG. 11 illustrates an exemplary processor 200 and memory 202 that may be used in a wearable device and/or a device remote from a subject to carry out various embodiments of the present invention. The processor 200 communicates with the memory 202 via an address/data bus 204. The processor 200 may be, for example, a commercially available or custom microprocessor or similar data processing device. The memory 202 is representative of the overall hierarchy of memory devices containing the software and data used to perform the various operations described herein. The memory 202 may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

As shown in FIG. 11, the memory 202 may hold various categories of software and data: an operating system 206, a physiological data collection module 208, an environmental data collection module 210, and a time-dependent relationship function module 212. The operating system 206 controls operations of the physiological and environmental sensors.

It should be noted that estimating a physiological metric at a selected time state need not necessarily require a direct measurement of current time. For example, if the relationship between at least one physiological parameter and time is already known, or if that relationship is developed by recording data for a subject wearing a physiological sensor over time as shown in FIG. 11, then the current time may be inferred through this relationship and factored into an estimate for a second physiological metric at a selected time state. For example, if the relationship between the subject’s core body temperature over time is known (as shown in FIG. 2), then a subject’s HRV may be estimated for a selected time-state by estimating the current time based on the measured core body temperature at a current state. In such case, the current time need not be measured. However, in such case, because the current time is inferred and not directly noted or measured, it may be further beneficial to measure the subject’s activity and have this factored into the relationship function 212 (as discussed for FIG. 5) so as to prevent activity-based artifacts from causing inaccurate estimates of a second physiological metric at a selected state.

The physiological data collection module 208 comprises logic for obtaining from a physiological sensor a value of a physiological parameter of a subject at a particular time-of-day. The physiological data collection module 208 may also comprise logic for obtaining from a physiological sensor the value of a physiological parameter at the same time-of-day for multiple days, and logic for determining an average value for the multiple obtained values. The physiological data collection module 208 may also comprise logic for obtaining values of a physiological parameter of a subject at multiple times during at least one previous day.

The environmental data collection module 210 comprises logic for obtaining from an environmental sensor a value of an environmental parameter in a vicinity of a subject at a particular time-of-day.

The time-dependent relationship function module 212 comprises logic for applying a time-dependent relationship function to an obtained physiological parameter value to determine a value of the physiological parameter at a selected state, and logic for applying the time-dependent relationship function and an environmental-dependent relationship function to an obtained physiological parameter value (and average value) to determine a value of the physiological parameter at the selected state. In addition, the

time-dependent relationship function module 212 may comprise logic for determining if a subject is in a condition of heightened activity at a selected time-of-day by determining if at least one obtained physiological parameter value is at a level associated with heightened activity, and may comprise logic for adjusting the time-dependent relationship function for the heightened activity condition of the subject prior to determining a value of the physiological parameter at the selected state. The time-dependent relationship function module 212 may comprise logic for generating a personalized time-dependent relationship function between a measured value of a physiological value and a value of the physiological parameter at a selected state using obtained values from at least one previous day, and may comprise logic for applying the personalized time-dependent relationship function to a obtained physiological parameter value to determine a value of the physiological parameter at the selected state.

The time-dependent relationship function module 212 may also comprise logic for adjusting a time-dependent relationship function for calories consumed by a subject prior to determining a value of the physiological parameter at a selected state. The time-dependent relationship function module 212 may also comprise logic for adjusting a time-dependent relationship function for blood oxygen level of a subject prior to determining a value of the physiological parameter at a selected state.

