US009215957B2

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

(10) **Patent No.: US 9,215,957 B2**
(45) **Date of Patent: Dec. 22, 2015**

(54) **AUTONOMOUS ROBOT AUTO-DOCKING AND ENERGY MANAGEMENT SYSTEMS AND METHODS**

(71) Applicant: **iRobot Corporation**, Bedford, MA (US)

(72) Inventors: **David A. Cohen**, Brookline, MA (US); **Daniel N. Ozick**, Newton, MA (US); **Clara Vu**, Cambridge, MA (US); **James Lynch**, Georgetown, MA (US); **Philip R. Mass**, Portland, OR (US)

(73) Assignee: **iRobot Corporation**, Bedford, MA (US)

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

(21) Appl. No.: **14/475,984**

(22) Filed: **Sep. 3, 2014**

(65) **Prior Publication Data**

US 2015/0057800 A1 Feb. 26, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/291,633, filed on Nov. 8, 2011, now Pat. No. 8,854,001, which is a continuation of application No. 11/648,230, filed on Dec. 29, 2006, now Pat. No. 8,749,196, which is a continuation of application No. 10/762,219, filed on Jan. 21, 2004, now Pat. No. 7,332,890.

(51) **Int. Cl.**
H02J 7/00 (2006.01)
A47L 9/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A47L 9/0063*** (2013.01); ***A47L 9/009*** (2013.01); ***A47L 9/2805*** (2013.01); ***A47L 9/2852*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H02J 7/0021; A47L 2201/002; A47L 2201/04
USPC 320/104, 107, 109, 134; 700/258, 262; 901/46; 180/167
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,755,054 A 4/1930 Darst
1,780,221 A 11/1930 Buchmann
(Continued)

FOREIGN PATENT DOCUMENTS

DE 2128842 C3 12/1980
DE 3317376 C2 12/1987
(Continued)

OTHER PUBLICATIONS

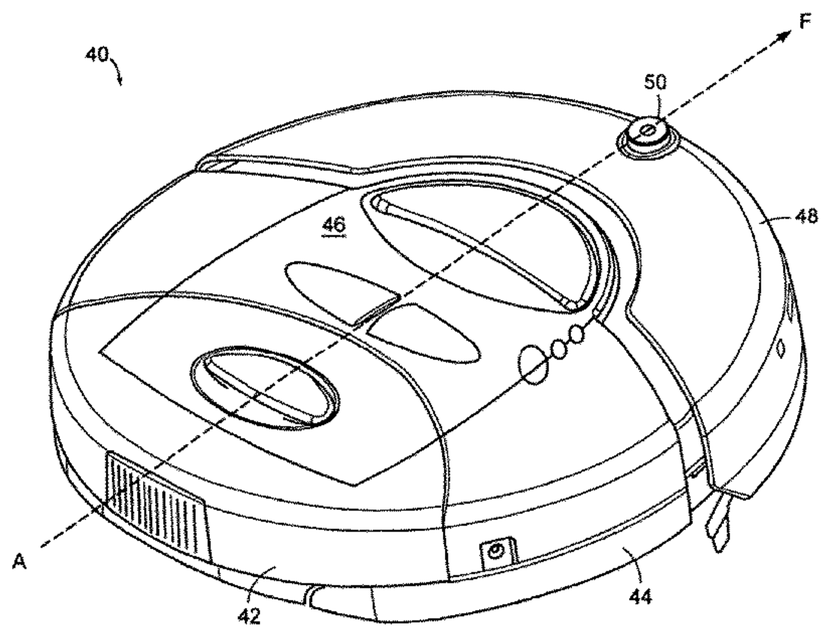
Andersen et al., "Landmark based navigation strategies," SPIE Conference on Mobile Robots XIII, SPIE vol. 3525, pp. 170-181, Jan. 8, 1999.
(Continued)

Primary Examiner — Edward Tso
Assistant Examiner — Aaron Piggush
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

A method for energy management in a robotic device includes providing a base station for mating with the robotic device, determining a quantity of energy stored in an energy storage unit of the robotic device, and performing a predetermined task based at least in part on the quantity of energy stored. Also disclosed are systems for emitting avoidance signals to prevent inadvertent contact between the robot and the base station, and systems for emitting homing signals to allow the robotic device to accurately dock with the base station.

13 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

A47L 9/28	(2006.01)
G05D 1/02	(2006.01)
H02J 7/04	(2006.01)
G01S 1/16	(2006.01)
G01S 1/70	(2006.01)

(52) **U.S. Cl.**

CPC ***A47L 9/2857*** (2013.01); ***A47L 9/2873*** (2013.01); ***A47L 9/2889*** (2013.01); ***A47L 9/2894*** (2013.01); ***G01S 1/16*** (2013.01); ***G01S 1/70*** (2013.01); ***G05D 1/0225*** (2013.01); ***G05D 1/0242*** (2013.01); ***H02J 7/0036*** (2013.01); ***H02J 7/0044*** (2013.01); ***H02J 7/045*** (2013.01); *A47L 2201/02* (2013.01); *A47L 2201/022* (2013.01); *G05D 1/0219* (2013.01); *G05D 1/0227* (2013.01); *G05D 2201/0203* (2013.01); *G05D 2201/0208* (2013.01); *G05D 2201/0215* (2013.01); *H02J 7/0052* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,970,302	A		8/1934	Gerhardt
2,136,324	A		11/1938	John
2,302,111	A		11/1942	Dow et al.
2,353,621	A		7/1944	Sav et al.
2,770,825	A		11/1956	Pullen
2,930,055	A		3/1960	Fallen et al.
3,119,369	A		1/1964	Harland et al.
3,166,138	A		1/1965	Dunn
3,333,564	A		8/1967	Waters
3,375,375	A		3/1968	Robert et al.
3,381,652	A		5/1968	Schaefer et al.
3,457,575	A		7/1969	Bienek
3,550,714	A		12/1970	Bellinger
3,569,727	A		3/1971	Aggarwal et al.
3,649,981	A		3/1972	Woodworth
3,674,316	A		7/1972	De Bray
3,678,882	A		7/1972	Kinsella
3,690,559	A		9/1972	Rudloff
3,744,586	A		7/1973	Leinauer
3,756,667	A		9/1973	Bombardier et al.
3,809,004	A		5/1974	Leonheart
3,816,004	A		6/1974	Bignardi
3,845,831	A		11/1974	James
RE28,268	E		12/1974	Autrand
3,851,349	A		12/1974	Lowder
3,853,086	A		12/1974	Asplund
3,863,285	A		2/1975	Hukuba
3,888,181	A		6/1975	Kups
3,937,174	A		2/1976	Haaga
3,952,361	A		4/1976	Wilkins
3,989,311	A		11/1976	Debrey
3,989,931	A		11/1976	Phillips
4,004,313	A		1/1977	Capra
4,012,681	A		3/1977	Finger et al.
4,070,170	A		1/1978	Leinfelt
4,099,284	A		7/1978	Shinozaki et al.
4,119,900	A		10/1978	Kremnitz
4,175,589	A		11/1979	Nakamura et al.
4,175,892	A		11/1979	De bray
4,196,727	A		4/1980	Verkaart et al.
4,198,727	A		4/1980	Farmer
4,199,838	A		4/1980	Simonsson
4,209,254	A		6/1980	Reymond et al.
D258,901	S		4/1981	Keyworth
4,297,578	A		10/1981	Carter
4,305,234	A		12/1981	Pichelman
4,306,329	A		12/1981	Yokoi
4,309,758	A		1/1982	Halsall et al.
4,328,545	A		5/1982	Halsall et al.
4,367,403	A		1/1983	Miller
4,369,543	A		1/1983	Chen et al.
4,401,909	A		8/1983	Gorsek
4,416,033	A		11/1983	Specht
4,445,245	A		5/1984	Lu
4,465,370	A		8/1984	Yuasa et al.
4,477,998	A		10/1984	You
4,481,692	A		11/1984	Kurz
4,482,960	A		11/1984	Pryor
4,492,058	A		1/1985	Goldfarb et al.
4,513,469	A		4/1985	Godfrey et al.
D278,732	S		5/1985	Ohkado
4,518,437	A		5/1985	Sommer
4,534,637	A		8/1985	Suzuki et al.
4,556,313	A		12/1985	Miller et al.
4,575,211	A		3/1986	Matsumura et al.
4,580,311	A		4/1986	Kurz
4,601,082	A		7/1986	Kurz
4,618,213	A		10/1986	Chen
4,620,285	A		10/1986	Perdue
4,624,026	A		11/1986	Olson et al.
4,626,995	A		12/1986	Lofgren et al.
4,628,454	A		12/1986	Ito
4,638,445	A		1/1987	Mattaboni
4,644,156	A		2/1987	Takahashi et al.
4,649,504	A		3/1987	Krouglicof et al.
4,652,917	A		3/1987	Miller
4,654,492	A		3/1987	Koerner et al.
4,654,924	A		4/1987	Getz et al.
4,660,969	A		4/1987	Sorimachi et al.
4,662,854	A		5/1987	Fang
4,674,048	A		6/1987	Okumura
4,679,152	A	*	7/1987	Perdue B25J 19/005 180/167
4,680,827	A		7/1987	Hummel
4,696,074	A		9/1987	Cavalli
D292,223	S		10/1987	Trumbull
4,700,301	A		10/1987	Dyke
4,700,427	A		10/1987	Knepper
4,703,820	A		11/1987	Reinaud
4,709,773	A		12/1987	Clement et al.
4,710,020	A		12/1987	Maddox et al.
4,712,740	A		12/1987	Duncan et al.
4,716,621	A		1/1988	Zoni
4,728,801	A		3/1988	O'Connor
4,733,343	A		3/1988	Yoneda et al.
4,733,430	A		3/1988	Westergren
4,733,431	A		3/1988	Martin
4,735,136	A		4/1988	Lee et al.
4,735,138	A		4/1988	Gawler et al.
4,748,336	A		5/1988	Fujie et al.
4,748,833	A		6/1988	Nagasawa
4,756,049	A		7/1988	Uehara
4,767,213	A		8/1988	Hummel
4,769,700	A		9/1988	Pryor
4,777,416	A		10/1988	George et al.
D298,766	S		11/1988	Tanno et al.
4,782,550	A		11/1988	Jacobs
4,796,198	A		1/1989	Boultinghouse et al.
4,806,751	A		2/1989	Abe et al.
4,811,228	A		3/1989	Hyyppa
4,813,906	A		3/1989	Matsuyama et al.
4,815,157	A		3/1989	Tsuchiya
4,817,000	A		3/1989	Eberhardt
4,818,875	A		4/1989	Weiner
4,829,442	A		5/1989	Kadonoff et al.
4,829,626	A		5/1989	Harkonen et al.
4,832,098	A		5/1989	Palinkas et al.
4,851,661	A		7/1989	Everett
4,854,000	A		8/1989	Takimoto
4,854,006	A		8/1989	Nishimura et al.
4,855,915	A		8/1989	Dallaire
4,857,912	A		8/1989	Everett et al.
4,858,132	A		8/1989	Holmquist
4,867,570	A		9/1989	Sorimachi et al.
4,880,474	A		11/1989	Koharagi et al.
4,887,415	A		12/1989	Martin
4,891,762	A		1/1990	Chotiros
4,893,025	A		1/1990	Lee
4,901,394	A		2/1990	Nakamura et al.
4,905,151	A		2/1990	Weiman et al.
4,909,972	A		3/1990	Britz

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,912,643	A	3/1990	Beirne
4,918,441	A	4/1990	Bohman
4,919,224	A	4/1990	Shyu et al.
4,919,489	A	4/1990	Kopsco
4,920,060	A	4/1990	Parrent et al.
4,920,605	A	5/1990	Takashima
4,933,864	A	6/1990	Evans et al.
4,937,912	A	7/1990	Kurz
4,953,253	A	9/1990	Fukuda et al.
4,954,962	A	9/1990	Evans et al.
4,955,714	A	9/1990	Stotler et al.
4,956,891	A	9/1990	Wulff
4,961,303	A	10/1990	McCarty et al.
4,961,304	A	10/1990	Ovsborn et al.
4,962,453	A	10/1990	Pong et al.
4,967,862	A	11/1990	Pong et al.
4,971,591	A	11/1990	Raviv et al.
4,973,912	A	11/1990	Kaminski et al.
4,974,283	A	12/1990	Holsten et al.
4,977,618	A	12/1990	Allen
4,977,639	A	12/1990	Takahashi et al.
4,986,663	A	1/1991	Cecchi et al.
5,001,635	A	3/1991	Yasutomi et al.
5,002,145	A	3/1991	Wakaumi et al.
5,012,886	A	5/1991	Jonas et al.
5,018,240	A	5/1991	Holman
5,020,186	A	6/1991	Lessig et al.
5,022,812	A	6/1991	Coughlan et al.
5,023,788	A	6/1991	Kitazume et al.
5,024,529	A	6/1991	Svetkoff et al.
D318,500	S	7/1991	Malewicki et al.
5,032,775	A	7/1991	Mizuno et al.
5,033,151	A	7/1991	Kraft et al.
5,033,291	A	7/1991	Podoloff et al.
5,040,116	A	8/1991	Evans et al.
5,045,769	A	9/1991	Everett
5,049,802	A	9/1991	Mintus et al.
5,051,906	A	9/1991	Evans et al.
5,062,819	A	11/1991	Mallory
5,070,567	A	12/1991	Holland
5,084,934	A	2/1992	Lessig et al.
5,086,535	A	2/1992	Grossmeyer et al.
5,090,321	A	2/1992	Abouav
5,093,955	A	3/1992	Blehert et al.
5,094,311	A	3/1992	Akeel
5,098,262	A	3/1992	Wecker et al.
5,105,502	A	4/1992	Takashima
5,105,550	A	4/1992	Shenoha
5,109,566	A	5/1992	Kobayashi et al.
5,111,401	A	5/1992	Everett, Jr. et al.
5,115,538	A	5/1992	Cochran et al.
5,127,128	A	7/1992	Lee
5,136,675	A	8/1992	Hodson
5,136,750	A	8/1992	Takashima et al.
5,142,985	A	9/1992	Stearns et al.
5,144,471	A	9/1992	Takanashi et al.
5,144,714	A	9/1992	Mori et al.
5,144,715	A	9/1992	Matsuyo et al.
5,152,028	A	10/1992	Hirano
5,152,202	A	10/1992	Strauss
5,154,617	A	10/1992	Suman et al.
5,155,684	A	10/1992	Burke et al.
5,163,202	A	11/1992	Kawakami et al.
5,163,320	A	11/1992	Goshima et al.
5,164,579	A	11/1992	Pryor et al.
5,165,064	A	11/1992	Mattaboni
5,170,352	A	12/1992	McTamaney et al.
5,173,881	A	12/1992	Sindle
5,182,833	A	2/1993	Yamaguchi et al.
5,187,662	A	2/1993	Kamimura et al.
5,202,742	A	4/1993	Frank et al.
5,204,814	A	4/1993	Noonan et al.
5,206,500	A	4/1993	Decker et al.
5,208,521	A	5/1993	Aoyama
5,216,777	A	6/1993	Moro et al.
5,222,786	A	6/1993	Sovis et al.
5,227,985	A	7/1993	DeMenthon
5,233,682	A	8/1993	Abe et al.
5,239,720	A	8/1993	Wood et al.
5,251,358	A	10/1993	Moro et al.
5,261,139	A	11/1993	Lewis
5,276,618	A	1/1994	Everett
5,276,939	A	1/1994	Uenishi
5,277,064	A	1/1994	Knigga et al.
5,279,672	A	1/1994	Betker et al.
5,284,452	A	2/1994	Corona
5,284,522	A	2/1994	Kobayashi et al.
5,293,955	A	3/1994	Lee
D345,707	S	4/1994	Alister
5,303,448	A	4/1994	Hennessey et al.
5,307,273	A	4/1994	Oh et al.
5,309,592	A	5/1994	Hiratsuka
5,310,379	A	5/1994	Hippely et al.
5,315,227	A	5/1994	Pierson et al.
5,319,827	A	6/1994	Yang
5,319,828	A	6/1994	Waldhauser et al.
5,321,614	A	6/1994	Ashworth
5,323,483	A	6/1994	Baeg
5,324,948	A	6/1994	Dudar et al.
5,331,713	A	7/1994	Tipton
5,341,186	A	8/1994	Kato
5,341,540	A	8/1994	Soupert et al.
5,341,549	A	8/1994	Wirtz et al.
5,345,649	A	9/1994	Whitlow
5,352,901	A	10/1994	Poorman
5,353,224	A	10/1994	Lee et al.
5,363,305	A	11/1994	Cox et al.
5,363,935	A	11/1994	Schempf et al.
5,369,347	A	11/1994	Yoo
5,369,838	A	12/1994	Wood et al.
5,386,862	A	2/1995	Glover et al.
5,399,951	A	3/1995	Lavallee et al.
5,400,244	A	3/1995	Watanabe et al.
5,404,612	A	4/1995	Ishikawa
5,410,479	A	4/1995	Coker
5,435,405	A	7/1995	Schempf et al.
5,440,216	A	8/1995	Kim
5,442,358	A	8/1995	Keeler et al.
5,444,965	A	8/1995	Colens
5,446,356	A	8/1995	Kim
5,446,445	A	8/1995	Bloomfield et al.
5,451,135	A	9/1995	Schempf et al.
5,454,129	A	10/1995	Kell
5,455,982	A	10/1995	Armstrong et al.
5,465,525	A	11/1995	Mifune et al.
5,465,619	A	11/1995	Sotack et al.
5,467,273	A	11/1995	Faibish et al.
5,471,560	A	11/1995	Allard et al.
5,491,670	A	2/1996	Weber
5,497,529	A	3/1996	Boesi
5,498,948	A	3/1996	Bruni et al.
5,502,638	A	3/1996	Takenaka
5,505,072	A	4/1996	Oreper
5,507,067	A	4/1996	Hoekstra et al.
5,510,893	A	4/1996	Suzuki
5,511,147	A	4/1996	Abdel-Malek
5,515,572	A	5/1996	Hoekstra et al.
5,534,762	A	7/1996	Kim
5,535,476	A	7/1996	Kresse et al.
5,537,017	A	7/1996	Feiten et al.
5,537,711	A	7/1996	Tseng
5,539,953	A	7/1996	Kurz
5,542,146	A	8/1996	Hoekstra et al.
5,542,148	A	8/1996	Young
5,546,631	A	8/1996	Chambon
5,548,511	A	8/1996	Bancroft
5,551,119	A	9/1996	Wörwag
5,551,525	A	9/1996	Pack et al.
5,553,349	A	9/1996	Kilstrom et al.
5,555,587	A	9/1996	Guha
5,560,077	A	10/1996	Crotchett
5,568,589	A	10/1996	Hwang
D375,592	S	11/1996	Ljunggren
5,608,306	A	3/1997	Rybeck et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,608,894	A		3/1997	Kawakami et al.
5,608,944	A		3/1997	Gordon
5,610,488	A		3/1997	Miyazawa
5,611,106	A		3/1997	Wulff
5,611,108	A		3/1997	Knowlton et al.
5,613,261	A		3/1997	Kawakami et al.
5,613,269	A		3/1997	Miwa
5,621,291	A		4/1997	Lee
5,622,236	A		4/1997	Azumi et al.
5,634,237	A		6/1997	Paranjpe
5,634,239	A		6/1997	Tuvin et al.
5,636,402	A		6/1997	Kubo et al.
5,642,299	A		6/1997	Hardin et al.
5,646,494	A	*	7/1997	Han A47L 11/4011 318/587
5,647,554	A		7/1997	Ikegami et al.
5,650,702	A		7/1997	Azumi
5,652,489	A		7/1997	Kawakami
5,682,313	A		10/1997	Edlund et al.
5,682,839	A		11/1997	Grimsley et al.
5,696,675	A		12/1997	Nakamura et al.
5,698,861	A		12/1997	Oh
5,709,007	A		1/1998	Chiang
5,710,506	A		1/1998	Broell et al.
5,714,119	A		2/1998	Kawagoe et al.
5,717,169	A		2/1998	Liang et al.
5,717,484	A		2/1998	Hamaguchi et al.
5,720,077	A		2/1998	Nakamura et al.
5,732,401	A		3/1998	Conway
5,735,017	A		4/1998	Barnes et al.
5,735,959	A		4/1998	Kubo et al.
5,742,975	A		4/1998	Knowlton et al.
5,745,235	A		4/1998	Vercammen et al.
5,752,871	A		5/1998	Tsuzuki
5,756,904	A		5/1998	Oreper et al.
5,761,762	A		6/1998	Kubo
5,764,888	A		6/1998	Bolan et al.
5,767,437	A		6/1998	Rogers
5,767,960	A		6/1998	Orman
5,770,936	A		6/1998	Hirai et al.
5,777,596	A		7/1998	Herbert
5,778,486	A		7/1998	Kim
5,781,697	A		7/1998	Jeong
5,781,960	A		7/1998	Kilstrom et al.
5,784,755	A		7/1998	Karr et al.
5,786,602	A		7/1998	Pryor et al.
5,787,545	A		8/1998	Colens
5,793,900	A		8/1998	Nourbakhsh et al.
5,794,297	A		8/1998	Muta
5,802,665	A		9/1998	Knowlton et al.
5,812,267	A		9/1998	Everett et al.
5,814,808	A		9/1998	Takada et al.
5,815,880	A		10/1998	Nakanishi
5,815,884	A		10/1998	Imamura et al.
5,819,008	A		10/1998	Asama et al.
5,819,360	A		10/1998	Fujii
5,819,936	A		10/1998	Saveliev et al.
5,820,821	A		10/1998	Kawagoe et al.
5,821,730	A		10/1998	Drapkin
5,825,981	A		10/1998	Matsuda
5,828,770	A		10/1998	Leis et al.
5,831,597	A		11/1998	West et al.
5,836,045	A		11/1998	Anthony et al.
5,839,156	A		11/1998	Park et al.
5,839,532	A		11/1998	Yoshiji et al.
5,841,259	A		11/1998	Kim et al.
5,867,800	A		2/1999	Leif
5,867,861	A		2/1999	Kasen et al.
5,869,910	A		2/1999	Colens
5,894,621	A		4/1999	Kubo
5,896,611	A		4/1999	Haaga
5,903,124	A		5/1999	Kawakami
5,905,209	A		5/1999	Oreper
5,907,886	A		6/1999	Buscher
5,910,700	A		6/1999	Crotzer
5,911,260	A		6/1999	Suzuki
5,916,008	A		6/1999	Wong
5,924,167	A		7/1999	Wright et al.
5,926,909	A		7/1999	McGee
5,933,102	A		8/1999	Miller et al.
5,933,913	A		8/1999	Wright et al.
5,935,179	A		8/1999	Kleiner et al.
5,935,333	A		8/1999	Davis
5,940,346	A		8/1999	Sadowsky et al.
5,940,927	A		8/1999	Haegermarck et al.
5,940,930	A		8/1999	Oh et al.
5,942,869	A		8/1999	Katou et al.
5,943,730	A		8/1999	Boomgaarden
5,943,733	A		8/1999	Tagliaferri
5,943,933	A		8/1999	Evans et al.
5,947,225	A		9/1999	Kawakami et al.
5,950,408	A		9/1999	Schaedler
5,959,423	A		9/1999	Nakanishi et al.
5,968,281	A		10/1999	Wright et al.
5,974,348	A		10/1999	Rocks
5,974,365	A		10/1999	Mitchell
5,983,448	A		11/1999	Wright et al.
5,984,880	A		11/1999	Lander et al.
5,987,383	A		11/1999	Keller et al.
5,989,700	A		11/1999	Krivopal
5,991,951	A		11/1999	Kubo et al.
5,995,883	A		11/1999	Nishikado
5,995,884	A	*	11/1999	Allen et al. G05D 1/0025 180/167
5,996,167	A		12/1999	Close
5,998,953	A		12/1999	Nakamura et al.
5,998,971	A		12/1999	Corbridge
6,000,088	A		12/1999	Wright et al.
6,009,358	A		12/1999	Angott et al.
6,012,618	A		1/2000	Matsuo et al.
6,021,545	A		2/2000	Delgado et al.
6,023,813	A		2/2000	Thatcher et al.
6,023,814	A		2/2000	Imamura
6,025,687	A		2/2000	Himeda et al.
6,026,539	A		2/2000	Mouw et al.
6,030,464	A		2/2000	Azevedo
6,030,465	A		2/2000	Marcussen et al.
6,032,327	A		3/2000	Oka et al.
6,032,542	A		3/2000	Warnick et al.
6,036,572	A		3/2000	Sze
6,038,501	A		3/2000	Kawakami
6,040,669	A		3/2000	Hog
6,041,471	A		3/2000	Charky et al.
6,041,472	A		3/2000	Kasen et al.
6,046,800	A		4/2000	Ohtomo et al.
6,049,620	A		4/2000	Dickinson et al.
6,050,648	A		4/2000	Keleny
6,052,821	A		4/2000	Chouly et al.
6,055,042	A		4/2000	Sarangapani
6,055,702	A		5/2000	Imamura et al.
6,061,868	A		5/2000	Moritsch et al.
6,065,182	A		5/2000	Wright et al.
6,070,290	A		6/2000	Schwarze et al.
6,073,432	A		6/2000	Schaedler
6,076,025	A		6/2000	Ueno et al.
6,076,026	A		6/2000	Jambhekar et al.
6,076,226	A		6/2000	Reed
6,076,227	A		6/2000	Schallig et al.
6,081,257	A		6/2000	Zeller
6,088,020	A		7/2000	Mor
6,094,775	A		8/2000	Behmer
6,099,091	A		8/2000	Campbell
6,101,670	A		8/2000	Song
6,101,671	A		8/2000	Wright et al.
6,108,031	A		8/2000	King et al.
6,108,067	A		8/2000	Okamoto
6,108,076	A		8/2000	Hanseder
6,108,269	A		8/2000	Kabel
6,108,597	A		8/2000	Kirchner et al.
6,108,859	A		8/2000	Burgoon
6,112,143	A		8/2000	Allen et al.
6,112,996	A		9/2000	Matsuo
6,119,057	A		9/2000	Kawagoe
6,122,798	A		9/2000	Kobayashi et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,124,694	A	9/2000	Bancroft et al.
6,125,498	A	10/2000	Roberts et al.
6,131,237	A	10/2000	Kasper et al.
6,138,063	A	10/2000	Himeda
6,142,252	A	11/2000	Kinto et al.
6,146,041	A	11/2000	Chen et al.
6,146,278	A	11/2000	Kobayashi
6,154,279	A	11/2000	Thayer
6,154,694	A	11/2000	Aoki et al.
6,160,479	A	12/2000	Ahlen et al.
6,167,332	A	12/2000	Kurtzberg et al.
6,167,587	B1	1/2001	Kasper et al.
6,192,548	B1	2/2001	Huffman
6,192,549	B1	2/2001	Kasen et al.
6,202,243	B1	3/2001	Beaufoy et al.
6,216,307	B1	4/2001	Kaleta et al.
6,220,865	B1	4/2001	Macri et al.
6,226,830	B1	5/2001	Hendriks et al.
6,230,362	B1	5/2001	Kasper et al.
6,237,741	B1	5/2001	Guidetti
6,240,342	B1	5/2001	Fiegert et al.
6,243,913	B1	6/2001	Frank et al.
6,255,793	B1	7/2001	Peless et al.
6,259,979	B1	7/2001	Holmquist
6,261,379	B1	7/2001	Conrad et al.
6,263,539	B1	7/2001	Baig
6,263,989	B1	7/2001	Won
6,272,936	B1	8/2001	Oreper et al.
6,276,478	B1	8/2001	Hopkins et al.
6,278,918	B1	8/2001	Dickson et al.
6,279,196	B2	8/2001	Kasen et al.
6,282,526	B1	8/2001	Ganesh
6,283,034	B1	9/2001	Miles
6,285,778	B1	9/2001	Nakajima et al.
6,285,930	B1	9/2001	Dickson et al.
6,286,181	B1	9/2001	Kasper et al.
6,300,737	B1	10/2001	Bergvall et al.
6,321,337	B1	11/2001	Reshef et al.
6,321,515	B1	11/2001	Colens
6,323,570	B1	11/2001	Nishimura et al.
6,324,714	B1	12/2001	Walz et al.
6,327,741	B1	12/2001	Reed
6,332,400	B1	12/2001	Meyer
6,339,735	B1	1/2002	Peless et al.
6,362,875	B1	3/2002	Burkley
6,370,453	B2	4/2002	Sommer
6,374,155	B1	4/2002	Wallach et al.
6,374,157	B1	4/2002	Takamura
6,381,802	B2	5/2002	Park
6,385,515	B1	5/2002	Dickson et al.
6,388,013	B1	5/2002	Saraf et al.
6,389,329	B1	5/2002	Colens
6,397,429	B1	6/2002	Legatt et al.
6,400,048	B1	6/2002	Nishimura et al.
6,401,294	B2	6/2002	Kasper
6,408,226	B1	6/2002	Byrne et al.
6,412,141	B2	7/2002	Kasper et al.
6,415,203	B1	7/2002	Inoue et al.
6,418,586	B2	7/2002	Fulghum
6,421,870	B1	7/2002	Basham et al.
6,427,285	B1	8/2002	Legatt et al.
6,430,471	B1	8/2002	Kintou et al.
6,431,296	B1	8/2002	Won
6,437,227	B1	8/2002	Theimer
6,437,465	B1	8/2002	Nishimura et al.
6,438,456	B1	8/2002	Feddema et al.
6,438,793	B1	8/2002	Miner et al.
6,442,476	B1	8/2002	Poropat
6,442,789	B1	9/2002	Legatt et al.
6,443,509	B1	9/2002	Levin et al.
6,444,003	B1	9/2002	Sutcliffe
6,446,302	B1	9/2002	Kasper et al.
6,454,036	B1	9/2002	Airey et al.
D464,091	S	10/2002	Christianson
6,457,206	B1	10/2002	Judson
6,459,955	B1	10/2002	Bartsch et al.
6,463,368	B1	10/2002	Feiten et al.
6,465,982	B1	10/2002	Bergvall et al.
6,473,167	B1	10/2002	Odell
6,480,762	B1	11/2002	Uchikubo et al.
6,481,515	B1	11/2002	Kirkpatrick et al.
6,482,252	B1	11/2002	Conrad et al.
6,490,539	B1	12/2002	Dickson et al.
6,491,127	B1	12/2002	Holmberg et al.
6,493,612	B1	12/2002	Bisset et al.
6,493,613	B2	12/2002	Peless et al.
6,496,754	B2	12/2002	Song et al.
6,496,755	B2	12/2002	Wallach et al.
6,502,657	B2	1/2003	Kerrebrock et al.
6,504,610	B1	1/2003	Bauer et al.
6,507,773	B2	1/2003	Parker et al.
6,519,808	B2	2/2003	Legatt et al.
6,525,509	B1	2/2003	Petersson et al.
D471,243	S	3/2003	Cioffi et al.
6,530,102	B1	3/2003	Pierce et al.
6,530,117	B2	3/2003	Peterson
6,532,404	B2	3/2003	Colens
6,535,793	B2	3/2003	Allard
6,540,424	B1	4/2003	Hall et al.
6,540,607	B2	4/2003	Mokris et al.
6,548,982	B1	4/2003	Papanikolopoulos et al.
6,553,612	B1	4/2003	Dyson et al.
6,556,722	B1	4/2003	Russell et al.
6,556,892	B2	4/2003	Kuroki et al.
6,557,104	B2	4/2003	Vu et al.
D474,312	S	5/2003	Stephens et al.
6,563,130	B2	5/2003	Dworkowski et al.
6,571,415	B2	6/2003	Gerber et al.
6,571,422	B1	6/2003	Gordon et al.
6,572,711	B2	6/2003	Sclafani et al.
6,574,536	B1	6/2003	Kawagoe et al.
6,580,246	B2	6/2003	Jacobs
6,584,376	B1	6/2003	Van Kommer
6,586,908	B2	7/2003	Petersson et al.
6,587,573	B1	7/2003	Stam et al.
6,590,222	B1	7/2003	Bisset et al.
6,594,551	B2	7/2003	McKinney et al.
6,594,844	B2	7/2003	Jones
6,597,076	B2	7/2003	Scheible et al.
D478,884	S	8/2003	Slipy et al.
6,601,265	B1	8/2003	Burlington
6,604,021	B2	8/2003	Imai et al.
6,604,022	B2	8/2003	Parker et al.
6,605,156	B1	8/2003	Clark et al.
6,609,269	B2	8/2003	Kasper
6,611,120	B2	8/2003	Song et al.
6,611,734	B2	8/2003	Parker et al.
6,611,738	B2	8/2003	Ruffner
6,615,108	B1	9/2003	Peless et al.
6,615,434	B1	9/2003	Davis et al.
6,615,885	B1	9/2003	Ohm
6,622,465	B2	9/2003	Jerome et al.
6,624,744	B1	9/2003	Wilson et al.
6,625,843	B2	9/2003	Kim et al.
6,629,028	B2	9/2003	Paromtchik et al.
6,633,150	B1	10/2003	Wallach et al.
6,637,546	B1	10/2003	Wang
6,639,659	B2	10/2003	Granger
6,658,325	B2	12/2003	Zweig
6,658,354	B2	12/2003	Lin
6,658,692	B2	12/2003	Lenkiewicz et al.
6,658,693	B1	12/2003	Reed
6,661,239	B1	12/2003	Ozick
6,662,889	B2	12/2003	De Fazio et al.
6,668,951	B2	12/2003	Won
6,670,817	B2	12/2003	Fournier et al.
6,671,592	B1	12/2003	Bisset et al.
6,671,925	B2	1/2004	Field et al.
6,677,938	B1	1/2004	Maynard
6,687,571	B1	2/2004	Byrne et al.
6,690,134	B1	2/2004	Jones et al.
6,690,993	B2	2/2004	Foulke et al.
6,697,147	B2	2/2004	Ko et al.
6,705,332	B2	3/2004	Field et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,711,280	B2	3/2004	Stafsudd et al.
6,732,826	B2	5/2004	Song et al.
6,735,811	B2	5/2004	Field et al.
6,735,812	B2	5/2004	Hekman et al.
6,737,591	B1	5/2004	Lapstun et al.
6,741,054	B2	5/2004	Koselka et al.
6,741,364	B2	5/2004	Lange et al.
6,748,297	B2	6/2004	Song et al.
6,756,703	B2	6/2004	Chang
6,760,647	B2	7/2004	Nourbakhsh et al.
6,764,373	B1	7/2004	Osawa et al.
6,769,004	B2	7/2004	Barrett
6,774,596	B1	8/2004	Bisset
6,779,380	B1	8/2004	Nieuwkamp
6,781,338	B2	8/2004	Jones et al.
6,809,490	B2	10/2004	Jones et al.
6,810,305	B2	10/2004	Kirkpatrick
6,810,350	B2	10/2004	Blakley
6,830,120	B1	12/2004	Yashima et al.
6,832,407	B2	12/2004	Salem et al.
6,836,701	B2	12/2004	McKee
6,841,963	B2	1/2005	Song et al.
6,845,297	B2	1/2005	Allard
6,848,146	B2	2/2005	Wright et al.
6,854,148	B1	2/2005	Rief et al.
6,856,811	B2	2/2005	Burdue et al.
6,859,010	B2	2/2005	Jeon et al.
6,859,682	B2	2/2005	Naka et al.
6,860,206	B1	3/2005	Rudakevych et al.
6,865,447	B2	3/2005	Lau et al.
6,870,792	B2	3/2005	Chiappetta
6,871,115	B2	3/2005	Huang et al.
6,883,201	B2	4/2005	Jones et al.
6,886,651	B1	5/2005	Slocum et al.
6,888,333	B2	5/2005	Laby
6,901,624	B2	6/2005	Mori et al.
6,906,702	B1	6/2005	Tanaka et al.
6,914,403	B2	7/2005	Tsurumi
6,917,854	B2	7/2005	Bayer
6,925,357	B2	8/2005	Wang et al.
6,925,679	B2	8/2005	Wallach et al.
6,929,548	B2	8/2005	Wang
D510,066	S	9/2005	Hickey et al.
6,938,298	B2	9/2005	Aasen
6,940,291	B1	9/2005	Ozick
6,941,199	B1	9/2005	Bottomley et al.
6,956,348	B2	10/2005	Landry et al.
6,957,712	B2	10/2005	Song et al.
6,960,986	B2	11/2005	Asama et al.
6,965,209	B2	11/2005	Jones et al.
6,965,211	B2	11/2005	Tsurumi
6,968,592	B2	11/2005	Takeuchi et al.
6,971,140	B2	12/2005	Kim
6,975,246	B1	12/2005	Trudeau
6,980,229	B1	12/2005	Ebersole
6,985,556	B2	1/2006	Shanmugavel et al.
6,993,954	B1	2/2006	George et al.
6,999,850	B2	2/2006	McDonald
7,013,527	B2	3/2006	Thomas et al.
7,024,278	B2	4/2006	Chiappetta et al.
7,024,280	B2	4/2006	Parker et al.
7,027,893	B2	4/2006	Perry et al.
7,030,768	B2	4/2006	Wanie
7,031,805	B2	4/2006	Lee et al.
7,032,469	B2	4/2006	Bailey
7,040,869	B2	5/2006	Beenker
7,041,029	B2	5/2006	Fulghum et al.
7,051,399	B2	5/2006	Field et al.
7,053,578	B2	5/2006	Diehl et al.
7,054,716	B2	5/2006	McKee et al.
7,055,210	B2	6/2006	Keppler et al.
7,057,120	B2	6/2006	Ma et al.
7,057,643	B2	6/2006	Iida et al.
7,059,012	B2	6/2006	Song et al.
7,065,430	B2	6/2006	Naka et al.
7,066,291	B2	6/2006	Martins et al.
7,069,124	B1	6/2006	Whittaker et al.
7,079,923	B2	7/2006	Abramson et al.
7,085,623	B2	8/2006	Siegers
7,085,624	B2	8/2006	Aldred et al.
7,113,847	B2	9/2006	Chmura et al.
7,133,746	B2	11/2006	Abramson et al.
7,142,198	B2	11/2006	Lee
7,148,458	B2	12/2006	Schell et al.
7,155,308	B2	12/2006	Jones
7,167,775	B2	1/2007	Abramson et al.
7,171,285	B2	1/2007	Kim et al.
7,173,391	B2	2/2007	Jones et al.
7,174,238	B1	2/2007	Zweig
7,188,000	B2	3/2007	Chiappetta et al.
7,193,384	B1	3/2007	Norman et al.
7,196,487	B2	3/2007	Jones et al.
7,201,786	B2	4/2007	Wegelin et al.
7,206,677	B2	4/2007	Hulden
7,211,980	B1	5/2007	Bruemmer et al.
7,225,500	B2	6/2007	Diehl et al.
7,246,405	B2	7/2007	Yan
7,248,951	B2	7/2007	Hulden
7,275,280	B2	10/2007	Haegermarck et al.
7,283,892	B1	10/2007	Boillot et al.
7,288,912	B2	10/2007	Landry et al.
7,318,248	B1	1/2008	Yan et al.
7,320,149	B1	1/2008	Huffman et al.
7,321,807	B2	1/2008	Laski
7,324,870	B2	1/2008	Lee
7,328,196	B2	2/2008	Peters
7,332,890	B2	2/2008	Cohen et al.
7,346,428	B1	3/2008	Huffman et al.
7,352,153	B2	4/2008	Yan
7,359,766	B2	4/2008	Jeon et al.
7,360,277	B2	4/2008	Moshenrose et al.
7,363,108	B2	4/2008	Noda et al.
7,388,879	B2	6/2008	Sabe et al.
7,389,156	B2	6/2008	Ziegler et al.
7,389,166	B2	6/2008	Harwig et al.
7,408,157	B2	8/2008	Yan
7,418,762	B2	9/2008	Arai et al.
7,430,455	B2	9/2008	Casey et al.
7,430,462	B2	9/2008	Chiu et al.
7,441,298	B2	10/2008	Svendsen et al.
7,444,206	B2	10/2008	Abramson et al.
7,448,113	B2	11/2008	Jones et al.
7,459,871	B2	12/2008	Landry et al.
7,467,026	B2	12/2008	Sakagami et al.
7,474,941	B2	1/2009	Kim et al.
7,503,096	B2	3/2009	Lin
7,515,991	B2	4/2009	Egawa et al.
7,539,557	B2	5/2009	Yamauchi
7,555,363	B2	6/2009	Augenbraun et al.
7,557,703	B2	7/2009	Yamada et al.
7,568,259	B2	8/2009	Yan
7,571,511	B2	8/2009	Jones et al.
7,578,020	B2	8/2009	Jaworski et al.
7,600,521	B2	10/2009	Woo
7,603,744	B2	10/2009	Reindle
7,611,583	B2	11/2009	Buckley et al.
7,617,557	B2	11/2009	Reindle
7,620,476	B2	11/2009	Morse et al.
7,636,928	B2	12/2009	Uno
7,636,982	B2	12/2009	Jones et al.
7,647,144	B2	1/2010	Haegermarck
7,650,666	B2	1/2010	Jang
7,660,650	B2	2/2010	Kawagoe et al.
7,663,333	B2	2/2010	Jones et al.
7,693,605	B2	4/2010	Park
7,706,917	B1	4/2010	Chiappetta et al.
7,761,954	B2	7/2010	Ziegler et al.
7,765,635	B2	8/2010	Park
7,784,147	B2	8/2010	Burkholder et al.
7,801,645	B2	9/2010	Taylor et al.
7,805,220	B2	9/2010	Taylor et al.
7,809,944	B2	10/2010	Kawamoto
7,832,048	B2	11/2010	Harwig et al.
7,849,555	B2	12/2010	Hahm et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,853,645	B2	12/2010	Brown et al.
7,860,680	B2	12/2010	Arms et al.
7,920,941	B2	4/2011	Park et al.
7,937,800	B2	5/2011	Yan
7,957,836	B2	6/2011	Myeong et al.
8,087,117	B2	1/2012	Kapoor et al.
2001/0004719	A1	6/2001	Sommer
2001/0013929	A1	8/2001	Torsten
2001/0020200	A1	9/2001	Das et al.
2001/0025183	A1	9/2001	Shahidi
2001/0037163	A1	11/2001	Allard
2001/0043509	A1	11/2001	Green et al.
2001/0045883	A1	11/2001	Holdaway et al.
2001/0047231	A1	11/2001	Peless et al.
2001/0047895	A1	12/2001	De Fazio et al.
2002/0011367	A1	1/2002	Kolesnik
2002/0011813	A1	1/2002	Koselka et al.
2002/0016649	A1	2/2002	Jones
2002/0021219	A1	2/2002	Edwards
2002/0027652	A1	3/2002	Paromtchik et al.
2002/0036779	A1	3/2002	Kiyoi et al.
2002/0081937	A1	6/2002	Yamada et al.
2002/0095239	A1	7/2002	Wallach et al.
2002/0097400	A1	7/2002	Jung et al.
2002/0104963	A1	8/2002	Mancevski
2002/0108209	A1	8/2002	Peterson
2002/0112742	A1	8/2002	Bredo et al.
2002/0113973	A1	8/2002	Ge
2002/0116089	A1	8/2002	Kirkpatrick
2002/0120364	A1	8/2002	Colens
2002/0124343	A1	9/2002	Reed
2002/0153185	A1	10/2002	Song et al.
2002/0156556	A1	10/2002	Ruffner
2002/0159051	A1	10/2002	Guo
2002/0166193	A1	11/2002	Kasper
2002/0169521	A1	11/2002	Goodman et al.
2002/0173877	A1	11/2002	Zweig
2002/0189871	A1	12/2002	Won
2003/0009259	A1	1/2003	Hattori et al.
2003/0015232	A1	1/2003	Nguyen
2003/0019071	A1	1/2003	Field et al.
2003/0023356	A1	1/2003	Keable
2003/0024986	A1	2/2003	Mazz et al.
2003/0025472	A1	2/2003	Jones et al.
2003/0028286	A1	2/2003	Glenn et al.
2003/0030399	A1	2/2003	Jacobs
2003/0058262	A1	3/2003	Sato et al.
2003/0060928	A1	3/2003	Abramson et al.
2003/0067451	A1	4/2003	Tagg et al.
2003/0097875	A1	5/2003	Lentz et al.
2003/0120389	A1	6/2003	Abramson et al.
2003/0124312	A1	7/2003	Autumn
2003/0126352	A1	7/2003	Barrett
2003/0137268	A1	7/2003	Papanikolopoulos et al.
2003/0146384	A1	8/2003	Logsdon et al.
2003/0159232	A1	8/2003	Hekman et al.
2003/0168081	A1	9/2003	Lee et al.
2003/0175138	A1	9/2003	Beenker
2003/0192144	A1	10/2003	Song et al.
2003/0193657	A1	10/2003	Uomori et al.
2003/0216834	A1	11/2003	Allard
2003/0221114	A1	11/2003	Hino et al.
2003/0229421	A1	12/2003	Chmura et al.
2003/0229474	A1	12/2003	Suzuki et al.
2003/0233171	A1	12/2003	Heiligensetzer
2003/0233177	A1	12/2003	Johnson et al.
2003/0233870	A1	12/2003	Mancevski
2003/0233930	A1	12/2003	Ozick
2004/0016077	A1	1/2004	Song et al.
2004/0020000	A1	2/2004	Jones
2004/0030448	A1	2/2004	Solomon
2004/0030449	A1	2/2004	Solomon
2004/0030450	A1	2/2004	Solomon
2004/0030451	A1	2/2004	Solomon
2004/0030570	A1	2/2004	Solomon
2004/0030571	A1	2/2004	Solomon
2004/0031113	A1	2/2004	Wosewick et al.
2004/0049877	A1	3/2004	Jones et al.
2004/0055163	A1	3/2004	McCambridge et al.
2004/0068351	A1	4/2004	Solomon
2004/0068415	A1	4/2004	Solomon
2004/0068416	A1	4/2004	Solomon
2004/0074038	A1	4/2004	Im et al.
2004/0074044	A1	4/2004	Diehl et al.
2004/0076324	A1	4/2004	Burl et al.
2004/0083570	A1	5/2004	Song et al.
2004/0085037	A1	5/2004	Jones et al.
2004/0088079	A1	5/2004	Lavarec et al.
2004/0093122	A1	5/2004	Galibraith
2004/0098167	A1	5/2004	Yi et al.
2004/0111184	A1	6/2004	Chiappetta et al.
2004/0111821	A1	6/2004	Lenkiewicz et al.
2004/0113777	A1	6/2004	Matsuhira et al.
2004/0117064	A1	6/2004	McDonald
2004/0117846	A1	6/2004	Karaoguz et al.
2004/0118998	A1	6/2004	Wingett et al.
2004/0128028	A1	7/2004	Miyamoto et al.
2004/0133316	A1	7/2004	Dean
2004/0134336	A1	7/2004	Solomon
2004/0134337	A1	7/2004	Solomon
2004/0143919	A1	7/2004	Wilder
2004/0148419	A1	7/2004	Chen et al.
2004/0148731	A1	8/2004	Damman et al.
2004/0153212	A1	8/2004	Profio et al.
2004/0156541	A1	8/2004	Jeon et al.
2004/0158357	A1	8/2004	Lee et al.
2004/0181706	A1	9/2004	Chen et al.
2004/0187249	A1	9/2004	Jones et al.
2004/0187457	A1	9/2004	Colens
2004/0196451	A1	10/2004	Aoyama
2004/0200505	A1	10/2004	Taylor et al.
2004/0201361	A1	10/2004	Koh et al.
2004/0204792	A1	10/2004	Taylor et al.
2004/0204804	A1	10/2004	Lee et al.
2004/0210345	A1	10/2004	Noda et al.
2004/0210347	A1	10/2004	Sawada et al.
2004/0211444	A1	10/2004	Taylor et al.
2004/0221790	A1	11/2004	Sinclair et al.
2004/0236468	A1	11/2004	Taylor et al.
2004/0244138	A1	12/2004	Taylor et al.
2004/0255425	A1	12/2004	Arai et al.
2005/0000543	A1	1/2005	Taylor et al.
2005/0010330	A1	1/2005	Abramson et al.
2005/0010331	A1	1/2005	Taylor et al.
2005/0015920	A1	1/2005	Kim et al.
2005/0021181	A1	1/2005	Kim et al.
2005/0028316	A1	2/2005	Thomas et al.
2005/0053912	A1	3/2005	Roth et al.
2005/0055796	A1	3/2005	Wright et al.
2005/0067994	A1	3/2005	Jones et al.
2005/0081782	A1	4/2005	Buckley et al.
2005/0085947	A1	4/2005	Aldred et al.
2005/0091782	A1	5/2005	Gordon et al.
2005/0091786	A1	5/2005	Wright et al.
2005/0137749	A1	6/2005	Jeon et al.
2005/0144751	A1	7/2005	Kegg et al.
2005/0150074	A1	7/2005	Diehl et al.
2005/0150519	A1	7/2005	Keppler et al.
2005/0154795	A1	7/2005	Kuz et al.
2005/0156562	A1	7/2005	Cohen et al.
2005/0162119	A1	7/2005	Landry et al.
2005/0163119	A1	7/2005	Ito et al.
2005/0165508	A1	7/2005	Kanda et al.
2005/0166354	A1	8/2005	Uehigashi
2005/0166355	A1	8/2005	Tani
2005/0172445	A1	8/2005	Diehl et al.
2005/0183229	A1	8/2005	Uehigashi
2005/0183230	A1	8/2005	Uehigashi
2005/0187678	A1	8/2005	Myeong et al.
2005/0192707	A1	9/2005	Park et al.
2005/0204717	A1	9/2005	Colens
2005/0209736	A1	9/2005	Kawagoe
2005/0211880	A1	9/2005	Schell et al.
2005/0212929	A1	9/2005	Schell et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0213082	A1	9/2005	DiBernardo et al.
2005/0213109	A1	9/2005	Schell et al.
2005/0217042	A1	10/2005	Reindle
2005/0218852	A1	10/2005	Landry et al.
2005/0222933	A1	10/2005	Wesby
2005/0229340	A1	10/2005	Sawalski et al.
2005/0229355	A1	10/2005	Crouch et al.
2005/0235451	A1	10/2005	Yan
2005/0251292	A1	11/2005	Casey et al.
2005/0255425	A1	11/2005	Pierson
2005/0258154	A1	11/2005	Blankenship et al.
2005/0273967	A1	12/2005	Taylor et al.
2005/0288819	A1	12/2005	De Guzman
2006/0000050	A1	1/2006	Cipolla et al.
2006/0009879	A1	1/2006	Lynch et al.
2006/0010638	A1	1/2006	Shimizu et al.
2006/0020369	A1	1/2006	Taylor et al.
2006/0020370	A1	1/2006	Abramson
2006/0021168	A1	2/2006	Nishikawa
2006/0025134	A1	2/2006	Cho et al.
2006/0037170	A1	2/2006	Shimizu
2006/0042042	A1	3/2006	Mertes et al.
2006/0044546	A1	3/2006	Lewin et al.
2006/0060216	A1	3/2006	Woo
2006/0061657	A1	3/2006	Rew et al.
2006/0064828	A1	3/2006	Stein et al.
2006/0087273	A1	4/2006	Ko et al.
2006/0089765	A1	4/2006	Pack et al.
2006/0100741	A1	5/2006	Jung
2006/0107894	A1	5/2006	Buckley et al.
2006/0119839	A1	6/2006	Bertin et al.
2006/0143295	A1	6/2006	Costa-Requena et al.
2006/0146776	A1	7/2006	Kim
2006/0150361	A1	7/2006	Aldred et al.
2006/0184293	A1	8/2006	Konandreas et al.
2006/0185690	A1	8/2006	Song et al.
2006/0190133	A1	8/2006	Konandreas et al.
2006/0190134	A1	8/2006	Ziegler et al.
2006/0190146	A1	8/2006	Morse et al.
2006/0196003	A1	9/2006	Song et al.
2006/0200281	A1	9/2006	Ziegler et al.
2006/0220900	A1	10/2006	Ceskutti et al.
2006/0229774	A1	10/2006	Park et al.
2006/0259194	A1	11/2006	Chiu
2006/0259494	A1	11/2006	Watson et al.
2006/0278161	A1	12/2006	Burkholder et al.
2006/0288519	A1	12/2006	Jaworski et al.
2006/0293787	A1	12/2006	Kanda et al.
2006/0293808	A1	12/2006	Qian
2007/0006404	A1	1/2007	Cheng et al.
2007/0016328	A1	1/2007	Ziegler et al.
2007/0017061	A1	1/2007	Yan
2007/0028574	A1	2/2007	Yan
2007/0032904	A1	2/2007	Kawagoe et al.
2007/0042716	A1	2/2007	Goodall et al.
2007/0043459	A1	2/2007	Abbott et al.
2007/0061041	A1	3/2007	Zweig
2007/0061043	A1	3/2007	Ermakov et al.
2007/0114975	A1	5/2007	Cohen et al.
2007/0142964	A1	6/2007	Abramson
2007/0150096	A1	6/2007	Yeh et al.
2007/0156286	A1	7/2007	Yamauchi
2007/0157415	A1	7/2007	Lee et al.
2007/0157420	A1	7/2007	Lee et al.
2007/0179670	A1	8/2007	Chiappetta et al.
2007/0226949	A1	10/2007	Hahm et al.
2007/0234492	A1	10/2007	Svendsen et al.
2007/0244610	A1	10/2007	Ozick et al.
2007/0245511	A1	10/2007	Hahm et al.
2007/0250212	A1	10/2007	Halloran et al.
2007/0261193	A1	11/2007	Gordon et al.
2007/0266508	A1	11/2007	Jones et al.
2008/0007203	A1	1/2008	Cohen et al.
2008/0039974	A1	2/2008	Sandin et al.
2008/0052846	A1	3/2008	Kapoor et al.
2008/0091304	A1	4/2008	Ozick et al.
2008/0109126	A1	5/2008	Sandin et al.
2008/0134458	A1	6/2008	Ziegler et al.
2008/0140255	A1	6/2008	Ziegler et al.
2008/0155768	A1	7/2008	Ziegler et al.
2008/0184518	A1	8/2008	Taylor et al.
2008/0266748	A1	10/2008	Lee
2008/0276407	A1	11/2008	Schnittman et al.
2008/0281470	A1	11/2008	Gilbert et al.
2008/0282494	A1	11/2008	Won et al.
2008/0294288	A1	11/2008	Yamauchi
2008/0302586	A1	12/2008	Yan
2008/0307590	A1	12/2008	Jones et al.
2009/0007366	A1	1/2009	Svendsen et al.
2009/0038089	A1	2/2009	Landry et al.
2009/0048727	A1	2/2009	Hong et al.
2009/0049640	A1	2/2009	Lee et al.
2009/0055022	A1	2/2009	Casey et al.
2009/0102296	A1	4/2009	Greene et al.
2009/0292393	A1	11/2009	Casey et al.
2010/0006028	A1	1/2010	Buckley et al.
2010/0011529	A1	1/2010	Won et al.
2010/0049365	A1	2/2010	Jones et al.
2010/0063628	A1	3/2010	Landry et al.
2010/0082193	A1	4/2010	Chiappetta
2010/0107355	A1	5/2010	Won et al.
2010/0257690	A1	10/2010	Jones et al.
2010/0257691	A1	10/2010	Jones et al.
2010/0263158	A1	10/2010	Jones et al.
2010/0268384	A1	10/2010	Jones et al.
2010/0293742	A1	11/2010	Chung et al.
2010/0312429	A1	12/2010	Jones et al.