According to some embodiments of the present invention, collecting measured time-dependent metrics may be manual or automatic. Records can be taken over time, recorded, and processed into time-dependent relationships by skilled professionals or personal recording. However, it may be easier to record this data with one or more wearable devices having multiple wearable sensors. For example, wired and wireless vital parameter modules may be located along several parts of the body, or integrated into a single device worn at a single place along the body. These wearable devices may measure vital parameters throughout the day and, with microprocessors or other processing devices, generate estimations for resting parameters. Memory devices, such as memory chips, data storage devices, and the like, may be used to store and update physiological models according to embodiments of the present invention, and at least one processor may be used to estimate parameters based on the metrics and model. At least one processor may also be used to organize the data into a string of outputs for each measured parameter. There is great flexibility in the electronics that may be used to implement embodiments of the present invention. Individual electronic components or chips may be used and integrated within circuit board, or the electronics may integrate memory storage, data processing, and data translation within a single chip, or other combinations or electronics configurations may be used.

Some types of wearable devices may be more suited for sensor integration than other devices. For example, an ear-worn device may be especially suited for measuring blood flow, heart rate, breathing rate, EEG, and body temperature, due in part to the location of the ear with respect to physiological structures such as the carotid artery, capillaries, ear blood vessels, the brain, and the tympanic membrane. However many other form-factors for a single wearable device may be employed. For example, strong blood flow and heat generation in the limbs, digits, and torso enable integrated sensor locations in the arms, wrist, legs, hands, feet, fingers, toes, chest, head, hair, nose, waist, trunk, shoulder, neck, and other locations. Furthermore, physiological and environmental sensors may be embedded in

clothing or other wearable devices, such as headsets, earbuds, wrist watches, adhesive patches, rings, bracelets, necklaces, footwear, socks, shirts, pants, underwear, earrings and other body piercings, hats, glasses, and the like.

The ear is an ideal location for wearable health and environmental monitors. The ear is a relatively immobile platform that does not obstruct a person's movement or vision. Headsets located at an ear have, for example, access to the inner-ear canal and tympanic membrane (for measuring core body temperature), muscle tissue (for monitoring muscle tension), the pinna and earlobe (for monitoring blood gas levels), the region behind the ear (for measuring skin temperature and galvanic skin response), and the internal carotid artery (for measuring cardiopulmonary functioning), etc. The ear is also at or near the point of exposure to: environmental breathable toxicants of interest (volatile organic compounds, pollution, etc.); noise pollution experienced by the ear; and lighting conditions for the eye. Furthermore, as the ear canal is naturally designed for transmitting acoustical energy, the ear provides a good location for monitoring internal sounds, such as heartbeat, breathing rate, and mouth motion.

Wireless, Bluetooth®-enabled, and/or other personal communication headsets may be configured to incorporate physiological and/or environmental sensors, according to some embodiments of the present invention. As a specific example, Bluetooth® headsets are typically lightweight, unobtrusive devices that have become widely accepted socially. Moreover, Bluetooth® headsets are cost effective, easy to use, and are often worn by users for most of their waking hours while attending or waiting for cell phone calls. Bluetooth® headsets configured according to embodiments of the present invention are advantageous because they provide a function for the user beyond health monitoring, such as personal communication and multimedia applications, thereby encouraging user compliance. Exemplary physiological and environmental sensors that may be incorporated into a Bluetooth® or other type of headsets include, but are not limited to accelerometers, auscultatory sensors, pressure sensors, humidity sensors, color sensors, light intensity sensors, pressure sensors, etc.

Optical coupling into the blood vessels of the ear may vary between individuals. As used herein, the term "coupling" refers to the interaction or communication between excitation light entering a region and the region itself. For example, one form of optical coupling may be the interaction between excitation light generated from within a light-guiding earbud and the blood vessels of the ear. Light guiding earbuds are described in co-pending U.S. Patent Application Publication No. 2010/0217102, which is incorporated herein by reference in its entirety. In one embodiment, this interaction may involve excitation light entering the ear region and scattering from a blood vessel in the ear such that the intensity of scattered light is proportional to blood flow within the blood vessel. Another form of optical coupling may be the interaction between excitation light generated by an optical emitter within an earbud and the light-guiding region of the earbud.