FOREIGN PATENT DOCUMENTS

DE	3536907	C2	2/1989
DE	3404202	C2	12/1992
DE	199311014	U1	10/1993
DE	4338841	A1	5/1995
DE	4414683	A1	10/1995
DE	19849978		2/2001
DE	102004038074		6/2005
DE	10357636		7/2005
DE	102004041021	B3	8/2005
DE	102005046813	A1	4/2007
DK	338988	A	12/1988
EP	0265542	A1	5/1988
EP	0281085	A2	9/1988
EP	0286328	A1	10/1988
EP	0294101	A2	12/1988
EP	0352045	A2	1/1990
EP	0433697	A2	6/1991
EP	0437024	A1	7/1991
EP	0554978	A2	8/1993
EP	0615719	A1	9/1994
EP	0792726	A1	9/1997
EP	0930040	A2	7/1999
EP	0845237	B1	4/2000
EP	0861629	B1	9/2001
EP	1228734		8/2002
EP	1331537		7/2003
EP	1380245	A1	1/2004
EP	1380246	A2	1/2004
EP	1018315	B1	11/2004
EP	1553472	A1	7/2005
EP	1557730	A1	7/2005
EP	1642522	A2	4/2006
EP	1836941	A2	9/2007
ES	2238196	A1	8/2005
FR	722755		3/1932
FR	2601443	A1	1/1988
FR	2828589	A1	2/2003
GB	702426		1/1954
GB	2128842	A	5/1984
GB	2225221	A	5/1990
GB	2267360	A	12/1993
GB	2283838	A	5/1995
GB	2284957	A	6/1995
GB	2300082	A	10/1996

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

GB	2344747	A	6/2000
GB	2404330	A	2/2005
GB	2417354	A	2/2006
JP	53021869		2/1978
JP	53110257	A2	9/1978
JP	57064217		4/1982
JP	59005315		1/1984
JP	59033511	U	3/1984
JP	59094005		5/1984
JP	59099308		6/1984
JP	59112311		6/1984
JP	59120124	A	7/1984
JP	59131668	U	9/1984
JP	59164973		9/1984
JP	59184917	A	10/1984
JP	2283343	A2	11/1984
JP	59212924		12/1984
JP	59226909		12/1984
JP	60089213	A	5/1985
JP	60211510	A	10/1985
JP	60259895		12/1985
JP	61023221		1/1986
JP	61097712	A	5/1986
JP	61160366		7/1986
JP	62070709		4/1987
JP	62074018	A	4/1987
JP	62120510	A	6/1987
JP	62154008		7/1987
JP	62164431		7/1987
JP	62263507	A	11/1987
JP	62263508	A	11/1987
JP	62189057	U	12/1987
JP	63079623	A	4/1988
JP	63158032		7/1988
JP	63203483	A	8/1988
JP	63241610	A	10/1988
JP	1118752		8/1989
JP	2-6312	U	1/1990
JP	3051023	A	3/1991
JP	4019586		1/1992
JP	4074285	A	3/1992
JP	4084921	A	3/1992
JP	5023269	A	2/1993
JP	5042076	A	2/1993
JP	5046246		2/1993
JP	5091604	A	4/1993
JP	5095879	A	4/1993
JP	5150827	A	6/1993
JP	5150829	A	6/1993
JP	5054620	U	7/1993
JP	5040519	Y2	10/1993
JP	05257527	A	10/1993
JP	5257533		10/1993
JP	05285861	A	11/1993
JP	5302836	A	11/1993
JP	5312514	A	11/1993
JP	05046239	Y2	12/1993
JP	5341904	A	12/1993
JP	6003251	U	1/1994
JP	6038912		2/1994
JP	6105781	A	4/1994
JP	6137828	A	5/1994
JP	6154143	A	6/1994
JP	6293095	A	10/1994
JP	06327 598	A	11/1994
JP	7047046	A	2/1995
JP	07129239	A	5/1995
JP	7059702	B	6/1995
JP	07222705	A2	8/1995
JP	7270518	A	10/1995
JP	7313417	A	12/1995
JP	8000393	A	1/1996
JP	8016776	A	1/1996
JP	8084696	A	4/1996
JP	8089449	A	4/1996
JP	08089451	A	4/1996
JP	8123548	A	5/1996
JP	8152916	A	6/1996
JP	8263137	A	10/1996
JP	8335112	A	12/1996
JP	8339297	A	12/1996
JP	943901		2/1997
JP	9044240	A	2/1997
JP	9066855	A	3/1997
JP	9145309	A	6/1997
JP	09160644	A	6/1997
JP	09179625	A	7/1997
JP	09185410		7/1997
JP	9192069	A	7/1997
JP	2555263	Y2	8/1997
JP	9204223	A	8/1997
JP	09206258	A	8/1997
JP	09233712	A	9/1997
JP	9265319	A	10/1997
JP	9269807	A	10/1997
JP	9269810	A	10/1997
JP	9319431	A1	12/1997
JP	9319432	A	12/1997
JP	9319434	A	12/1997
JP	9325812	A	12/1997
JP	10055215	A	2/1998
JP	10117973	A	5/1998
JP	10118963	A	5/1998
JP	10165738	A	6/1998
JP	10177414	A	6/1998
JP	10295595	A	11/1998
JP	10314088		12/1998
JP	11015941	A	1/1999
JP	11102220	A	4/1999
JP	11162454	A	6/1999
JP	11174145	A	7/1999
JP	11175149	A	7/1999
JP	11178765	A	7/1999
JP	114008764	A	7/1999
JP	11212642	A	8/1999
JP	11213157	A	8/1999
JP	11282532	A	10/1999
JP	11282533	A	10/1999
JP	11295412	A	10/1999
JP	2000047728		2/2000
JP	2000056006	A	2/2000
JP	2000056831	A	2/2000
JP	2000060782	A	2/2000
JP	2000066722	A	3/2000
JP	2000075925	A	3/2000
JP	2000102499	A	4/2000
JP	2000275321		10/2000
JP	2000279353	A	10/2000
JP	2000353014	A	12/2000
JP	2001022443	A	1/2001
JP	2001067588		3/2001
JP	2001087182		4/2001
JP	2001121455		5/2001
JP	2001125641		5/2001
JP	2001508572	A	6/2001
JP	2001197008	A	7/2001
JP	3197758	B2	8/2001
JP	3201903	B2	8/2001
JP	2001216482	A	8/2001
JP	2001258807		9/2001
JP	2001265437	A	9/2001
JP	2001275908	A	10/2001
JP	2001289939		10/2001
JP	2001306170	A	11/2001
JP	2002073170	A	3/2002
JP	2002078650	A	3/2002
JP	2002204768	A	7/2002
JP	2002204769	A	7/2002
JP	2002247510	A	8/2002
JP	2002532180	A	10/2002
JP	2002323925		11/2002
JP	2002333920	A	11/2002
JP	2002355206		12/2002
JP	2002360471	A	12/2002

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2002360482	A	12/2002
JP	2002366227		12/2002
JP	2002369778		12/2002
JP	2003005296	A	1/2003
JP	2003010076	A	1/2003
JP	2003010088	A	1/2003
JP	2003028528	A	1/2003
JP	2003036116	A	2/2003
JP	2003038401	A	2/2003
JP	2003038402	A	2/2003
JP	2003047579		2/2003
JP	2003061882	A	3/2003
JP	2003084994		3/2003
JP	2003167628	A	6/2003
JP	2003180586	A	7/2003
JP	2003180587	A	7/2003
JP	2003186539	A	7/2003
JP	2003190064	A	7/2003
JP	2003241836	A	8/2003
JP	2003262520	A	9/2003
JP	2003304992	A	10/2003
JP	2003310509	A	11/2003
JP	2003330543	A	11/2003
JP	2004123040	A	4/2004
JP	2004148021	A	5/2004
JP	2004160102	A	6/2004
JP	2004166968	A	6/2004
JP	2004198330	A	7/2004
JP	2004219185		8/2004
JP	2004351234	A	12/2004
JP	2005118354	A	5/2005
JP	2005211360	A	8/2005
JP	2005224265	A	8/2005
JP	2005230032	A	9/2005
JP	2005245916	A	9/2005
JP	2005352707	A	12/2005
JP	2006043071	A	2/2006
JP	2006155274	A	6/2006
JP	2006164223	A	6/2006
JP	2006227673	A	8/2006
JP	2006247467	A	9/2006
JP	2006260161	A	9/2006
JP	2006293662	A	10/2006
JP	2006296697	A	11/2006
JP	2007034866	A	2/2007
JP	2007213180	A	8/2007
JP	2009015611	A	1/2009
JP	2010198552	A	9/2010
WO	9526512	A1	10/1995
WO	9530887	A1	11/1995
WO	9617258	A1	6/1996
WO	9715224	A1	5/1997
WO	9740734	A1	11/1997
WO	9741451	A1	11/1997
WO	9853456	A1	11/1998
WO	9905580	A2	2/1999
WO	9916078	A1	4/1999
WO	9938056	A1	7/1999
WO	9938237	A1	7/1999
WO	9943250	A1	9/1999
WO	0038026	A1	6/2000
WO	0038028	A1	6/2000
WO	0038029	A1	6/2000
WO	0004430	A1	10/2000
WO	0078410	A1	12/2000
WO	0106904	A1	2/2001
WO	0106905	A1	2/2001
WO	0180703	A1	11/2001
WO	0191623	A2	12/2001
WO	0224292	A1	3/2002
WO	0239864	A1	5/2002
WO	0239868	A1	5/2002
WO	02058527	A1	8/2002
WO	02062194	A1	8/2002
WO	02067744	A1	9/2002
WO	02067745	A1	9/2002
WO	02067752	A1	9/2002
WO	02069774	A1	9/2002
WO	02069775	A2	9/2002
WO	02071175	A1	9/2002
WO	02074150	A1	9/2002
WO	02075356	A1	9/2002
WO	02075469	A1	9/2002
WO	02075470	A1	9/2002
WO	02081074	A1	10/2002
WO	02101477	A2	12/2002
WO	03015220	A1	2/2003
WO	03024292	A2	3/2003
WO	03040546	A1	5/2003
WO	03040845	A1	5/2003
WO	03040846	A1	5/2003
WO	03062850	A2	7/2003
WO	03062852	A1	7/2003
WO	2004004533	A1	1/2004
WO	2004004534	A1	1/2004
WO	2004006034	A2	1/2004
WO	2004025947	A2	3/2004
WO	2004058028	A2	7/2004
WO	2004059409	A1	7/2004
WO	2005006935	A1	1/2005
WO	2005037496	A1	4/2005
WO	2005055795	A1	6/2005
WO	2005055796	A2	6/2005
WO	2005076545	A1	8/2005
WO	2005077243	A1	8/2005
WO	2005077244	A1	8/2005
WO	2005081074	A1	9/2005
WO	2005083541	A1	9/2005
WO	2005098475	A1	10/2005
WO	2005098476	A1	10/2005
WO	2006046400	A1	5/2006
WO	2006061133	A1	6/2006
WO	2006068403	A1	6/2006
WO	2006073248	A1	7/2006
WO	2006089307	A2	8/2006
WO	2007028049	A2	3/2007
WO	2007036490	A2	4/2007
WO	2007065033	A2	6/2007
WO	2007137234	A2	11/2007
WO	2002075350	A1	1/2012

OTHER PUBLICATIONS

Ascii, Mar. 25, 2002, http://ascii.jp/elem/000/000/330/330024/, accessed Nov. 2011, 15 pages (with English translation).

Barker, "Navigation by the Stars—Ben Barker 4th Year Project," Nov. 2004, 20 pages.

Becker et al., "Reliable Navigation Using Landmarks," IEEE International Conference on Robotics and Automation, 0-7803-1965-6, pp. 401-406, 1995.

Benayad-Cherif et al., "Mobile Robot Navigation Sensors," SPIE vol. 1831 Mobile Robots, VII, pp. 378-387, 1992.

Betke et al. "Mobile robot localization using landmarks," Proceedings of the IEEE/RSJ/GI International Conference on Intelligent Robots and Systems '94 Advanced Robotic Systems and the Real World' (IROS '94), Accessed via IEEE Xplore, 1994, 8 pages.

Bison et al., "Using a structured beacon for cooperative position estimation," *Robotics and Autonomous Systems*, 29(1):33-40, Oct. 1999.

Blaasvaer et al., "AMOR—An Autonomous Mobile Robot Navigation System," Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics, pp. 2266-2271, 1994.

Borges et al., "Optimal Mobile Robot Pose Estimation Using Geometrical Maps," IEEE Transactions on Robotics and Automation, 18(1): 87-94, Feb. 2002.

Braunstingl et al., "Fuzzy Logic Wall Following of a Mobile Robot Based on the Concept of General Perception," ICAR '95, 7th International Conference on Advanced Robotics, Sant Feliu De Guixols, Spain, pp. 367-376, Sep. 1995.

Bulusu et al., "Self Configuring Localization systems: Design and Experimental Evaluation,"*ACM Transactions on Embedded Computing Systems*, 3(1):24-60, 2003.

(56) **References Cited**

OTHER PUBLICATIONS

Caccia et al., "Bottom-Following for Remotely Operated Vehicles,"5th IFAC Conference, Alaborg, Denmark, pp. 245-250, Aug. 2000.
Certified U.S. Appl. No. 60/605,066 as provided to WIPO in PCT/US2005/030422, corresponding to U.S. Appl. No. 11/574,290, U.S. publication 2008/0184518, filed Aug. 27, 2004.
Certified U.S. Appl. No. 60/605,181 as provided to WIPO in PCT/US2005/030422, corresponding to U.S. Appl. No. 11/574,290, U.S. publication 2008/0184518, filed Aug. 27, 2004.
Chae et al., "StarLITE: A new artificial landmark for the navigation of mobile robots," http://www.irc.atr.jp/jk-nrs2005/pdf/Starlite.pdf, 4 pages, 2005.
Chamberlin et al., "Team 1: Robot Locator Beacon System, " NASA Goddard SFC, Design Proposal, 15 pages, Feb. 2006.
Champy, "Physical management of IT assets in Data Centers using RFID technologies," RFID 2005 University, Oct. 12-14, 2005 , 19 pages.
Chin, "Joystick Control for Tiny OS Robot," http://www.eecs.berkeley.edu/Programs/ugrad/superb/papers2002/chiri.pdf. 12 pages, Aug. 2002.
Christensen et al. "Theoretical Methods for Planning and Control in Mobile Robotics," 1997 First International Conference on Knowledge-Based Intelligent Electronic Systems, Adelaide, Australia, pp. 81-86, May 1997.
CleanMate 365, Intelligent Automatic Vacuum Cleaner, Model No. QQ-1, User Manual www.metapo.com/support/user_manual.pdf, Dec. 2005, 11 pages.
Clerentin et al., "A localization method based on two omnidirectional perception systems cooperation," *Proc of IEEE International Conference on Robotics & Automation*, San Francisco, CA vol. 2, pp. 1219-1224, Apr. 2000.
Corke, "High Performance Visual serving for robots end-point control," SPIE vol. 2056, Intelligent Robots and Computer Vision, 1993, 10 pages.
Cozman et al., "Robot Localization using a Computer Vision Sextant," IEEE International Midwest Conference on Robotics and Automation, pp. 106-111, 1995.
D'Orazio et al., "Model based Vision System for mobile robot position estimation", *SPIE*, vol. 2058 Mobile Robots VIII, pp. 38-49, 1992.
De Bakker et al., "Smart PSD- array for sheet of light range imaging", Proc. of *SPIE*, vol. 3965, pp. 1-12, May 2000.
Denning Roboscrub image (1989), 1 page.
Desaulniers et al., "An Efficient Algorithm to find a shortest path for a car-like Robot," *IEEE Transactions on robotics and Automation* , 11(6):819-828, Dec. 1995.
Dorfmüller-Ulhaas, "Optical Tracking From User Motion to 3D Interaction," http://www.cg.tuwien.ac.at/research/publications/2002/Dorfmueller-Ulhaas-thesis, 182 pages, 2002.
Dorsch et al., "Laser Triangulation: Fundamental uncertainty in distance measurement," *Applied Optics*, 33(7):1306-1314, Mar. 1994.
Doty et al., "Sweep Strategies for a Sensory-Driven, Behavior-Based Vacuum Cleaning Agent," AAAI 1993 Fall Symposium Series, Instantiating Real-World Agents, pp. 1-6, Oct. 22-24, 1993.
Dudek et al., "Localizing a Robot with Minimum Travel" *Proceedings of the sixth annual ACM-SIAM symposium on Discrete Algorithms*, 27(2):583-604, Apr. 1998.
Dulimarta et al., "Mobile Robot Localization in Indoor Environment", *Pattern Recognition*, 30(1):99-111, 1997.
Dyson's Robot Vacuum Cleaner—the DC06, May 2004, Retrieved from the Internet: URL< http://www.gizmag.com/go/1282/>. Accessed Nov. 2011, 3 pages.
EBay, "Roomba Timer -> Timed Cleaning—Floorvac Robotic Vacuum," Retrieved from the Internet: URL Cgi.ebay.com/ws/eBayISAPI.dll?viewitem&category=43526&item=4375198387 &rd=1, 5 pages, Apr. 2005.
Electrolux Trilobite, "Time to enjoy life," Retrieved from the Internet: URL<http://www.robocon.co.kr/trilobite/Presentation_Trilobite_Kor_030104.ppt, 26 pages, accessed Dec. 2011.
Electrolux Trilobite, Jan. 12, 2001, http://www.electroluxui.com:8080/2002%5C822%5C833102EN.pdf, accessed Jul. 2, 2012, 10 pages.
Electrolux, "Designed for the well-lived home," Retrieved from the Internet: URL<http://www.electroluxusa.com/node57.as[?currentURL=node142.asp%3F >. Accessed Mar. 2005, 2 pages.
Eren et al., "Accuracy in position estimation of mobile robots based on coded infrared signal transmission," Proceedings: Integrating Intelligent Instrumentation and Control, Instrumentation and Measurement Technology Conference, 1995, IMTC/95. pp. 548-551, 1995.
Eren et al., "Operation of Mobile Robots in a Structured Infrared Environment," Proceedings 'Sensing, Processing, Networking', IEEE Instrumentation and Measurement Technology Conference, 1997 (IMTC/97), Ottawa, Canada vol. 1, pp. 20-25, May 1997.
Euroflex Intelligente Monstre, (English excerpt only), 2006, 15 pages.
Euroflex, Jan. 2006, Retrieved from the Internet: URL< http://www.euroflex.tv/novita_dett.php?id=15, accessed Nov. 2011, 1 page.
eVac Robotic Vacuum S1727 Instruction Manual, Sharper Image Corp, Copyright 2004, 16 pages.
Everyday Robots, "Everyday Robots: Reviews, Discussion and News for Consumers," Aug. 2004, Retrieved from the Internet: URL< www.everydayrobots.com/index.php?option=content &task=view&id=9> (Sep. 2012), 4 pages.
Evolution Robotics, "NorthStar—Low-cost Indoor Localiztion—How it Works," E Evolution Robotics , 2 pages, 2005.
Facchinetti Claudio et al., "Self-Positioning Robot Navigation Using Ceiling Images Sequences," ACCV '95, 5 pages, Dec. 1995.
Facchinetti Claudio et al., "Using and Learning Vision-Based Self-Positioning for Autonomous Robot Navigation," ICARCV '94, vol. 3, pp. 1694-1698, 1994.
Facts on Trilobite, webpage, Retrieved from the Internet: URL< http://trilobiteelectroluxse/presskit_en/mode111335asp?print=yes &pressID=>. 2 pages, accessed Dec. 2003.
Fairfield et al., "Mobile Robot Localization with Sparse Landmarks," SPIE vol. 4573, pp. 148-155, 2002.
Favre-Bulle, "Efficient tracking of 3D—Robot Position by Dynamic Triangulation," IEEE Instrumentation and Measurement Technology Conference IMTC 98 Session on Instrumentation and Measurement in Robotics, vol. 1, pp. 446-449, May 1998.
Fayman, "Exploiting Process Integration and Composition in the context of Active Vision," IEEE Transactions on Systems, Man, and Cybernetics—Part C: Application and reviews, vol. 29, No. 1, pp. 73-86, Feb. 1999.
Floorbot GE Plastics—IMAGE, available at http://www.fuseid.com/, 1989-1990, Accessed Sep. 2012, 1 page.
Floorbotics, VR8 Floor Cleaning Robot, Product Description for Manufacturing, URL: <http://www.consensus.sem.au/SoftwareAwards/CSAarchive/CSA2004/CSAart04/FloorBot/F>. Mar. 2004, 11 pages.
Franz et al., "Biomimetric robot navigation", Robotics and Autonomous Systems, vol. 30 pp. 133-153, 2000.
Friendly Robotics, "Friendly Robotics—Friendly Vac, Robotic Vacuum Cleaner," Retrieved from the Internet: URL< www.friendlyrobotics.com/vac.htm > 5 pages, Apr. 2005.
Friendly Robotics, Retrieved from the Internet: URL<http://www.robotsandrelax.com/PDFs/RV400Manual.pdf>. 18 pages, accessed Dec. 2011.
Fuentes et al., "Mobile Robotics 1994," University of Rochester. Computer Science Department, TR 588, 44 pages, Dec. 1994.
Fukuda et al., "Navigation System based on Ceiling Landmark Recognition for Autonomous mobile robot," 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems 95. 'Human Robot Interaction and Cooperative Robots', Pittsburgh, PA, pp. 1466-1471, Aug. 1995.
Gat, "Robust Low-Computation Sensor-driven Control for Task-Directed Navigation," Proc of IEEE International Conference on Robotics and Automation , Sacramento, CA pp. 2484-2489, Apr. 1991.
Gionis, "A hand-held optical surface scanner for environmental Modeling and Virtual Reality," Virtual Reality World, 16 pages, 1996.

(56) **References Cited**

OTHER PUBLICATIONS

Goncalves et al., "A Visual Front-End for Simultaneous Localization and Mapping", Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, pp. 44-49, Apr. 2005.
Gregg et al., "Autonomous Lawn Care Applications," 2006 Florida Conference on Recent Advances in Robotics, Miami, Florida, May 25-26, 2006, Florida International University, 5 pages.
Grumet, "Robots Clean House," Popular Mechanics, Nov. 2003, 3 pages.
Hamamatsu "SI PIN Diode S5980, S5981 S5870—Multi-element photodiodes for surface mounting," Hamatsu Photonics, 2 pages, Apr. 2004.
Haralick et al. "Pose Estimation from Corresponding Point Data", *IEEE Transactions on Systems, Man, and Cybernetics*, 19(6):1426-1446, Nov. 1989.
Hausler, "About the Scaling Behaviour of Optical Range Sensors," Fringe '97, Proceedings of the 3rd International Workshop on Automatic Processing of Fringe Patterns, Bremen, Germany, pp. 147-155, Sep. 1997.
Hitachi, accessed at http://www.hitachi.co.jp/New/cnews/hi_030529_hi_030529.pdf , May 29, 2003, 15 pages (with English translation).
Hitachi: News release: "The home cleaning robot of the autonomous movement type (experimental machine)," Retrieved from the Internet: URL< www.i4u.com./japanreleases/hitachirobot.htm>. 5 pages, Mar. 2005.
Hoag et al., "Navigation and Guidance in interstellar space," ACTA Astronautica, vol. 2, pp. 513-533 , Feb. 1975.
Home Robot—UBOT; Microbotusa.com, retrieved from the WWW at www.microrobotusa.com, accessed Dec. 2, 2008, 2 pages.
Huntsberger et al., "CAMPOUT: A Control Architecture for Tightly Coupled Coordination of Multirobot Systems for Planetary Surface Exploration," *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, 33(5):550-559, Sep. 2003.
Iirobotics.com, "Samsung Unveils Its Multifunction Robot Vacuum," Retrieved from the Internet: URL<.www.iirobotics.com/webpages/hotstuff.php?ubre=111>. 3 pages, Mar. 2005.
InMach "Intelligent Machines," Retrieved from the Internet: URL<www.inmach.de/inside.html>. 1 page , Nov. 2008.
Innovation First, "2004 EDU Robot Controller Reference Guide," Retrieved from the Internet: URL<http://www.ifirobotics.com>. 13 pages, Mar. 2004.
IT media, Retrieved from the Internet: URL<http://www.itmedia.co.jp/news/0111/16/robofesta_m.html>. Accessed Nov. 1, 2011, 8 pages (with English translation).
It's eye, Retrieved from the Internet: URL< www.hitachi.co.jp/rd/pdf/topics/hitac2003_10.pdf>. 2003, 11 pages (with English translation).
Jarosiewicz et al., "Final Report—Lucid," University of Florida, Departmetn of Electrical and Computer Engineering, EEL 5666—Intelligent Machine Design Laboratory, 50 pages, Aug. 1999.
Jensfelt et al., "Active Global Localization for a mobile robot using multiple hypothesis tracking," *IEEE Transactions on Robots and Automation*, 17(5): 748-760, Oct. 2001.
Jeong et al., "An intelligent map-building system for indoor mobile robot using low cost photo sensors,"*SPIE*, vol. 6042, 6 pages, 2005.
Kahney, "Robot Vacs are in the House," Retrieved from the Internet: URL<www.wired.com/news/technology/o,1282,59237,00.html>. 6 pages, Jun. 2003.
Karcher "Karcher RoboCleaner RC 3000," Retrieved from the Internet: URL<www.robocleaner.de/english/screen3.html>. 4 pages, Dec. 2003.
Karcher RC 3000 Cleaning Robot-user manual Manufacturer: Alfred-Karcher GmbH & Co, Cleaning Systems, Alfred Karcher-Str 28-40, PO Box 160, D-71349 Winnenden, Germany, Dec. 2002, 8 pages.
Karcher RC3000 RoboCleaner,—IMAGE, Accessed at <http://www.karcher.de/versions/int/assets/video/2_4_robo_en.swf>. Accessed Sep. 2009, 1 page.
Karcher USA, RC3000 Robotic Cleaner, website: http://www.karcher-usa.com/showproducts.php?op=view prod&param1=143&param2=&param3=, 3 pages, accessed Mar. 2005.
Karcher, "Product Manual Download Karch", available at www.karcher.com, 16 pages, 2004.
Karlsson et al, "Core Technologies for service Robotics," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 3, pp. 2979-2984, Sep. 2004.
Karlsson et al., The vSLAM Algorithm for Robust Localization and Mapping, Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, pp. 24-29, Apr. 2005.
King and Weiman, "HelpmateTM Autonomous Mobile Robots Navigation Systems," SPIE vol. 1388 Mobile Robots, pp. 190-198, 1990.
Kleinberg, The Localization Problem for Mobile Robots, Laboratory for Computer Science, Massachusetts Institute of Technology, 1994 IEEE, pp. 521-531, 1994.
Knights, et al., "Localization and Identification of Visual Landmarks," *Journal of Computing Sciences in Colleges*, 16(4):312-313, May 2001.
Kolodko et al., "Experimental System for Real-Time Motion Estimation," Proceedings of the 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003), pp. 981-986, 2003.
Komoriya et al., "Planning of Landmark Measurement for the Navigation of a Mobile Robot," Proceedings of the 1992 IEEE/RSJ International Cofnerence on Intelligent Robots and Systems, Raleigh, NC pp. 1476-1481, Jul. 1992.
KOOLVAC Robotic Vacuum Cleaner Owner's Manual, Koolatron, 2004, 13 pages.
Krotkov et al., "Digital Sextant," Downloaded from the internet at: http://www.cs.cmu.edu/~epk/ , 1 page, 1995.
Krupa et al., "Autonomous 3-D Positioning of Surgical Instruments in Robotized Laparoscopic Surgery Using Visual Servoin," *IEEE Transactions on Robotics and Automation*, 19(5):842-853, Oct. 2003.
Kuhl et al., "Self Localization in Environments using Visual Angles," VRCAI '04 Proceedings of the 2004 ACM SIGGRAPH international conference on Virtual Reality continuum and its applications in industry, pp. 472-475, 2004.
Kurs et al, Wireless Power transfer via Strongly Coupled Magnetic Resonances, Downloaded from www.sciencemag.org, Aug. 2007, 5 pages.
Kurth, "Range-Only Robot Localization and SLAM with Radio", http://www.ri.cmu.edu/pub_files/pub4/kurth_derek_2004_1/kurth_derek_2004_1.pdf. 60 pages, May 2004, accessed Jul. 27, 2012.
Kwon et al., "Table Recognition through Range-based Candidate Generation and Vision based Candidate Evaluation," ICAR 2007, The 13th International Conference on Advanced Robotics Aug. 21-24, 2007, Jeju, Korea, pp. 918-923, 2007.
Lambrinos et al., "A mobile robot employing insect strategies for navigation," Retrieved from the Internat: URL<http://www8.cs.umu.se/kurser/TDBD17/VT04/dl/Assignment%20Papers/lambrinos-RAS-2000.pdf>. 38 pages, Feb. 1999.
Lang et al., "Visual Measurement of Orientation Using Ceiling Features", 1994 IEEE, pp. 552-555, 1994.
Lapin, "Adaptive position estimation for an automated guided vehicle," *SPIE*, vol. 1831 Mobile Robots VII, pp. 82-94, 1992.
LaValle et al., "Robot Motion Planning in a Changing, Partially Predictable Environment," 1994 IEEE International Symposium on Intelligent Control, Columbus, OH, pp. 261-266, Aug. 1994.
Lee et al., "Development of Indoor Navigation system for Humanoid Robot Using Multi-sensors Integration", ION NTM, San Diego, CA pp. 798-805, Jan. 2007.
Lee et al., "Localization of a Mobile Robot Using the Image of a Moving Object," *IEEE Transaction on Industrial Electronics*, 50(3):612-619, Jun. 2003.
Leonard et al., "Mobile Robot Localization by tracking Geometric Beacons," *IEEE Transaction on Robotics and Automation*, 7(3):376-382, Jun. 1991.

(56) **References Cited**

OTHER PUBLICATIONS

Li et al. "Robust Statistical Methods for Securing Wireless Localization in Sensor Networks," Information Processing in Sensor Networks, 2005, Fourth International Symposium on, pp. 91-98, Apr. 2005.
Li et al., "Making a Local Map of Indoor Environments by Swiveling a Camera and a Sonar," Proceedings of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 954-959, 1999.
Lin et al., "Mobile Robot Navigation Using Artificial Landmarks," *Journal of robotics System*, 14(2): 93-106, 1997.
Linde, Dissertation—"On Aspects of Indoor Localization," Available at: https://eldorado.tu-dortmund.de/handle/2003/22854, University of Dortmund, 138 pages, Aug. 2006.
Lumelsky et al., "An Algorithm for Maze Searching with Azimuth Input", 1994 IEEE International Conference on Robotics and Automation, San Diego, CA vol. 1, pp. 111-116, 1994.
Luo et al., "Real-time Area-Covering Operations with Obstacle Avoidance for Cleaning Robots," IEEE, pp. 2359-2364, 2002.
Ma, Thesis—"Documentation on Northstar," California Institute of Technology, 14 pages, May 2006.
Madsen et al., "Optimal landmark selection for triangulation of robot position," Journal of Robotics and Autonomous Systems, vol. 13 pp. 277-292, 1998.
Malik et al., "Virtual Prototyping for Conceptual Design of a Tracked Mobile Robot," Electrical and Computer Engineering, Canadian Conference on, IEEE, PI. pp. 2349-2352, May 2006.
Martishevcky, "The Accuracy of point light target coordinate determination by dissectoral tracking system", SPIE vol. 2591, pp. 25-30, Oct. 23, 2005.
Maschinemarkt Würzburg 105, No. 27, pp. 3, 30, Jul. 5, 1999 (with English translation).
Matsumura Camera Online Shop: Retrieved from the Internet: URL< http://www.rakuten.co.jp/matsucame/587179/711512/>. Accessed Nov. 2011, 15 pages (with English translation).
Matsutek Enterprises Co. Ltd, "Automatic Rechargeable Vacuum Cleaner," http://matsutek.manufacturer.globalsources.com/si/6008801427181/pdtl/Home-vacuum/10 . . . , Apr. 2007, 3 pages.
McGillem et al., "Infra-red Lacation System for Navigation and Autonomous Vehicles," 1988 IEEE International Conference on Robotics and Automation, vol. 2, pp. 1236-1238, Apr. 1988.
McGillem,et al. "A Beacon Navigation Method for Autonomous Vehicles," *IEEE Transactions on Vehicular Technology*, 38(3):132-139, Aug. 1989.
McLurkin "Stupid Robot Tricks: A Behavior-based Distributed Algorithm Library for Programming Swarms of Robots," Paper submitted for requirements of BSEE at MIT, May 2004, 127 pages.
McLurkin, "The Ants: A community of Microrobots," Paper submitted for requirements of BSEE at MIT, May 1995, 60 pages.
Michelson, "Autonomous navigation," McGraw-Hill—Access Science, Encyclopedia of Science and Technology Online, 2007, 4 pages.
Miro et al., "Towards Vision Based Navigation in Large Indoor Environments," Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, China, pp. 2096-2102, Oct. 2006.
MobileMag, "Samsung Unveils High-tech Robot Vacuum Cleaner," Retrieved from the Internet: URL<http://www.mobilemag.com/content/100/102/C2261/>. 4 pages, Mar. 2005.
Monteiro et al., "Visual Servoing for Fast Mobile Robot: Adaptive Estimation of Kinematic Parameters," Proceedings of the IECON '93., International Conference on Industrial Electronics, Maui, HI, pp. 1588-1593, Nov. 1993.
Moore et al., "A simple Map-bases Localization strategy using range measurements," *SPIE*, vol. 5804 pp. 612-620, 2005.
Morland,"Autonomous Lawnmower Control", Downloaded from the internet at: http://cns.bu.edu/~cjmorlan/robotics/lawnmower/report.pdf, 10 pages, Jul. 2002.
Munich et al., "ERSP: A Software Platform and Architecture for the Service Robotics Industry," Intelligent Robots and Systems, 2005. (IROS 2005), pp. 460-467, Aug. 2005.
Munich et al., "SIFT-ing Through Features with ViPR", IEEE Robotics & Automation Magazine, pp. 72-77, Sep. 2006.
Nam et al., "Real-Time Dynamic Visual Tracking Using PSD Sensors and extended Trapezoidal Motion Planning", Applied Intelligence 10, pp. 53-70, 1999.
Nitu et al., "Optomechatronic System for Position Detection of a Mobile Mini-Robot," *IEEE Ttransactions on Industrial Electronics*, 52(4):969-973, Aug. 2005.
On Robo, "Robot Reviews Samsung Robot Vacuum (VC-RP3OW)," Retrieved from the Internet: URL <www.onrobo.com/reviews/AT_Home/vacuum_cleaners/on00vcrb30rosam/index.htm>. 2 pages, 2005.
OnRobo "Samsung Unveils Its Multifunction Robot Vacuum," Retrieved from the Internet: URL <www.onrobo.com/enews/0210/samsung_vacuum.shtml>. 3 pages, Mar. 2005.
Pages et al., "A camera-projector system for robot positioning by visual serving," Proceedings of the 2006 Conference on Computer Vision and Pattern Recognition Workshop (CVPRW06), 8 pages, Jun. 2006.
Pages et al., "Optimizing Plane-to-Plane Positioning Tasks by Image-Based Visual Servoing and Structured Light," *IEEE Transactions on Robotics*, 22(5):1000-1010, Oct. 2006.
Pages et al., "Robust decoupled visual servoing based on structured light," 2005 IEEE/RSJ, Int. Conf. on Intelligent Robots and Systems, pp. 2676-2681, 2005.
Park et al., "A Neural Network Based Real-Time Robot Tracking Controller Using Position Sensitive Detectors," IEEE World Congress on Computational Intelligence., 1994 IEEE International Conference on Neutral Networks, Orlando, Florida pp. 2754-2758, Jun./Jul. 1994.
Park et al., "Dynamic Visual Servo Control of Robot Manipulators using Neutral Networks," *The Korean Institute Telematics and Electronics*, 29-B(10):771-779, Oct. 1992.
Paromtchik "Toward Optical Guidance of Mobile Robots," Proceedings of the Fourth World Multiconference on Systemics, Cybermetics and Informatics, Orlando, FL, USA, Jul. 23, 2000, vol. IX, pp. 44-49, available at http://emotion.inrialpes.fr/~paromt/infos/papers/paromtchik:asama:sci:2000.ps.gz, accessed Jul. 3, 2012, 6 pages.
Paromtchik et al., "Optical Guidance System for Multiple mobile Robots," Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation, vol. 3, pp. 2935-2940, May 2001.
Penna et al., "Models for Map Building and Navigation", IEEE Transactions on Systems. Man. and Cybernetics., 23(5):1276-1301, Sep./Oct. 1993.
Pirjanian et al. "Representation and Execution of Plan Sequences for Multi-Agent Systems," Proceedings of the 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems, Maui, Hawaii, pp. 2117-2123, Oct. 2001.
Pirjanian et al., "A decision-theoretic approach to fuzzy behavior coordination", 1999 IEEE International Symposium on Computational Intelligence in Robotics and Automation, 1999. CIRA '99., Monterey, CA, pp. 101-106, Nov. 1999.
Pirjanian et al., "Distributed Control for a Modular, Reconfigurable Cliff Robot," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C. pp. 4083-4088, May 2002.
Pirjanian et al., "Improving Task Reliability by Fusion of Redundant Homogeneous Modules Using Voting Schemes," Proceedings of the 1997 IEEE International Conference on Robotics and Automation, Albuquerque, NM, pp. 425-430, Apr. 1997.
Pirjanian et al., "Multi-Robot Target Acquisition using Multiple Objective Behavior Coordination," Proceedings of the 2000 IEEE International Conference on Robotics & Automation, San Francisco, CA, pp. 2696-2702, Apr. 2000.
Pirjanian, "Challenges for Standards for consumer Robotics," IEEE Workshop on Advanced Robotics and its Social impacts, pp. 260-264, Jun. 2005.
Pirjanian, "Reliable Reaction," Proceedings of the 1996 IEEE/SICE/RSJ International Conference on Multisensor Fusion and Integration for Intelligent Systems, pp. 158-165, 1996.