Embodiments of the present invention are not limited to headsets and devices that communicate wirelessly. In some embodiments of the present invention, headsets and devices configured to monitor an individual's physiology and/or environment may be wired to a device that stores and/or processes data. In some embodiments, this information may be stored on the headset itself.

Embodiments of the present invention may apply to the estimation of parameters at another state (other than resting

state) by measuring current state parameters and processing this data via a model to generate an estimate of parameters at the desired state. For example, embodiments of the present invention may be applied to estimating vital parameters at the state of peak metabolism during midday. In another example, embodiments of the present invention may be applied to estimating vital parameters at the state of lowered metabolism associated with evening time, for example, just before bedtime. A more general model or equation 160 for estimating vital parameters at a desired state is presented in FIG. 9.

It should also be understood that user input may be used to improve the accuracy of resting state (or other state) parameters. For example, relationships may exist between resting vs. measured parameters and weight, gender, height, habitual information, and the like. A particular example of habitual information may be the time-of-day someone wakes up in the morning. For example, the time of waking up may replace “7 AM” shown in FIG. 2.

Methods for estimating a physiological parameter at a selected state, according to some embodiments of the present invention, may be applied to wearable sensors as well as nonwearable sensors capable of measuring one or more physiological parameters and physical activity in a time-correlated manner, during enough times of the day to build or execute a time-correlated model. For example, whereas multiple examples of wearable devices have been described herein, alternative embodiments may employ wall-mounted sensors, bed-mounted sensors, car-mounted sensors, portable sensors, or other sensor configurations that can measure physiological parameters or physical activity at a “stand-off” distance from a subject. As a specific example, a wall-mounted camera may be configured to measure the heart rate, breathing rate, and physical activity of a subject and to record a time stamp of that subject. Measuring heart rate or breathing rate with a mounted camera may be achieved via algorithms capable of assessing individual video frames for changes in the chest size in time or by detecting certain wavelengths of light associated with heat changes, for example. Additionally, physical activity may be assessed by algorithms capable of identifying subjects and subject motion and translating this identified motion to activity level. In such case, a time-correlated relationship function may be generated for the subject. Thus, the heart rate or respiration rate of the subject may be accurately estimated for a selected state, such as a resting state or other state, when the subject is not in view of the camera by applying the time-correlated relationship function for the subject at the selected state. Suitable stand-off detection methods may employ, for example, electromagnetic, electrical, magnetic, inductive, capacitive, thermal, acoustic, or other energy detection techniques. For example, the heart rate, breathing rate, and activity of a subject sleeping in a bed, and coupled to a stand-off capacitive or inductive sensor, may be monitored through changes in capacitance or inductance. If this data is time-stamped by a processor, the inventive aspects described herein may be applied for determining one or more physiological parameters for that subject at a selected state, such as a state of reduced or elevated activity.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the teachings and advantages of this invention. Accordingly, all such modifi-

cations are intended to be included within the scope of this invention as defined in the claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

That which is claimed is:

1. A method of estimating a value of a physiological parameter for a subject at a selected metabolic state, the method comprising:

obtaining, via a device attached to the subject, a value of the physiological parameter of the subject at a time-of-day, wherein the device comprises a physiological sensor, wherein the physiological sensor detects and/or measures physiological information from the subject; and

estimating the value of the physiological parameter for the subject at the selected metabolic state by applying a time-dependent relationship function to the obtained physiological parameter value via at least one processor, wherein the selected metabolic state is different from a current metabolic state of the subject.

2. The method of claim 1, wherein the time-dependent relationship function is derived from a circadian rhythm for the subject.

3. The method of claim 1, wherein the time-dependent relationship function is a lookup table.

4. The method of claim 1, wherein the physiological parameter includes one or more of the following: subject body temperature, subject heart rate, subject heart rate variability, subject blood gas levels, subject metabolic rate, subject respiration rate, subject blood analyte levels, subject blood pressure, and subject pulse pressure.

5. The method of claim 1, wherein estimating the value of the physiological parameter for the subject at the selected metabolic state comprises obtaining the value of the physiological parameter at the same time-of-day for multiple days and determining an average value for the multiple obtained values, and wherein applying the time-dependent relationship function to the obtained physiological parameter value comprises applying the time-dependent relationship function to the average value.

6. The method of claim 1, further comprising determining if the subject is in a condition of heightened activity at the time-of-day by determining via the device if at least one obtained physiological parameter value is at a level associated with heightened activity, and wherein the time-dependent relationship function is adjusted for the heightened activity condition of the subject prior to estimating the value of the physiological parameter at the selected metabolic state.

7. The method of claim 1, wherein prior to obtaining a value of the physiological parameter of the subject at the time-of-day, values of the physiological parameter of the subject are obtained at multiple times during at least one previous day, and a personalized time-dependent relationship function between at least one of value of the physiological parameter and a value of the physiological parameter at the selected metabolic state is generated for the subject using the obtained values from the at least one previous day, and wherein applying the time-dependent relationship function to the obtained physiological parameter value comprises applying the personalized time-dependent relationship function to the obtained physiological parameter value via the processor to estimate the value of the physiological parameter at the selected metabolic state.

8. The method of claim 1, wherein the device further includes an environmental sensor that detects and/or measures environmental condition information in a vicinity of

the subject, and further comprising obtaining, via the device, a value of an environmental parameter in a vicinity of the subject at the time-of-day, and wherein applying the time-dependent relationship function to the obtained physiological parameter value comprises applying the time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value via the processor to estimate the value of the physiological parameter at the selected metabolic state.

9. The method of claim 1, further comprising adjusting the time-dependent relationship function for one or more of the following prior to estimating the value of the physiological parameter at the selected metabolic state: calories consumed by the subject and blood oxygen level of the subject.

10. The method of claim 1, wherein the selected metabolic state includes one or more of the following: state of peak metabolism, state of lowered metabolism, state of rest.

11. The method of claim 1, wherein the device is configured to be attached to one or more of the following portions of a body of the subject: arm, wrist, leg, hand, foot, finger, toe, chest, head, hair, nose, waist, trunk, shoulder, neck, and ear.

12. The method of claim 1, wherein the device is configured to be embedded within clothing and other wearable objects.

13. An apparatus, comprising:

a housing configured to be attached to a subject;  
a physiological sensor attached to the housing, wherein the physiological sensor detects and/or measures physiological information from the subject; and

at least one processor attached to the housing, wherein the at least one processor is configured to obtain from the physiological sensor a value of a physiological parameter of the subject at a time-of-day, and to estimate a value of the physiological parameter for the subject at a selected metabolic state by applying a time-dependent relationship function to the obtained physiological parameter value, wherein the selected metabolic state is different from a current metabolic state of the subject.

14. The apparatus of claim 13, wherein the processor is configured to:

obtain from the physiological sensor the value of the physiological parameter at the same time-of-day for multiple days;

determine an average value for the multiple obtained values; and

apply the time-dependent relationship function to the average value.

15. The apparatus of claim 13, wherein the processor is configured to:

determine if the subject is in a condition of heightened activity at the selected time-of-day by determining if a heart rate of the subject is at an elevated level; and

adjust the time-dependent relationship function for the elevated heart rate level of the subject prior to estimating the value of the physiological parameter at the selected metabolic state.

16. The apparatus of claim 13, wherein the processor is configured to:

obtain values of the physiological parameter of the subject at multiple times during at least one previous day;

generate a personalized time-dependent relationship function between a measured value of the physiological value and the estimated value of the physiological parameter at the selected metabolic state using the obtained values from the at least one previous day; and

estimating the value of the physiological parameter for the subject at the selected metabolic state by applying the personalized time-dependent relationship function to the obtained physiological parameter value.