(56) **References Cited**

OTHER PUBLICATIONS

Prassler et al., "A Short History of Cleaning Robots," Autonomous Robots 9, 211-226, 2000, 16 pages.
Put Your Roomba . . . On, Automatic webpages: http://www.acomputeredge.com/roomba, 5 pages, accessed Apr. 2005.
Remazeilles et al., "Image based robot navigation in 3D environments," Proc. of *SPIE*, vol. 6052, pp. 1-14, Dec. 2005.
Rives et al., "Visual servoing based on ellipse features," *SPIE*, vol. 2056 Intelligent Robots and Computer Vision pp. 356-367, 1993.
Roboking—not just a vacuum cleaner, a robot!, Jan. 21, 2004, infocom.uz/2004/01/21/robokingne-prosto-pyilesos-a-robot/, accessed Oct. 10, 2011, 5 pages.
RoboMaid Sweeps Your Floors so You Won't Have to, the Official Site, website: Retrieved from the Internet: URL<http://therobomaid.com>. 2 pages, accessed Mar. 2005.
Robot Buying Guide, "LG announces the first robotic vacuum cleaner for Korea," Retrieved from the Internet: URL<http://robotbg.com/news/2003/04/22/1g_announces_the_first_robotic_vacu>. 1 page, Apr. 2003.
Robotics World, "A Clean Sweep," 5 pages, Jan. 2001.
Ronnback, "On Methods for Assistive Mobile Robots," Retrieved from the Internet: URL<http://www.openthesis.org/documents/methods-assistive-mobile-robots-595019.html>. 218 pages, Jan. 2006.
Roth-Tabak et al., "Environment Model for mobile Robots Indoor Navigation," *SPIE*, vol. 1388 Mobile Robots, pp. 453-463, 1990.
Sahin et al., "Development of a Visual Object Localization Module for Mobile Robots," 1999 Third European Workshop on Advanced Mobile Robots, (Eurobot '99), pp. 65-72, 1999.
Salomon et al., "Low-Cost Optical Indoor Localization system for Mobile Objects without Image Processing," IEEE Conference on Emerging Technologies and Factory Automation, 2006. (ETFA '06), pp. 629-632, Sep. 2006.
Sato, "Range Imaging Based on Moving Pattern Light and Spatio-Temporal Matched Filter," Proceedings International Conference on Image Processing, vol. 1., Lausanne, Switzerland, pp. 33-36, Sep. 1996.
Schenker et al., "Lightweight rovers for Mars science exploration and sample return," Intelligent Robots and Computer Vision XVI, *SPIE* Proc. 3208, pp. 24-36, 1997.
Schlemmer, "Electrolux Trilobite Robotic Vacuum," Retrieved from the Internet: URL< www.hammacher.com/publish/71579.asp?promo=xsells>. 3 pages, Mar. 2005.
Schofield, "Neither Master nor slave-A Practical Study in the Development and Employment of Cleaning Robots, Emerging Technologies and Factory Automation," 1999 Proceedings ETFA '99 1999 7th IEEE International Conference on Barcelona, Spain, pp. 1427-1434, Oct. 1999.
Shimoga et al., "Touch and Force Reflection for Telepresence Surgery," Engineering in Medicine and Biology Society, 1994. Engineering Advances: New Opportunities for Biomedical Engineers. Proceedings of the 16th Annual International Conference of the IEEE, Baltimore, MD, pp. 1049-1050, 1994.
Sim et al, "Learning Visual Landmarks for Pose Estimation," IEEE International Conference on Robotics and Automation, vol. 3, Detroit, MI, pp. 1972-1978, May 1999.
Sobh et al., "Case Studies in Web-Controlled Devices and Remote Manipulation," Automation Congress, 2002 Proceedings of the 5th Biannual World, pp. 435-440, Dec. 2002.
Special Reports, "Vacuum Cleaner Robot Operated in Conjunction with 3G Celluar Phone," 59(9): 3 pages, Retrieved from the Internet: URL<http://www.toshiba.co.jp/tech/review/2004/09/59_0>. 2004.
Stella et al., "Self-Location for Indoor Navigation of Autonomous Vehicles," Part of the SPIE conference on Enhanced and Synthetic Vision SPIE vol. 3364, pp. 298-302, 1998.
Summet, "Tracking Locations of Moving Hand-held Displays Using Projected Light," Pervasive 2005, LNCS 3468, pp. 37-46, 2005.
Svedman et al., "Structure from Stereo Vision using Unsynchronized Cameras for Simultaneous Localization and Mapping," 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 2993-2998, 2005.
SVET Computers—New Technologies—Robot Vacuum Cleaner, Oct. 1999, available at http://www.sk.rs/1999/10/sknt01.html, 1 page, accessed Nov. 1, 2011.
Taipei Times, "Robotic vacuum by Matsuhita about to undergo testing," Retrieved from the Internet: URL<http://www.taipeitimes.com/News/worldbiz/archives/2002/03/26/0000129338>. accessed Mar. 2002, 2 pages.
Takio et al., "Real-Time Position and Pose Tracking Method of Moving Object Using Visual Servo System," 47th IEEE International Symposium on Circuits and Systems, pp. 167-170, 2004.
"Tech-on!," Retrieved from the Internet: URL http://techon.nikkeibp.co.jp/members/01db/200203/1006501/, accessed Nov. 2011, 7 pages (with English translation).
Teller, "Pervasive pose awareness for people, Objects and Robots," http://www.ai.mit.edu/lab/dangerous-ideas/Spring2003/teller-pose.pdf, 6 pages, Apr. 2003.
Terada et al., "An Acquisition of the Relation between Vision and Action using Self-Organizing Map and Reinforcement Learning," 1998 Second International Conference on Knowledge-Based Intelligent Electronic Systems, Adelaide, Australia, pp. 429-434, Apr. 1998.
The Sharper Image, eVac Robotic Vacuum—Product Details, www.sharperiamge.com/us/en/templates/products/pipmorework1printable.jhtml, 1 page, Accessed Mar. 2005.
TheRobotStore.com, "Friendly Robotics Robotic Vacuum RV400—The Robot Store," www.therobotstore.com/s.nl/sc.9/category.-109/it.A/id.43/.f, 1 page, Apr. 2005.
Thrun, Sebastian, "Learning Occupancy Grid Maps With Forward Sensor Models," Autonomous Robots 15, 28 pages, Sep. 1, 2003.
TotalVac.com, RC3000 RoboCleaner website, 2004, Accessed at http://ww.totalvac.com/robot_vacuum.htm (Mar. 2005), 3 pages.
Trebi-Ollennu et al., "Mars Rover Pair Cooperatively Transporting a Long Payload," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C. pp. 3136-3141, May 2002.
Tribelhorn et al., "Evaluating the Roomba: A low-cost, ubiquitous platform for robotics research and education," *IEEE*, pp. 1393-1399, 2007.
Tse et al., "Design of a Navigation System for a Household Mobile Robot Using Neural Networks," Department of Manufacturing Engg. & Engg. Management, City University of Hong Kong, pp. 2151-2156, 1998.
UAMA (Asia) Industrial Co., Ltd., "RobotFamily," 2005, 1 page.
UBOT, cleaning robot capable of wiping with a wet duster, Retrieved from the Internet: URL<http://us.aving.net/news/view.php?articleId=23031>. 4 pages, accessed Nov. 2011.
Watanabe et al., "Position Estimation of Mobile Robots With Internal and External Sensors Using Uncertainty Evolution Technique," 1990 IEEE International Conference on Robotics and Automation, Cincinnati, OH, pp. 2011-2016, May 1990.
Watts, "Robot, boldly goes where no man can," The Times—pp. 20, Jan. 1985.
Wijk et al., "Triangulation-Based Fusion of Sonar Data with Application in Robot Pose Tracking," *IEEE Transactions on Robotics and Automation*, 16(6):740-752, Dec. 2000.
Wolf et al., "Robust Vision-Based Localization by Combining an Image-Retrieval System with Monte Carol Localization,", *IEEE Transactions on Robotics*, 21(2):208-216, Apr. 2005.
Wolf et al., "Robust Vision-based Localization for Mobile Robots Using an Image Retrieval System Based on Invariant Features," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C., pp. 359-365, May 2002.
Wong, "EIED Online>> Robot Business", ED Online ID# 13114, 17 pages, Jul. 2006.
Yamamoto et al., "Optical Sensing for Robot Perception and Localization," 2005 IEEE Workshop on Advanced Robotics and its Social Impacts, pp. 14-17, 2005.

(56) **References Cited**

OTHER PUBLICATIONS

Yata et al., "Wall Following Using Angle Information Measured by a Single Ultrasonic Transducer," Proceedings of the 1998 IEEE, International Conference on Robotics & Automation, Leuven, Belgium, pp. 1590-1596, May 1998.
Yujin Robotics,"An intelligent cleaning robot," Retrieved from the Internet: URL<http://us.aving.net/news/view.php?articleId=7257>. 8 pages, accessed Nov. 2011.
Yun et al., "Image-Based Absolute Positioning System for Mobile Robot Navigation," IAPR International Workshops SSPR, Hong Kong, pp. 261-269, Aug. 2006.
Yun et al., "Robust Positioning a Mobile Robot with Active Beacon Sensors," *Lecture Notes in Computer Science*, 2006, vol. 4251, pp. 890-897, 2006.
Yuta et al., "Implementation of an Active Optical Range sensor Using Laser Slit for In-Door Intelligent Mobile Robot," IEE/RSJ International Workshop on Intelligent Robots and Systems (IROS 91) vol. 1, Osaka, Japan, pp. 415-420, Nov. 3-5, 1991.
Zha et al., "Mobile Robot Localization Using Incomplete Maps for Change Detection in a Dynamic Environment," Advanced Intelligent Mechatronics '97. Final Program and Abstracts., IEEE/ASME International Conference, pp. 110, Jun. 1997.
Zhang et al., "A Novel Mobile Robot Localization Based on Vision," *SPIE* vol. 6279, 6 pages, Jan. 2007.
Zoombot Remote Controlled Vaccuum-RV-500 New Roomba 2, website: http://cgi.ebay.com/ws/eBayISAPI.d11?ViewItem&category=43526&item=4373497618&rd=1, accessed Apr. 20, 2005, 7 pages.
Office Action received for U.S. Appl. No. 11/648,241, dated Mar. 18, 2011, 11 pages.
Office Action received for U.S. Appl. No. 11/648,230, dated Mar. 2, 2011, 11 pages.
Office Action received for Australian Patent Application No. 2010212297, mailed on Feb. 16, 2011, 3 pages.
Office Action received for Australian Patent Application No. 2004316156, mailed on Feb. 13, 2009, 2 pages.
Extended Search Report received for European Patent Application No. 10181174.3, mailed on Feb. 10, 2011, 6 pages.
Extended Search Report received for corresponding European Patent Application No. 10181187.5, mailed on Feb. 10, 2011, 8 pages.
Office Action received for European Patent Application No. 1 0160949.3, mailed on Mar. 17, 2011, 5 pages.
Office Action received for European Patent Application No. 04704061.3, mailed on Mar. 6, 2007, 4 pages.
Office Action received for European Patent Application No. 04704061.3, mailed on Nov. 30, 2007, 4 pages.
Office Action received for Singapore Patent Application No. 200505559-5, mailed on Oct. 30, 2007, 4 pages.
Examination report dated Jan. 7, 2008 for U.S. Appl. No. 11/648,241.
Examination report dated Jan. 27, 2009 for U.S. Appl. No. 11/648,241.
Examination report dated Jan. 30, 2006 for U.S. Appl. No. 10/762,219.
Examination report dated Feb. 25, 2008 for U.S. Appl. No. 11/648,230.
Examination report dated Apr. 2, 2010 for U.S. Appl. No. 11/648,241.
Examination report dated Apr. 6, 2009 for U.S. Appl. No. 11/648,230.
Examination report dated May 14, 2007 for U.S. Appl. No. 10/762,219.
Examination report dated Jul. 29, 2008 for U.S. Appl. No. 11/648,241.
Examination report dated Oct. 17, 2008 for U.S. Appl. No. 11/648,230.
Examination report dated Nov. 12, 2009 for U.S. Appl. No. 11/648,230.
Examination report dated Aug. 12, 2010 for corresponding application (KR) 10-2006-7014807.
Examination report dated Aug. 12, 2010 for corresponding application (KR) 10-2009-7025882.
Examination report dated Jun. 11, 2010 for U.S. Appl. No. 11/648,230.
Examination report dated May 27, 2010 for corresponding application (EP) 10160949.3.
Examination report dated Sep. 10, 2008 for corresponding application (EP) 08151962.1.
Examination report dated Feb. 16, 2011 from corresponding Australian Patent Application No. 2010212297.
Extended Search Report dated Feb. 10, 2011 from corresponding EP Application No. 10181187.
JP 2006-551013; Office Action dated Apr. 27, 2009 for Japanese counterpart application (7 pages).
JP 2007-10829; Office Action dated May 11, 2009 for Japanese counterpart application (6 pages).
JP2006-551013; Office Action dated Apr. 27, 2009 for Japanese counterpart (7 pages).
Office Action received for European Patent Application No. 10160949.3, mailed on Mar. 17, 2011, 5 pages.
Office Action received for Korean Patent Application No. 10-2006-7014807, mailed on May 10, 2011.
Office Action received for Korean Patent Application No. 10-2009-7025882, mailed on May 10, 2011.
Office Action received for Korean Patent Application No. 10-2010-7025523, mailed on Feb. 15, 20011, 11 pages including English translation.
Office Action received for Korean Patent Application No. 10-2010-7025523, mailed on Feb. 15, 2011, 11 pages including English translation.
Office Action received for U.S. Appl. No. 11/834,575, mailed on May 29, 2009.
Office Action received for U.S. Appl. No. 11/834,575, mailed on May 5, 2008.
Office Action received for U.S. Appl. No. 11/834,575, mailed on Nov. 28, 2008.
Written Opinion for corresponding application PCT/US2004/001504, Aug. 20, 2012, 9 pages.

* cited by examiner

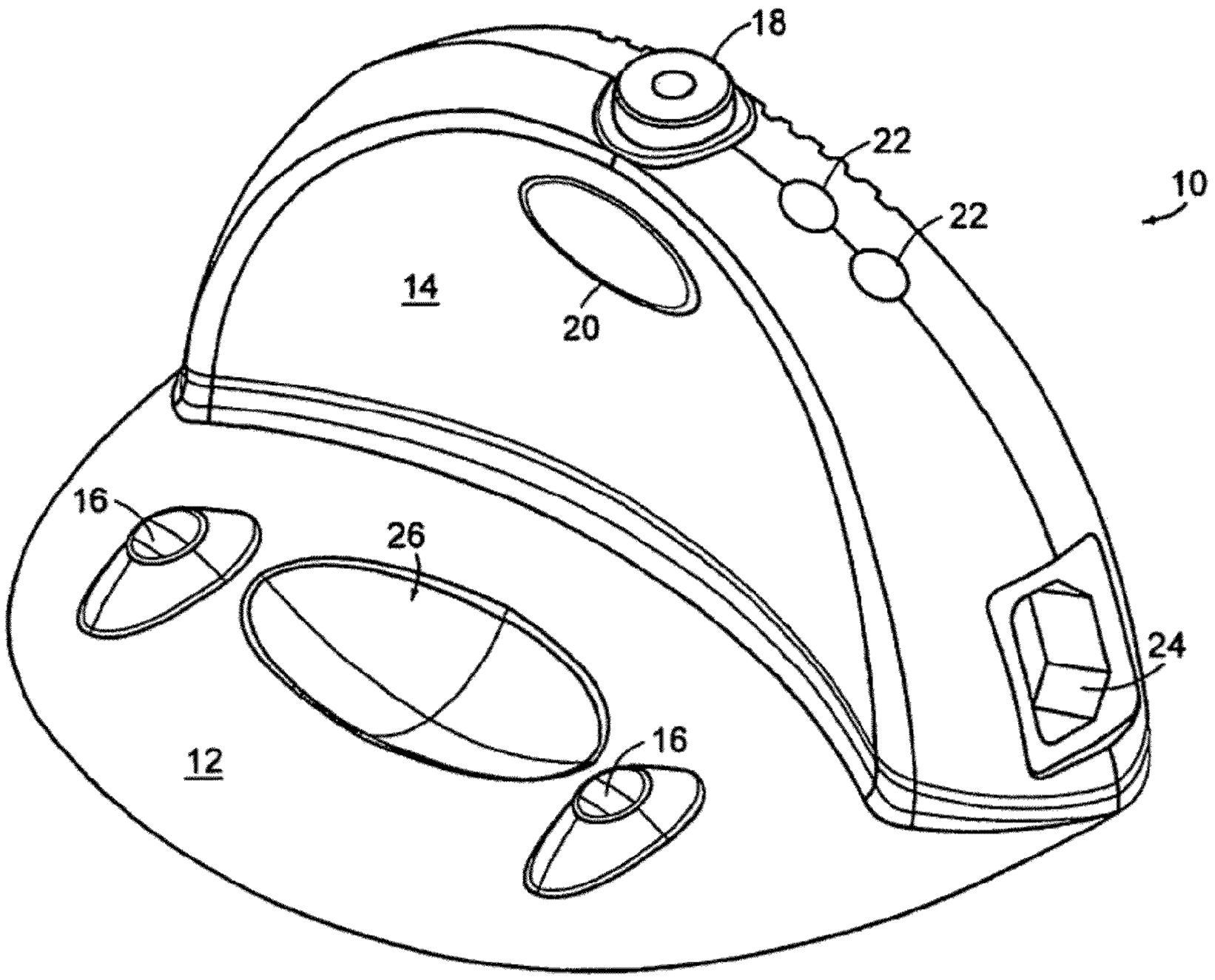


FIG. 1

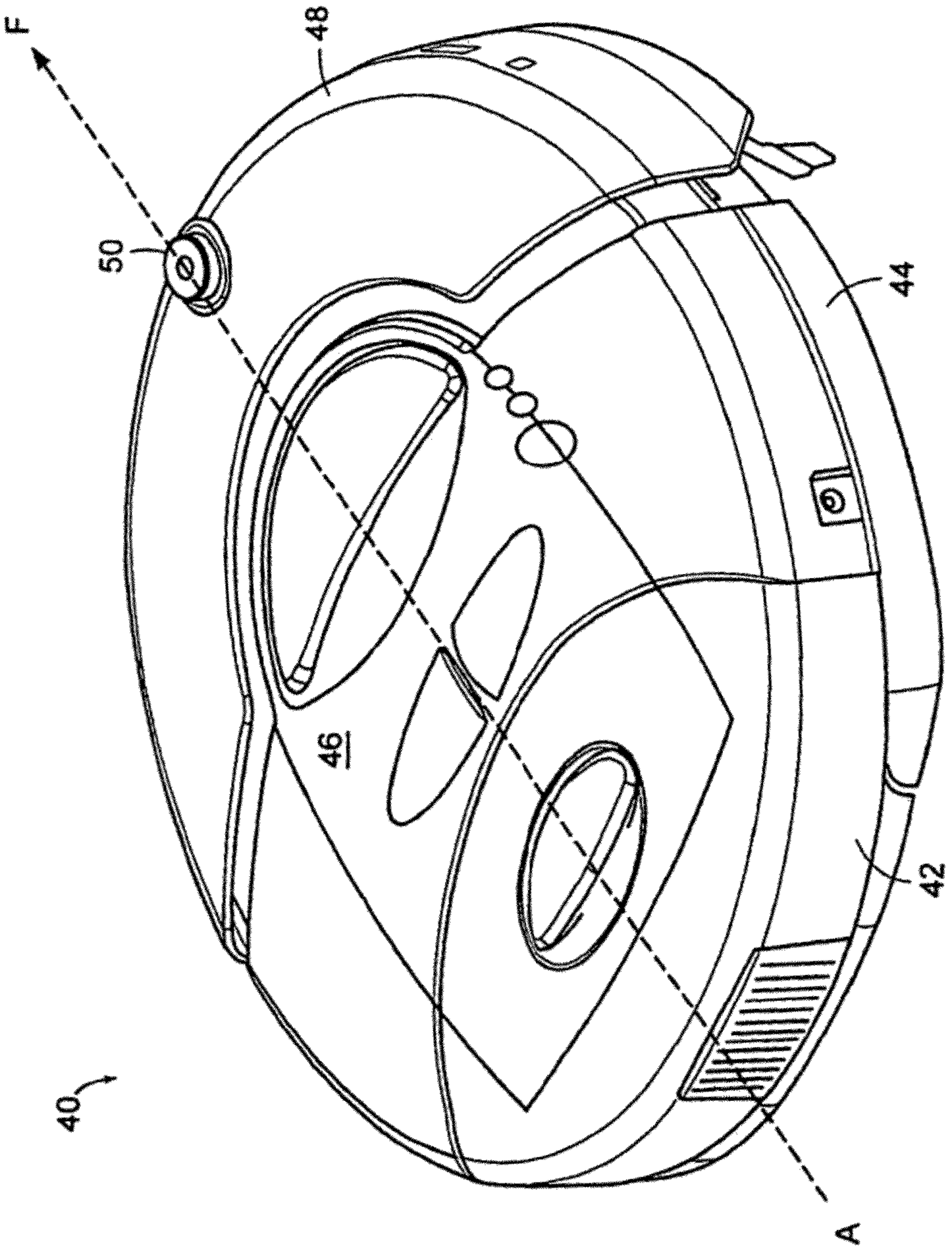


FIG. 2A

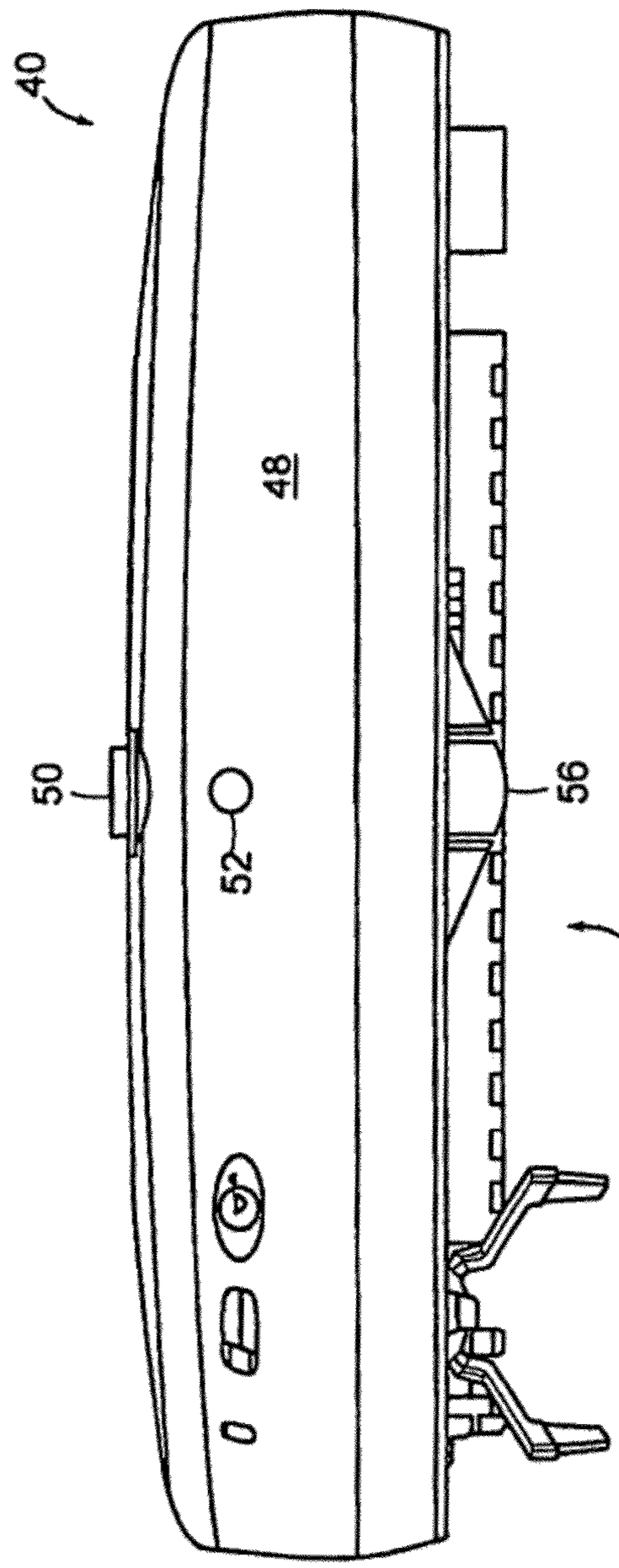


FIG. 2B

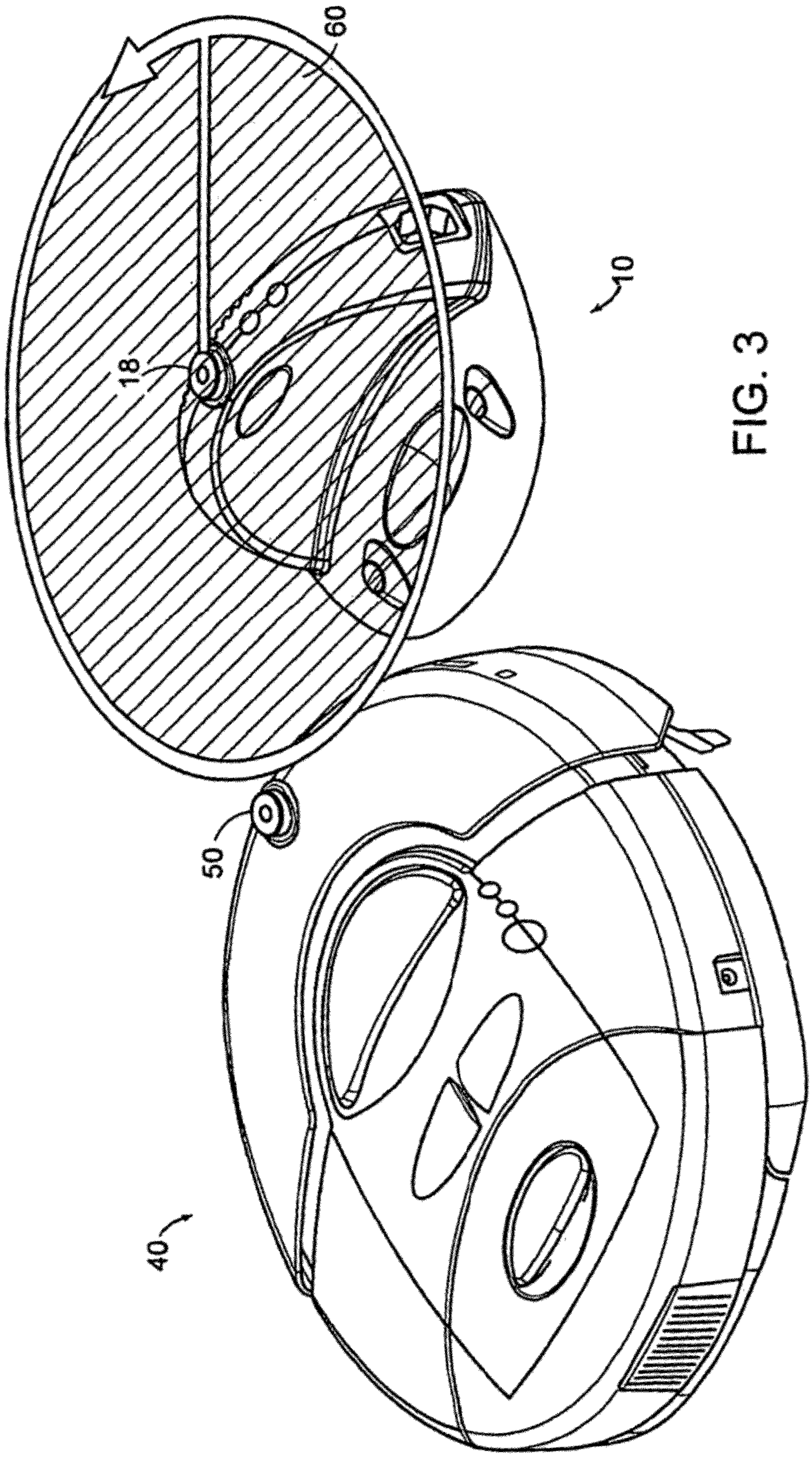


FIG. 3

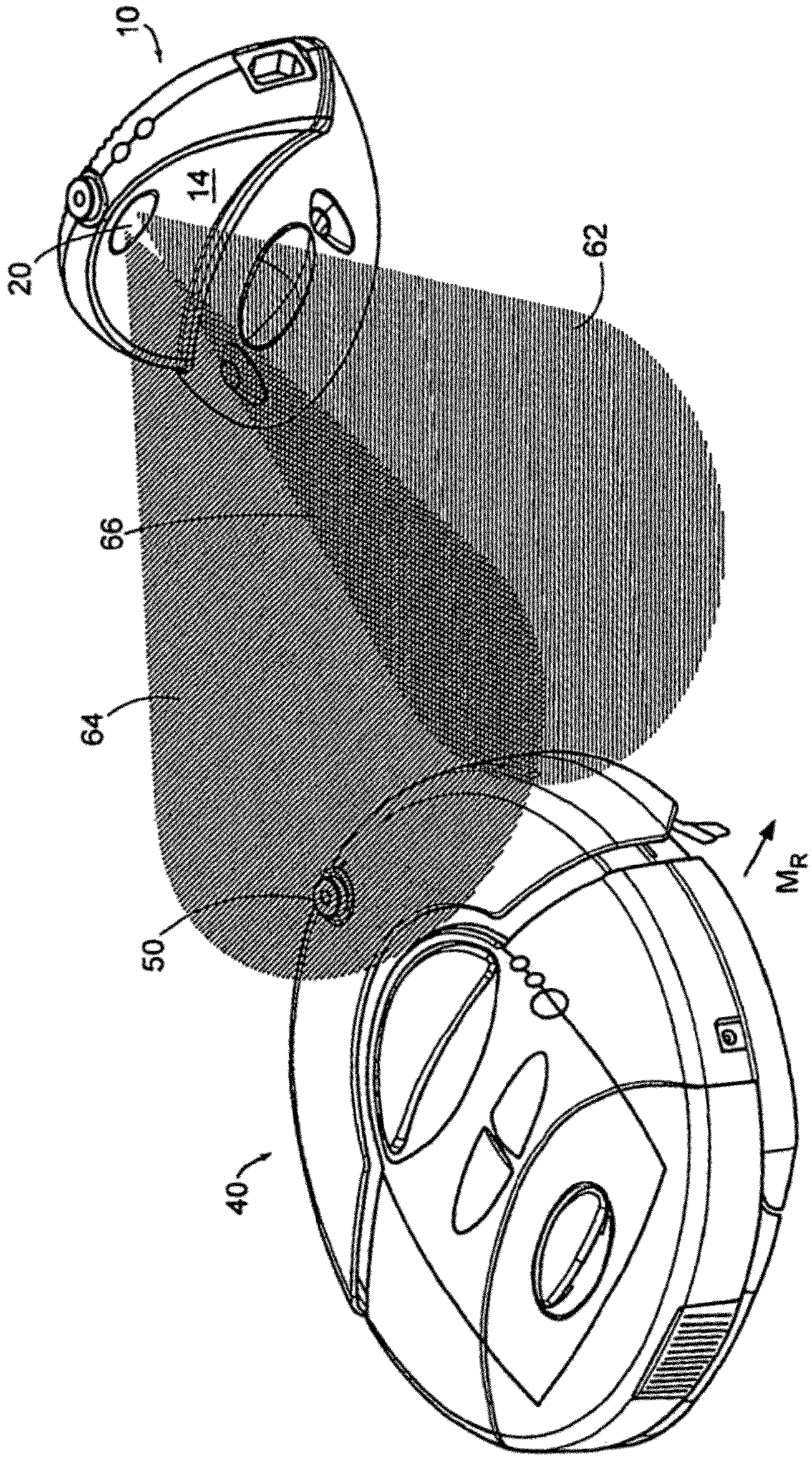


FIG. 4A

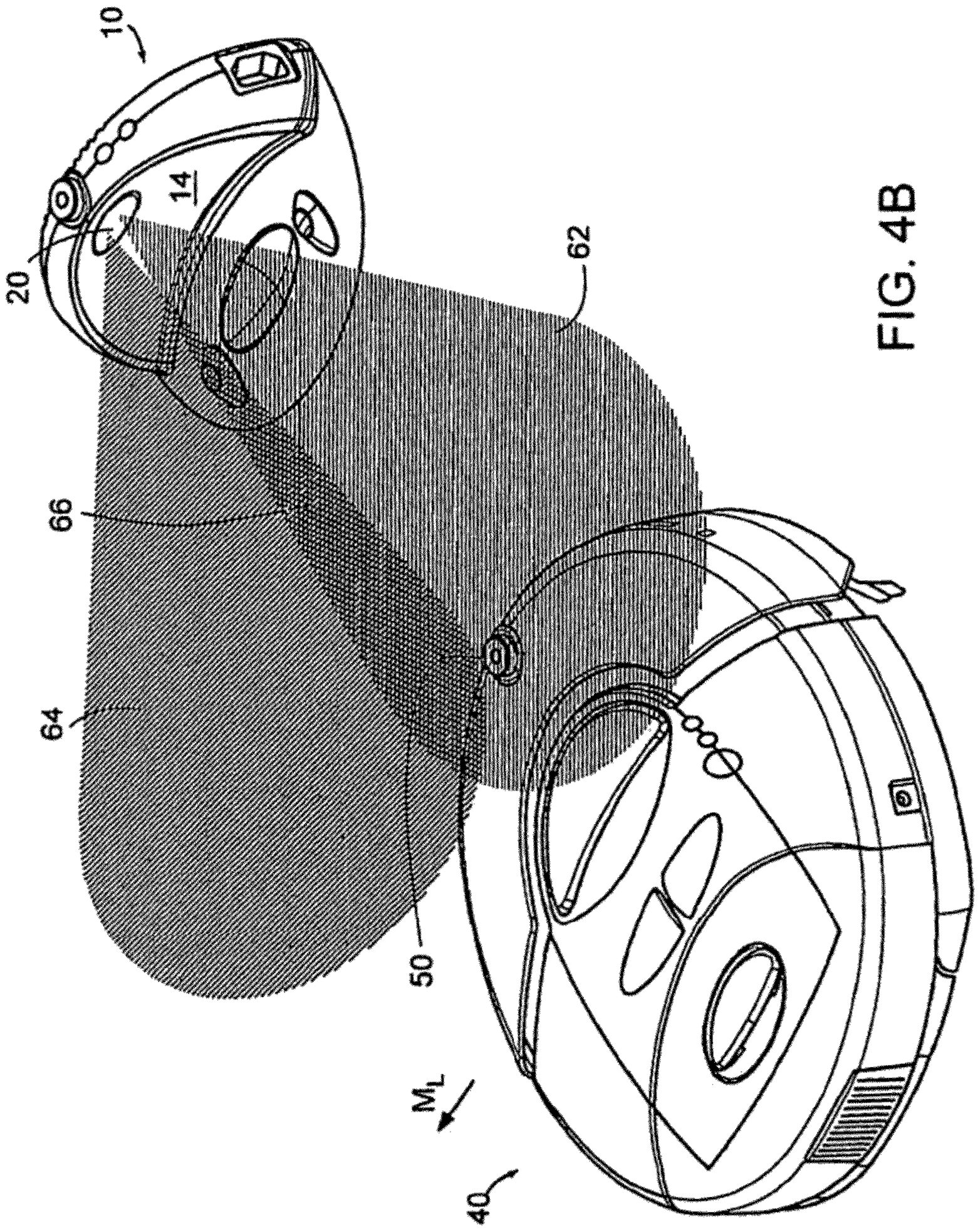


FIG. 4B

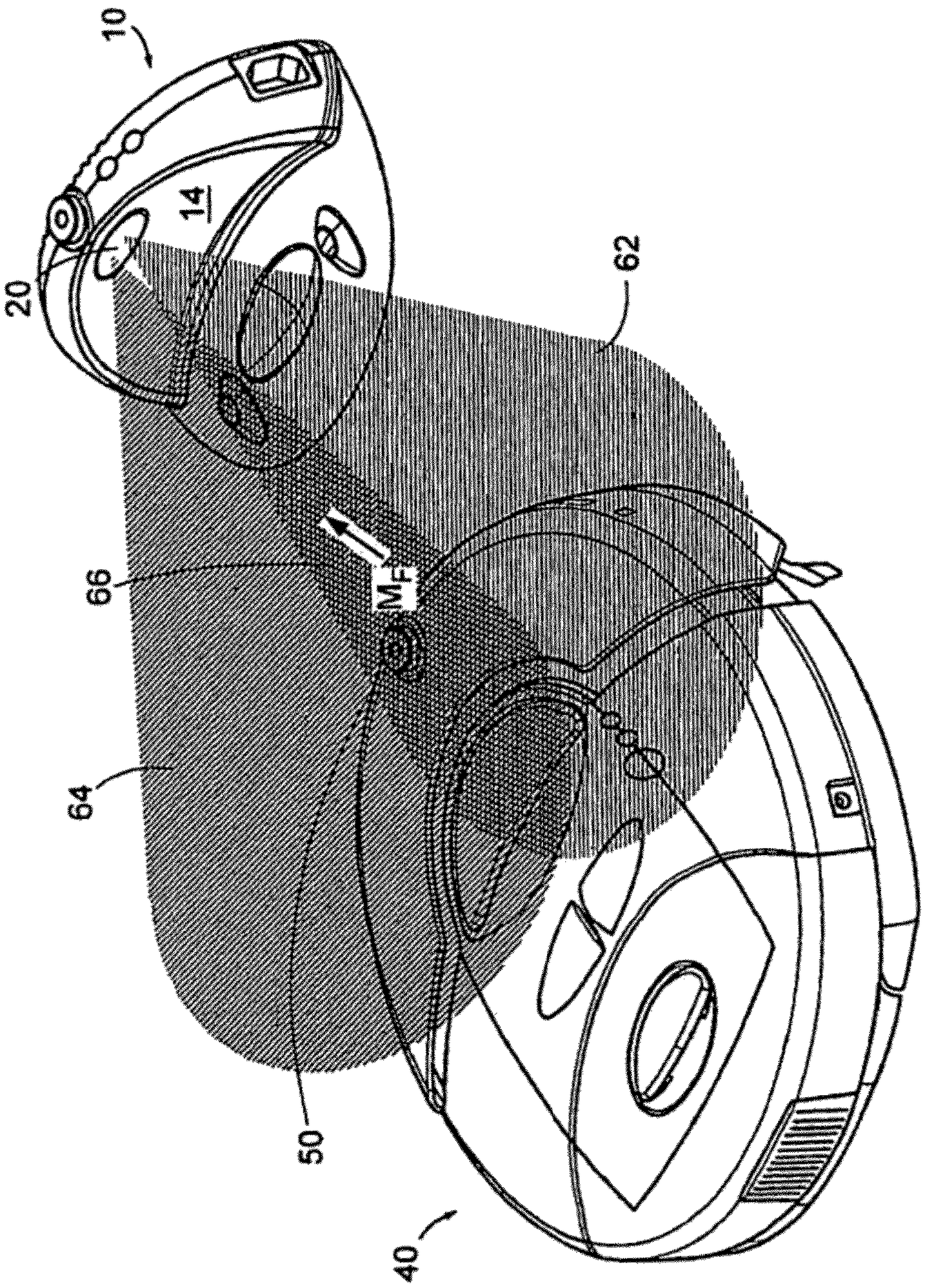


FIG. 4C

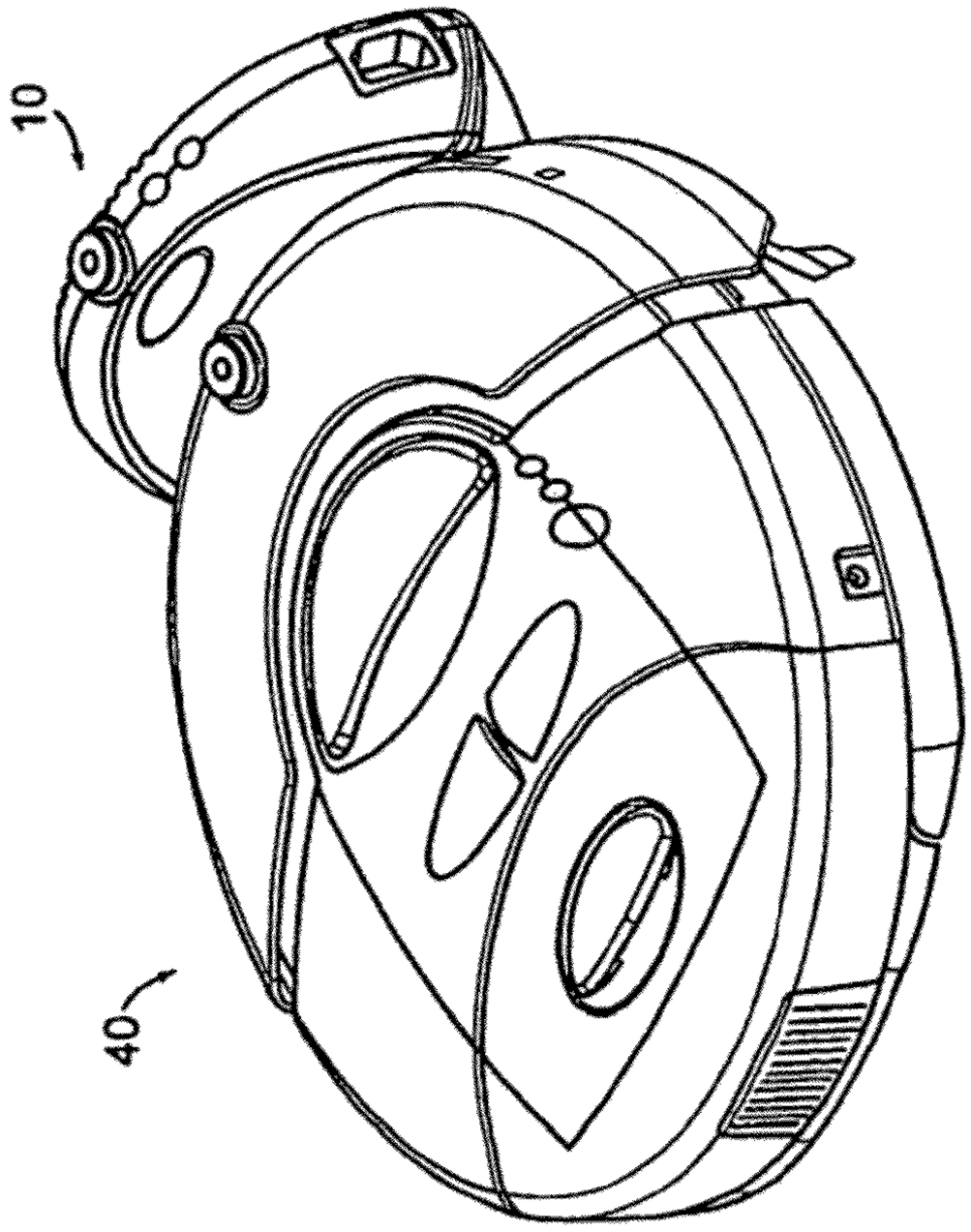


FIG. 5

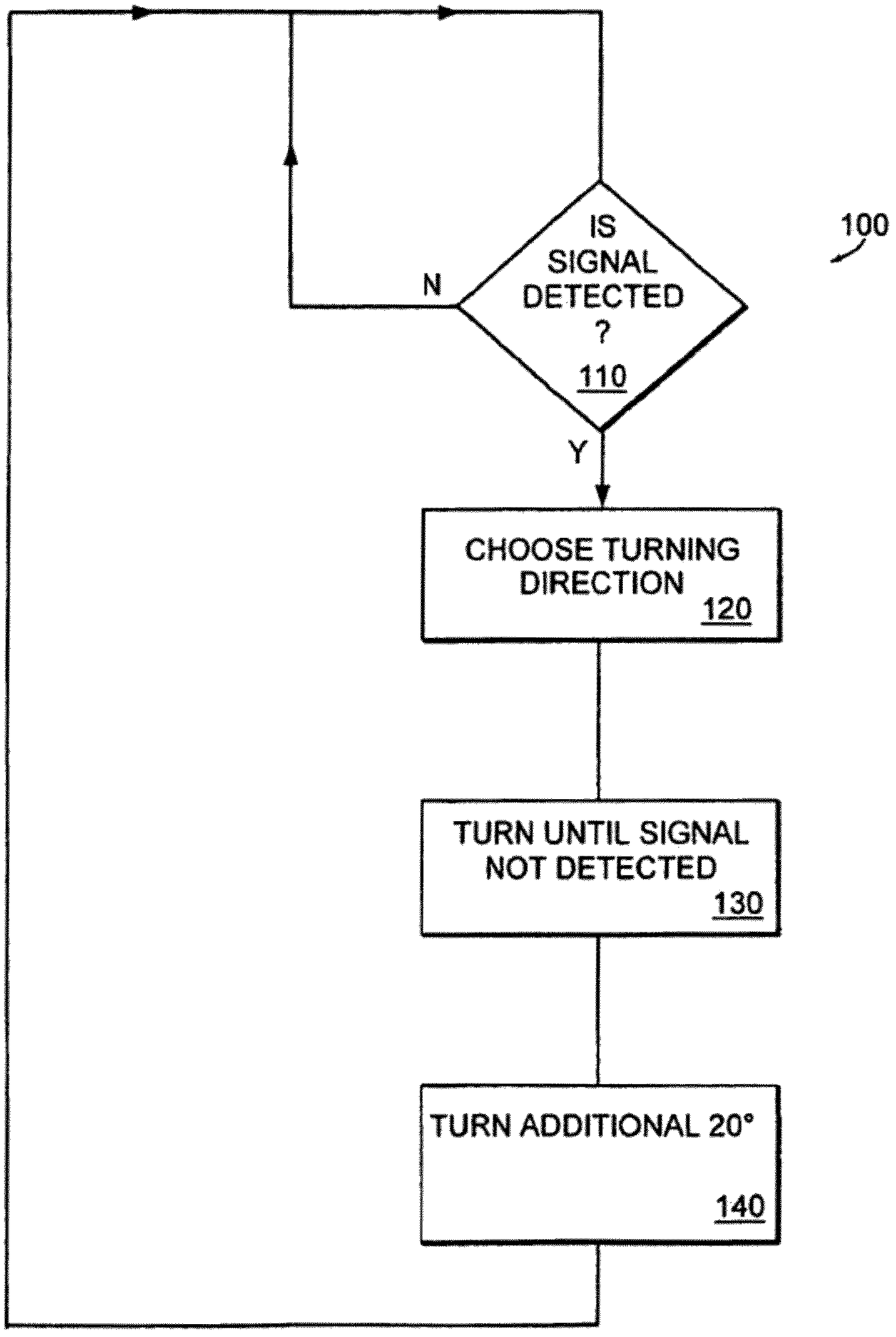

100
IS SIGNAL DETECTED ?
110
N
Y
CHOOSE TURNING DIRECTION
120
TURN UNTIL SIGNAL NOT DETECTED
130
TURN ADDITIONAL 20°
140

FIG. 6A

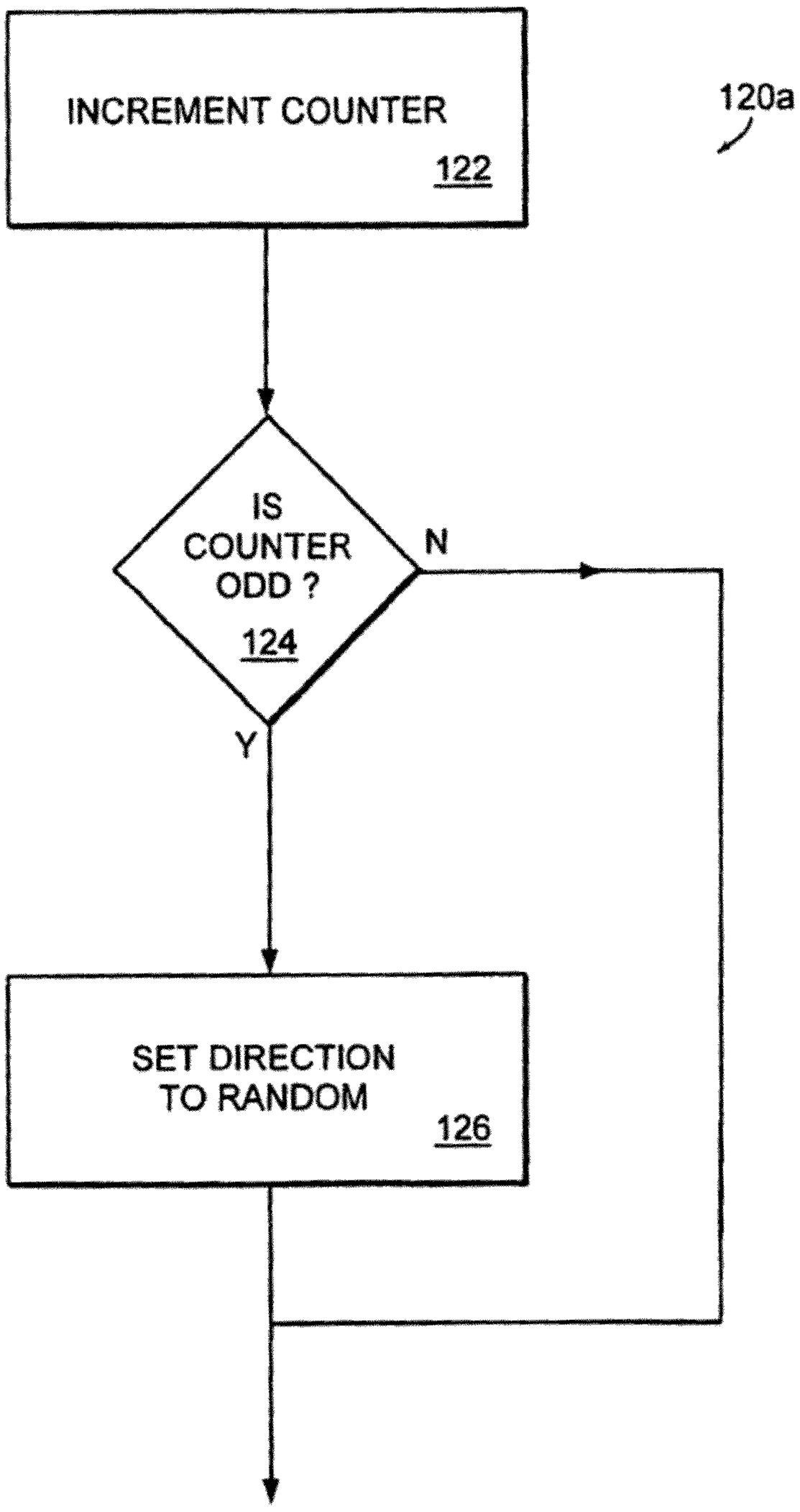

INCREMENT COUNTER
122
120a
IS COUNTER ODD ?
124
N
Y
SET DIRECTION TO RANDOM
126

FIG. 6B

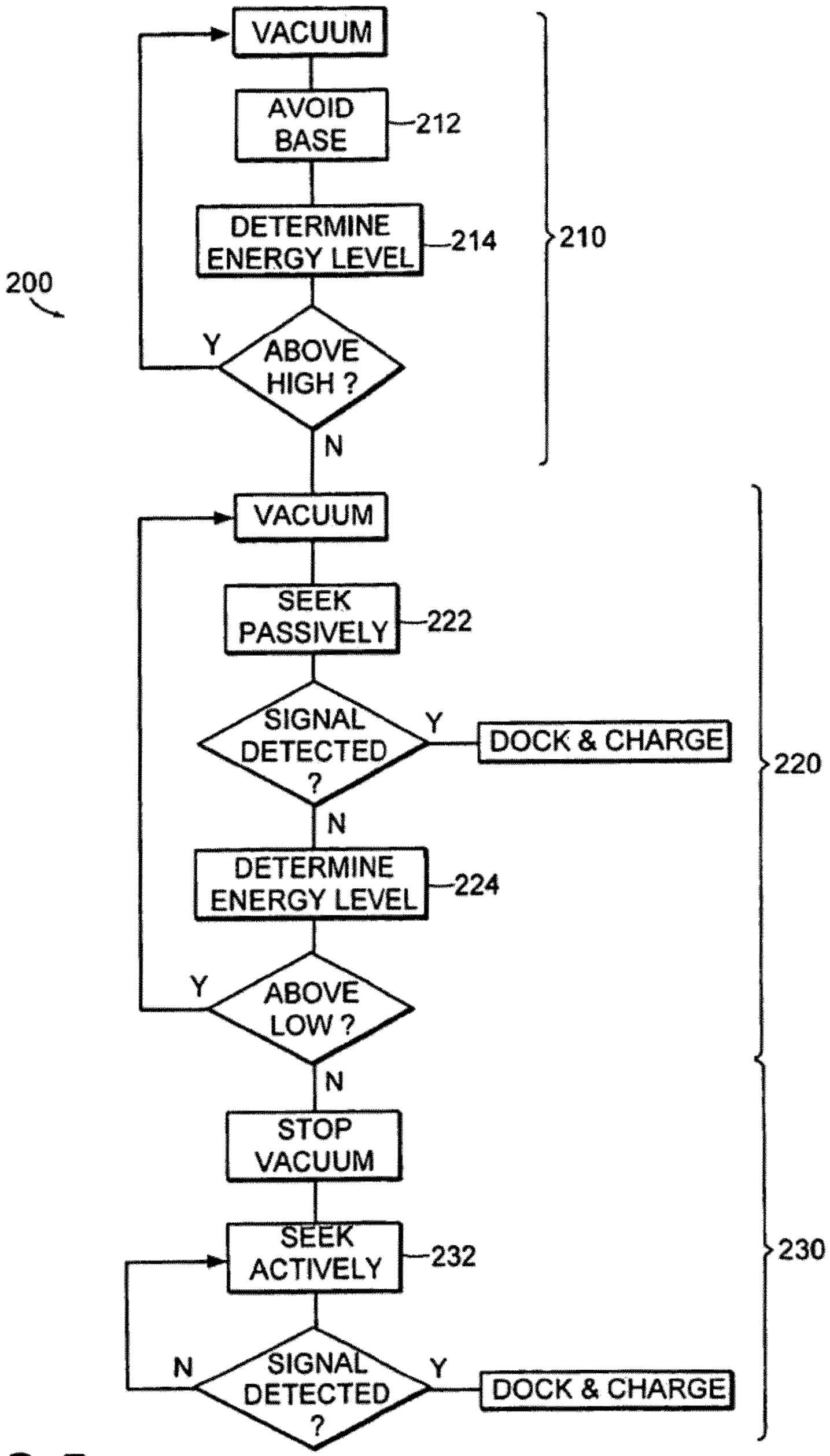

200
VACUUM
AVOID BASE
212
DETERMINE ENERGY LEVEL
214
210
Y
ABOVE HIGH ?
N
VACUUM
SEEK PASSIVELY
222
SIGNAL DETECTED ?
Y
DOCK & CHARGE
220
N
DETERMINE ENERGY LEVEL
224
Y
ABOVE LOW ?
N
STOP VACUUM
SEEK ACTIVELY
232
230
N
SIGNAL DETECTED ?
Y
DOCK & CHARGE

FIG. 7

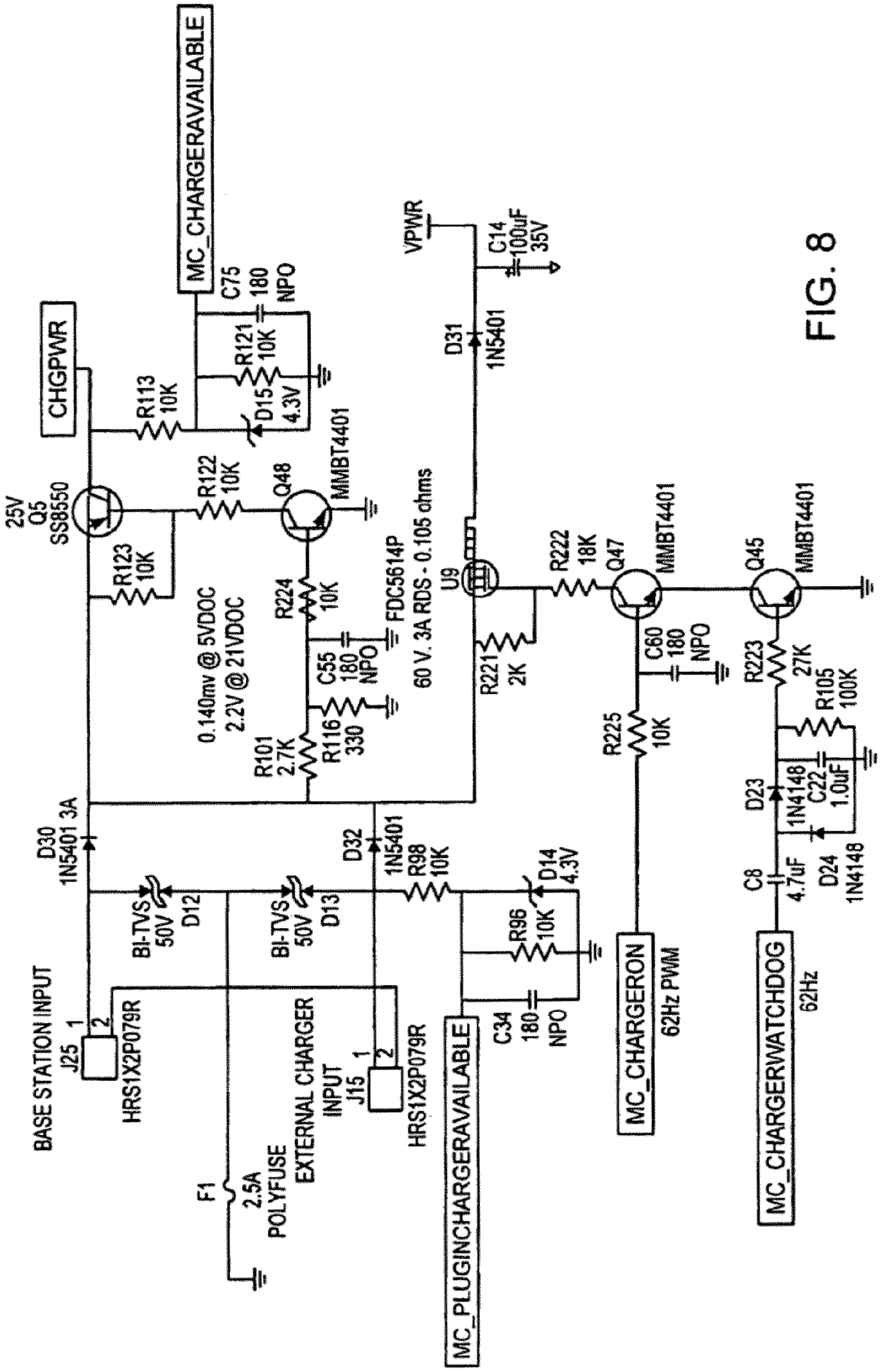

MC_CHARGERAVAILABLE
C75 180 NPO
CHGPWR
R113 10K
R121 10K
D15 4.3V
25V Q5 SS8550
R122 10K
Q48 MMBT4401
R123 10K
R224 10K
C55 180 NPO
FDC5614P
0.140mv @ 5VDOC 2.2V @ 21VDOC
60 V. 3A RDS - 0.105 ohms
R101 2.7K
R116 330
VPWR
C14 100uF 35V
D31 1N5401
U9
R222 18K
Q47 MMBT4401
R221 2K
C60 180 NPO
R225 10K
Q45 MMBT4401
R223 27K
R105 100K
D23 1N4148
C22 1.0uF
C8 4.7uF
D24 1N4148
D30 1N5401 3A
D32 1N5401
R98 10K
D14 4.3V
R96 10K
BI-TVS 50V D12
BI-TVS 50V D13
BASE STATION INPUT J25 1 2 HRS1X2P079R
F1 2.5A POLYFUSE
EXTERNAL CHARGER INPUT J15 1 2 HRS1X2P079R
MC_PLUGINCHARGERAVAILABLE
C34 180 NPO
MC_CHARGERON
62Hz PWM
MC_CHARGERWATCHDOG
62Hz

FIG. 8

AUTONOMOUS ROBOT AUTO-DOCKING AND ENERGY MANAGEMENT SYSTEMS AND METHODS

This application is a continuation of, and claims priority under 35 U.S.C. §120 from, U.S. application Ser. No. 13/291,633, entitled "Autonomous Robot Auto-Docking and Energy Management Systems and Methods," filed on Nov. 8, 2011, which is a continuation of, and claims priority under 35 U.S.C. §120 from, U.S. application Ser. No. 11/648,230, entitled "Autonomous Robot Auto-Docking and Energy Management Systems and Methods," filed on Dec. 29, 2006, which is a divisional, and claims priority under 35 U.S.C. §120 from, U.S. application Ser. No. 10/762,219, entitled "Autonomous Robot Auto-Docking and Energy Management Systems and Methods," filed on Jan. 21, 2004. The disclosures of each of these prior applications are considered part of the disclosure of this application and are hereby incorporated by reference in their entireties.

TECHNICAL FIELD

The present invention relates generally to robotic systems and, more specifically, to auto-docking and energy management systems for autonomous robots.

BACKGROUND

Automated robots and robotic devices are becoming more prevalent today and are used to perform tasks traditionally considered mundane, time-consuming, or dangerous. As the programming technology increases, so too does the demand for robotic devices that require a minimum of human interaction for tasks such as robot refueling, testing, and servicing. A goal is a robot that could be configured a single time, which would then operate autonomously, without any need for human assistance or intervention.

Robotic devices and associated controls, navigational systems, and other related systems moving in this direction are being developed. For example, U.S. Pat. No. 6,594,844 discloses a Robot Obstacle Detection System, the disclosure of which is hereby incorporated by reference in its entirety. Additional robot control and navigation systems are disclosed in U.S. patent application Ser. Nos. 10/167,851, 10/056,804, 10/696,456, 10/661,835, and 10/320,729 the disclosures of which are hereby incorporated by reference in their entireties.

Generally, autonomous robotic devices include an on-board power unit (usually a battery) that is recharged at a base or docking station. The types of charging stations and methods used by robots in finding or docking with them (e.g., radio signals, dead reckoning, ultrasonic beams, infrared beams coupled with radio signals, etc.) vary greatly in both effectiveness and application. Wires buried below the surface on which the robot operates are common, but are obviously limited in application, as it is costly to install guide wires within the floor of a building or below a road surface. If installed on the surface, the guide wires may be damaged by the robot itself or other traffic. Moreover, the wires need to be moved when the base station is relocated. A base station that emits a beam or beacon to attract the robotic device is, therefore, more desirable. Such devices, however, still exhibit numerous operational limitations.

Base stations that utilize emitted signals often still require additional safeguards to ensure proper mating between the robot and base station and, therefore, safe and effective charging. Some require mechanical locking devices to prevent