17. The apparatus of claim 13, further comprising an environmental sensor attached to the housing that detects and/or measures environmental condition information in a vicinity of the subject, and wherein the processor is configured to obtain a value of an environmental parameter in a vicinity of the subject at the time-of-day from the environmental sensor, and to apply the time-dependent relationship function and an environmental-dependent relationship function to the obtained physiological parameter value to estimate the value of the physiological parameter at the selected metabolic state.

18. The apparatus of claim 13, wherein the processor is configured to adjust the time-dependent relationship function for one or more of the following prior to estimating the value of the physiological parameter at the selected metabolic state: calories consumed by the subject and blood oxygen level of the subject.

19. The apparatus of claim 13, wherein the processor is configured to adjust the time-dependent relationship function for blood oxygen level of the subject prior to estimating the value of the physiological parameter at the selected metabolic state.

20. The apparatus of claim 13, wherein the housing is configured to be attached to one or more of the following portions of the body of the subject: arm, wrist, leg, hand, foot, finger, toe, chest, head, hair, nose, waist, trunk, shoulder, neck, and ear.

21. The apparatus of claim 13, wherein the housing is configured to be embedded within clothing and other wearable objects.

22. The apparatus of claim 13, wherein the housing is configured to be embedded within the skin or within the body of the subject.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 9,427,191 B2  
APPLICATION NO. : 14/116641  
DATED : August 30, 2016  
INVENTOR(S) : LeBoeuf

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

(56) References Cited, p. 5, Left Column, Falkner et al.:

Please correct "*Hypertension* 1:23-30"  
to read -- *Hypertension* 1979, 1:23-30 --

Left Column, Martins et al.:

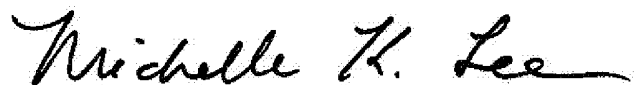
Please correct "96(3): 1398-1408."  
to read -- 96(3): 1398-1408 (2004) --

In the Specification

Column 11, Line 20: Please correct " $(t^{n-1} a_{n-2}(t^{n-2})+)$ "  
to read --  $(t^{n-1})+a_{n-2}(t^{n-2})+ --$

Line 33: Please correct " $_{measured} HRV_{circadian}$ "  
to read --  $_{measured} - \Delta HRV_{circadian} --$

Signed and Sealed this  
Eleventh Day of April, 2017



Michelle K. Lee  
Director of the United States Patent and Trademark Office

专利名称(译)	用于估计时间 - 状态生理参数的装置和方法		
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[标]申请(专利权)人(译)	勒伯夫史蒂芬FRANCIS		
申请(专利权)人(译)	史蒂文-勒伯夫, 弗朗西斯		
当前申请(专利权)人(译)	VALENCELL INC.		
[标]发明人	LEBOEUF STEVEN FRANCIS		
发明人	LEBOEUF, STEVEN FRANCIS		
IPC分类号	A61B5/02 A61B5/00 A61B5/1455 A61B5/0205 A61B5/08 A61B5/024 A61B5/021 G16H10/60		
CPC分类号	A61B5/02055 A61B5/14551 A61B5/4857 A61B5/4866 A61B5/021 A61B5/02405 A61B5/0816 A61B2560/0242 A61B5/0077 A61B5/02438 A61B5/1118 A61B5/14542 A61B5/14546 A61B5/6889 A61B5/6891 A61B5/6892 A61B5/6893 A61B2562/0204 A61B2562/0271		
优先权	61/511238 2011-07-25 US		
其他公开文献	US20140128690A1		
外部链接	<a href="#">Espacenet</a> <a href="#">USPTO</a>		

摘要(译)

确定处于选定状态的受试者的生理参数的值的方法包括经由附着于受试者的装置获得在特定时间的受试者的生理参数的值，并且施加时间 - 依赖关系通过处理器对所获得的生理参数值起作用，以确定所选状态下的生理参数的值。