dislocation of the robot during charging, or other components such raised guiding surfaces to direct the robot into contact with the station. Such components can increase the size of the base station while decreasing the aesthetics, important considerations for automated robots directed at the consumer market. An increase in base station size also typically makes unobtrusive placement in the home more difficult and decreases the floor area available for cleaning. Additionally, existing base stations generally lack the ability to protect themselves from contact with the robot during operation, increasing the likelihood of damage to either the station or robot, or dislocation of the base station. Such an unintentional collision may require human intervention to reposition the base station or repair a damaged component.

These limitations are, at present, a hurdle to creating a truly independent autonomous robot, free from human interaction. There is, therefore, a need for a robot and base station that can ensure proper mating regardless of location of the base station. Moreover, a system that can prevent inadvertent dislocation of the base station by eliminating collisions between the station and robot is desirable.

SUMMARY OF THE INVENTION

In one aspect, the invention relates to a method for energy management in a robotic device, the robotic device including at least one energy storage unit and a signal detector. The method includes the steps of: a base station for mating with the robotic device, the base station having a plurality of signal emitters including a first signal emitter and a second signal emitter; determining a quantity of energy stored in the energy storage unit, the quantity characterized at least by a high energy level and a low energy level; and performing, by the robotic device, a predetermined task based at least in part on the quantity of energy stored. In various embodiments of the foregoing aspect, coulometry or setting a time period are used to determine the quantity of energy stored or task period of the device.

In other embodiments of the foregoing aspect, the step of performing the predetermined task occurs when the quantity of energy stored exceeds the high energy level, the predetermined task including movement of the robotic device away from the base station in response to reception, by the signal detector, of a base station avoidance signal. Still other embodiments include the step of returning the robotic device to the base station in response to reception, by the signal detector, of a base station homing signal and/or returning the robotic device to the base station when the quantity of energy stored is less than the high energy level. In other embodiments of the foregoing aspect, the step of returning the robotic device to the base station occurs when the quantity of energy stored is less than the low energy level, and wherein the predetermined task includes a reduction in energy use by the robotic device. Various embodiments further include altering a travel characteristic of the robotic device to locate effectively the base station, charging the device upon contact, and/or resuming the predetermined or a different task.

In another aspect, the invention relates to a method of docking a robotic device with a base station that has a plurality of signal emitters, including a first signal emitter and a second signal emitter. The method includes the steps of orienting the robotic device in relation to (i) a first signal transmitted by the first signal emitter and (ii) a second signal transmitted by the second signal emitter, and maintaining an orientation of the robotic device relative to the first and second signals as the robotic device approaches to the base station. Certain embodiments of the method of the foregoing

aspect include the steps of detecting, by the robotic device, an overlap between the first signal and the second signal; following, by the robotic device, a path defined at least in part by the signal overlap; and docking the robotic device with the base station. Other related embodiments include reducing the velocity of the robotic device in the step of following the path defined at least in part by the signal overlap.

Various embodiments of the method of the foregoing aspect also include, during the step of docking the robotic device with the base station: detecting, by the robotic device, contact with charging terminals on the base station, and stopping movement of the robotic device. In some embodiments, contact of one or more on-board tactile sensors can be used, additionally or alternatively, to stop movement of the robotic device. Other embodiments include the step of charging fully the robotic device and/or charging the robotic device to one of a plurality of charging levels. Certain embodiments allow for resumption of the predetermined task or a new task upon completion of charging.

In another aspect of the invention, the invention relates to an autonomous system including a base station, that includes charging terminals for contacting external terminals of a robotic device, and a first signal emitter and a second signal emitter. Certain embodiments of the above aspect provide that the first signal emitter transmit a base station avoidance signal and the second signal emitter transmit a base station homing signal. In other embodiments, the homing signal is a pair of signals, which can be either the same or different. The pair of signals may be emitted by a pair of emitters. In some embodiments, the signals may overlap, and may be optical signals.

Certain embodiments of the above aspect further include a robotic device for performing a predetermined task, the robotic device having at least one energy storage unit with an external terminal for contacting the charging terminal, and at least one signal detector. In certain embodiments, the at least one signal detector is adapted to detect at least one optical signal. The robotic device has, in certain embodiments, the capability to distinguish between the signals generated by multiple emitters.

Still other aspects of the current invention relate to an energy manager including: a robotic device having at least one energy storage unit and a signal detector; a base station for mating with the robotic device, the base station having a plurality of signal emitters including a first signal emitter and a second signal emitter; and a processor for determining a quantity of energy stored in the energy storage unit. Certain embodiments of the foregoing aspect use coulometry or set a time period to determine the quantity of energy stored or task period of the device. In still other embodiments the first signal emitter transmits an avoidance signal, thereby restricting a movement of the robotic device to directions away from the base station, and the second signal emitter transmits a homing signal, thereby directing a movement of the robotic device to the base station.

Other aspects of the invention relate to a homing system including a robotic device having a signal detector, and a base station having a first signal emitter and a second signal emitter. Certain embodiments of the foregoing aspect overlap signals transmitted by the first signal emitter and the second signal emitter. Still other embodiments further include charging terminals on the base station, and charging terminals on the robotic device.

An additional aspect of the invention relates to a horning system for base station including a first signal emitter that transmits a first signal projected outward from the first signal emitter, and a second signal emitter that transmits a second signal projected outward from the second signal emitter, such that the first signal and the second signal overlap. Another aspect relates to an avoidance system for restricting a movement of at least one of a first device and a second device, the avoidance system including a first device that emits a signal, and a second device that receives the signal, thereby restricting the movement of at least one of the first device and the second device.

Still another aspect of the invention relates to a base station, including a base plate and a backstop, for a robotic device including: electrical contacts located on a top side of the base plate; a first signal emitter located on the backstop wherein a signal transmitted by the first signal emitter restricts the robotic device from moving within a predetermined distance of the base station; and a second signal emitter and a third signal emitter, wherein a plurality of signals transmitted by the second signal emitter and the third signal emitter guide at least one electrical contact of the robotic device to contact the at least one electrical contact of the base station.

Another aspect of the invention relates to a method of charging a battery of a device, the method having the steps of providing low power to charging terminals of a charger, detecting presence of the device by monitoring at least one of a predetermined change in and a predetermined magnitude of a parameter associated with the charger, and increasing power to the charging terminals to charge the battery. One embodiment of the method of the above aspect further includes the steps of determining a level of charge in the device, and permitting charging of the battery in the device when the level of charge is below a predetermined threshold.

Still another aspect of the invention relates to a system for charging a mobile device, the system having: a stationary charger comprising first charging terminals, circuitry for detecting presence of the device by monitoring at least one of a predetermined change in and a predetermined magnitude of a parameter associated with the charger, and a mobile device having: a battery, and second charging terminals adapted to mate with first charging terminals. Various embodiments of the above aspect include systems wherein the circuitry determines a level of charge in the battery and controls a power level provided to the first charging terminals. Still other embodiments include systems wherein the circuitry increases the power level provided to the first charging terminals upon measuring a predetermined voltage across the first charging terminals when mated with the second charging terminal.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the present invention are described with reference to the following drawings, in which:

FIG. **1** is a schematic perspective view a base station in accordance with one embodiment of the invention;

FIG. **2**A is a schematic perspective view of an robotic device in accordance with one embodiment of the invention;

FIG. **2**B is a schematic side view of the robotic device of FIG. **2**A.

FIG. **3** is a schematic perspective view of a representation of robotic device and base station, depicting an avoidance signal in accordance with one embodiment of the invention transmitted by the base station and detected by the robotic device;

FIGS. **4**A-**4**C are schematic perspective views of representations of homing signals in accordance with one embodiment of the invention transmitted by the base station and detected by the robotic device;

FIG. **5** is a schematic perspective view of the robotic device and the base station in a docking or mating position;

FIGS. **6**A-**6**B are flow charts of avoidance algorithms in accordance with one embodiment of the invention;

FIG. **7** is a flow chart of an energy management algorithm in accordance with one embodiment of the invention; and

FIG. **8** depicts an embodiment of the charger circuitry schematic in accordance with one embodiment of the invention.

DETAILED DESCRIPTION

FIG. **1** is a schematic perspective view a base station **10** in accordance with one embodiment of the invention. The base station **10** includes both a substantially horizontal base plate **12** and a substantially vertical backstop **14**. The base station **10** may be any of a variety of shapes or sizes, providing sufficient space for the desired components and systems, described below. The base plate **12** is generally parallel to the ground surface on which the base station **10** rests, but may have a slight upwards angle directed toward the backstop **14**. By minimizing the angle of rise of the base plate **12**, the robotic device (FIGS. **2**A-**2**B) may easily dock with the station **10**. Electrical charging contacts **16** are located on a top surface of the base plate **12**, allowing them to contact corresponding contacts (FIG. **2**B) on the underside of the robotic device. The contacts **16** or the contacts on the robot may be either fixed or compliant. In the depicted embodiment, two contacts **16** (one positive, one negative) are utilized to properly detect a completed circuit when the robot **40** docks with the base station **10**. This circuit recognition sequence is described in more detail below. In other embodiments, however, a single contact **16** or more than two contacts may be utilized. An additional contact would provide redundancy in the event that one of the robot contacts becomes damaged, dirty, or obstructed. This would allow the robot to dock and recharge itself properly, even after such an occurrence. Other embodiments utilize two contacts **16** to charge the battery and additional contacts to transmit data and information between the devices.

The contacts **16** are sized and positioned to reliably and repeatably contact the corresponding contacts on the robot. For example, the contacts **16** may be oversized and/or may extend above the base plate **12**, e.g., in a domed shape, to ensure contact with the robot contacts. Alternatively, the contacts **16** may be flush-mounted on a base plate **12** with a higher angle of rise or may protrude above a base plate **12** that is flat or has substantially no rise. Depending on the application, the base plate **12** angle of rise may vary from 0° to up to 20° and greater. The embodiment depicted in FIG. **1** also includes a depression **26** in the base plate **12**, between the two contacts **16**, sized to engage a front caster (FIG. **28**) of the robot. The depression **26**, in combination with the configuration of the charging contacts **16**, ensures proper alignment and registration between the charging contacts on both the base station **14** and the robot. Alternatively, the depression **26** may contain one or more of the contacts **16** arranged to mate with one or more corresponding contacts on the front caster of the robot.

The backstop **14** provides locations for many of the base station **10** components. Specifically, in the depicted embodiment, the backstop **14** includes a top signal emitter **18**, a front signal emitter **20**, several indicator LEDs **22**, and an AC plug receptacle **24**. The top signal emitter **18** generates a first signal, such as an avoidance signal (FIG. **3**), in a diffuse region near the base station **10** to prevent generally the robot from coming into inadvertent direct contact with the base station **10** while performing a task, such as vacuuming. The top signal emitter **18** generally utilizes a parabolic reflector to transmit the avoidance signal. In such an embodiment, the avoidance signal is emitted by a single LED directed at a lens whose geometry is determined by rotating a parabola about its focus. This parabolic reflector thus projects the avoidance signal **60** out in a 360° pattern, without the necessity of multiple emitters. A similar configuration can be employed in the detector on the robot, with a single receiver used in place of the single LED.

While the location of the top signal emitter **18** may vary, locating the emitter **18** on top of the backstop **14** transmits the avoidance signal through an uninterrupted 360° field around the base station **10**. Alternatively, base stations designed for corner, on-wall, or near-wall installation may project the avoidance signal substantially only along the unobstructed side. The front signal emitter **20** projects one or more additional signals, such as homing beams (FIGS. **4**A-**4**C), to allow the robotic device to orient itself during docking with the base station **10** for recharging or during periods of non-use. Naturally, if properly located on the base station **10**, a single emitter may be used to perform the functions of both emitters **18**, **20**. Both the avoidance signal and homing beams described in more detail below.

FIGS. **2**A-**2**B are schematic perspective views of a robotic device, such as an autonomous robot **40** adapted to mate with the base station **10**. In the following description of the autonomous robot **40**, use of the terminology "forward/fore" refers generally to the primary direction of motion of the robot **40**, and the terminology fore-aft axis (see reference characters "FA" in FIG. **2**A) defines the forward direction of motion (indicated by arrowhead of the fore-aft axis FA), which is coincident with the fore-aft diameter of the robot **40**.

In the embodiment depicted, the housing infrastructure **42** of the robot **40** includes a chassis **44**, a cover **46**, and a displaceable bumper **48**. The chassis **44** may be molded from a material such as plastic as a unitary element that includes a plurality of preformed wells, recesses, and structural members for, inter alia, mounting or integrating elements of the various subsystems that operate the robotic device **40**. Such subsystems may include a microprocessor, a power subsystem (including one or more power sources for the various subsystems and components), a motive subsystem, a sensor subsystem, and task-specific component subsystems. The cover **46** may be molded from a material such as plastic as a unitary element that is complementary in configuration with the chassis **44** and provides protection of and access to elements and components mounted to the chassis **44**. The chassis **44** and the cover **46** are detachably integrated in combination by any suitable means (e.g., screws), and in combination, the chassis **44** and cover **46** form a structural envelope of minimal height having a generally cylindrical configuration that is generally symmetrical along the fore-aft axis FA.

The displaceable bumper **48**, which has a generally arcuate configuration, is mounted in movable combination at the forward portion of the chassis **44** to extend outwardly therefrom (the "normal operating position"). The mounting configuration of the displaceable bumper **48** is such that it is displaced towards the chassis **44** (from the normal operating position) whenever the bumper **48** encounters a stationary object or obstacle of predetermined mass (the "displaced position"), and returns to the normal operating position when contact with the stationary object or obstacle is terminated

(due to operation of a control sequence which, in response to any such displacement of the bumper **48**, implements a "bounce" mode that causes the robot **40** to evade the stationary object or obstacle and continue its task routine).

Mounted on the robotic device **40** are a pair of detectors **50**, **52**. In this embodiment of the robotic device **40**, the detectors **50**, **52** receive signals projected from the emitters **18**, **20** on the base station **10**. In other embodiments, a single detector receives signals from both emitters **18**, **20** on the base station **10**, or more than two detectors may be used. In certain embodiments, the detectors **50**, **52** are standard infrared ("IR") detector modules, that include a photodiode and related amplification and detection circuitry, in conjunction with an omni-directional lens, where omni-directional refers to a substantially single plane. The IR detector module can be of the type manufactured by East Dynamic Corporation (p/n IRM-8601S). However, any detector, regardless of modulation or peak detection wavelength, can be used as long as the emitters **18**, **20** on the base station **10** are adapted to match the detectors **50**, **52** on the robot **40**. In another embodiment, IR phototransistors may be used with or without electronic amplification elements and may be connected directly to the analog inputs of a microprocessor. Signal processing tray then be used to measure the intensity of IR light at the robot **40**, which provides an estimate of the distance between the robot **40** and the source of IR light. Alternatively, radio frequencies, magnetic fields, and ultrasonic sensors and transducers may be employed. As shown in FIGS. **2**A-**2**B, at least one detector **50** is mounted at the highest point on the robot **40** and toward the front of the robot **40** as defined by the primary traveling direction, as indicated by an arrow on axis FA.

While the detector **50** is mounted at the highest point of the robot **40** in order to avoid shadows, it is desirable in certain applications to minimize the height of the robot **40** and/or the detector **50** to prevent operational difficulties and to allow the robot **40** to pass under obstacles. In certain embodiments, the detector **50** can be spring-mounted to allow the detector **50** to collapse into the body of the robot **40** when the robot **40** runs under a solid overhanging object.

One of skill in the art will recognize that, in alternative embodiments, multiple detectors can be used. Such an embodiment might include using multiple side-mounted sensors or detectors. Each of the sensors can be oriented in a manner so that a collective field of view of all the sensors corresponds to that of the single, top mounted sensor. Because a single, omni-directional detector is mounted at the highest point of the robot for optimal performance, it is possible to lower the profile of the robot by incorporating multiple, side mounted detectors.

The undercarriage of the robotic device **40** is indicated generally by numeral **54**. One or more charging contacts are present in the undercarriage **54**, configured in such a location to correspond with the location of the electrical contacts **16** of the base station **10**. Generally, the charging contacts on the robotic device mirror those present on the base station **10**, regardless of their location or orientation. In certain embodiments, the charging contacts may be larger on either the base station **10** or robot **40**, to allow wider compliance in making contact. Also, the motive and task specific components of the robot **40** are located in the undercarriage **54**. The motive components may include any combination of motors, wheels, drive shafts, or tracks as desired, based on cost or intended application of the robot **40**, all of which are well known in the art. The motive components may include at least one caster **56** which, in this embodiment, drives the robot **40** and mates with the depression **26** on the base plate **12**. As the tasks to which the robotic device **40** is suited are virtually unlimited, so too are the components to perform those tasks. For example, the robotic device **40** may be used for floor waxing and polishing, floor scrubbing, ice resurfacing (as typically performed by equipment manufactured under the brand name Zamboni®), sweeping and vacuuming, unfinished floor sanding and stain/paint application, ice melting and snow removal, grass cutting, etc. Any number of components may be required for such tasks, and may each be incorporated into the robotic device **40**, as necessary. For simplicity, this application will describe vacuuming as the demonstrative predetermined task. It will be apparent, though, that the energy management and auto-docking functions disclosed herein have wide application across a variety of robotic systems.

The robotic device **40** uses a variety of behavioral modes to vacuum effectively a working area. Behavioral modes are layers of control systems that can be operated in parallel. The microprocessor is operative to execute a prioritized arbitration scheme to identify and implement one or more dominant behavioral modes for any given scenario, based upon inputs from the sensor system. The microprocessor is also operative to coordinate avoidance, homing, and docking maneuvers with the base station **10**.

Generally, the behavioral modes for the described robotic device **40** can be characterized as: (1) coverage behavioral modes; (2) escape behavioral modes, and (3) safety behavioral modes. Coverage behavioral modes are primarily designed to allow the robotic device **40** to perform its operations in an efficient and effective manner, while the escape and safety behavioral modes are priority behavioral modes implemented when a signal from the sensor system indicates that normal operation of the robotic device **40** is impaired (e.g., obstacle encountered), or is likely to be impaired (e.g., drop-off detected).

Representative and illustrative coverage behavioral modes (for vacuuming) for the robotic device **40** include: (1) a Spot Coverage pattern; (2) an Obstacle-Following (or Edge-Cleaning) Coverage pattern, and (3) a Room Coverage pattern. The Spot Coverage pattern causes the robotic device **40** to clean a limited area within the defined working area, e.g., a high-traffic area. In a certain embodiments the Spot Coverage pattern is implemented by means of a spiral algorithm (but other types of self-bounded area algorithms, such as polygonal, can be used). The spiral algorithm, which causes outward or inward spiraling movement of the robotic device **40**, is implemented by control signals from the microprocessor to the motive system to change the turn radius/radii thereof as a function of time or distance traveled (thereby increasing/decreasing the spiral movement pattern of the robotic device **40**).

The robotic device **40** is operated in the Spot Coverage pattern for a predetermined or random period of time, for a predetermined or random distance (e.g., a maximum spiral distance) and/or until the occurrence of a specified event, e.g., activation of one or more of the obstacle detection systems (collectively a transition condition). Once a transition condition occurs, the robotic device **40** can implement or transition to a different behavioral mode, e.g., a Straight Line behavioral mode (in one embodiment of the robotic device **40**, the Straight Line behavioral mode is a low priority, default behavior that propels the robot in an approximately straight line at a preset velocity of approximately 0.306 m/s) or a Bounce behavioral mode in combination with a Straight Line behavioral mode. The Bounce behavioral mode is a basic function that allows the robot **40** to evade a stationary object or obstacle and continue its task routine. Avoidance is achieved by executing a series of turns until the obstacle is no longer detected (i.e., the bumper **48** is no longer compressed).

If the transition condition is the result of the robotic device **40** encountering an obstacle, the robotic device **40** can take other actions in lieu of transitioning to a different behavioral mode. The robotic device **40** can momentarily implement a behavioral mode to avoid or escape the obstacle and resume operation under control of the spiral algorithm (i.e., continue spiraling in the same direction). Alternatively, the robotic device **40** can momentarily implement a behavioral mode to avoid or escape the obstacle and resume operation under control of the spiral algorithm (but in the opposite direction—reflective spiraling).

The Obstacle-Following Coverage pattern causes the robotic device **40** to clean the perimeter of the defined working area, e.g., a room bounded by walls, and/or the perimeter of an obstacle (e.g., furniture) within the defined working area. Preferably, the robotic device **40** utilizes an obstacle-following system to continuously maintain its position with respect to an obstacle, such as a wall or a piece of furniture, so that the motion of the robotic device **40** causes it to travel adjacent to and concomitantly clean along the perimeter of the obstacle. Different embodiments of the obstacle-following system can be used to implement the Obstacle-Following behavioral pattern.

In certain embodiments, the obstacle-following system is operated to detect the presence or absence of the obstacle. In an alternative embodiment, the obstacle-following system is operated to detect an obstacle and then maintain a predetermined distance between the obstacle and the robotic device **40**. In the first embodiment, the microprocessor is operative, in response to signals from the obstacle-following system, to implement small clockwise or counterclockwise turns to maintain its position with respect to the obstacle. The robotic device **40** implements a small clockwise turn when the robotic device **40** transitions from obstacle detection to non-detection (reflection to non-reflection) or to implement a small counterclockwise turn when the robotic device **40** transitions from non-detection to detection (non-reflection to reflection). Similar turning behaviors are implemented by the robotic device **40** to maintain the predetermined distance from the obstacle.

The robotic device **40** is operated in the Obstacle-Following behavioral mode for a predetermined or random period of time, for a predetermined or random distance (e.g., a maximum or minimum distance) and/or until the occurrence of a specified event, e.g., activation of one or more of the obstacle detection system a predetermined number of times (collectively a transition condition). In certain embodiments, the microprocessor will cause the robotic device **40** to implement an Align behavioral mode upon activation of the obstacle-detection system in the Obstacle-Following behavioral mode, wherein the robot **40** implements a minimum angle counterclockwise turn to align the robotic device **40** with the obstacle.

The Room Coverage pattern can be used by the robotic device **40** to clean any defined working area that is bóunded by walls, stairs, obstacles or other barriers (e.g., a virtual wall unit that prevents the robotic device **40** from passing through an otherwise unbounded zone). Certain embodiments of the Room Coverage pattern include the Random-Bounce behavioral mode in combination with the Straight Line behavioral mode. Initially, the robotic device **40** travels under control of the Straight-Line behavioral mode (wheels operating at the same rotational speed in the same direction) until an obstacle is encountered. The obstacle may be indicated by physical contact with a wall or detection of the base station avoidance signal. Upon activation of one or more of the obstacle detection system, the microprocessor is operative to compute an acceptable range of new directions based upon the obstacle detection system activated. The microprocessor selects a new heading from within the acceptable range and implements a clockwise or counterclockwise turn to achieve the new heading with minimal movement. In some embodiments, the new turn heading may be followed by forward movement to increase the cleaning efficiency of the robotic device **40**. The new heading may be randomly selected across the acceptable range of headings, or based upon some statistical selection scheme, such as Gaussian distribution. In other embodiments of the Room. Coverage behavioral mode, the microprocessing unit can be programmed to change headings randomly or at predetermined times, without input from the sensor system.

The robotic device **40** is operated in the Room Coverage behavioral mode for a predetermined or random period of time, for a predetermined or random distance (e.g., a maximum or minimum distance) and/or until the occurrence of a specified event, e.g., activation of the obstacle-detection system a predetermined number of times (collectively a transition condition).

Certain embodiments of the robotic device **40** include four escape behavioral modes: a Turn behavioral mode, an Edge behavioral mode, a Wheel Drop behavioral mode, and a Slow behavioral mode. One skilled in the art will appreciate that other behavioral modes can be utilized by the robotic device **40**. One or more of these behavioral modes may be implemented, for example, in response to a current rise in one of the task components (indicating some sort of interference), the forward bumper **48** being in compressed position for determined time period, or detection of a wheel-drop event.

In the Turn behavioral mode, the robotic device **40** turns in place in a random direction, starting at higher velocity (e.g., twice normal turning velocity) and decreasing to a lower velocity (one-half normal turning velocity), i.e., small panic turns and large panic turns, respectively. Low panic turns are preferably in the range of 45° to 90°, large panic turns are preferably in the range of 90° to 270°. The Turn behavioral mode prevents the robotic device **40** from becoming stuck on surface impediments (e.g., high spot on carpet), from becoming stuck under other obstacles (e.g., an overhang), or from becoming trapped in a confined area.

In the Edge behavioral mode, the robotic device **40** follows the edge of an obstacle unit it has turned through a predetermined number of degrees, without activation of any of the obstacle detection units, or until the robotic device **40** has turned through a predetermined number of degrees, since initiation of the Edge behavioral mode. The Edge behavioral mode allows the robotic device **40** to move through the smallest possible openings to escape from confined areas.

In the Wheel Drop behavioral mode, the microprocessor reverses the direction of the main wheel drive assemblies momentarily, then stops them. If the activated wheel drop sensor deactivates within a predetermined time, the microprocessor then reimplements the behavioral mode that was being executed prior to the activation of the wheel drop sensor.

In response to certain events, e.g., activation of a wheel drop sensor or a cliff detector, the Slow behavioral mode is implemented to slow down the robotic device **40** for a predetermined distance and then ramp back up to its normal operating speed.

When a safety condition is detected by the sensor subsystem, e.g., a series of task component or wheel stalls that cause the corresponding electric motors to be temporarily cycled off, or a wheel drop sensor or a cliff detection sensor activated for greater that a predetermined period of time, the

robotic device **40** is generally cycled to an off state. In addition, an audible alarm may be generated.

The foregoing description of typical behavioral modes for the robotic device **40** are intended to be representative of the types of operating modes that can be implemented by the robotic device **40**. One skilled in the art will appreciate that the behavioral modes described above can be implemented in other combinations and other modes can be defined to achieve a desired result in a particular application.

A navigational control system may be used advantageously in combination with the robotic device **40** to enhance the cleaning efficiency thereof, by adding a deterministic component (in the form of a control signal that controls the movement of the robotic device **40**) to the motion algorithms, including random motion, autonomously implemented by the robotic device **40**. The navigational control system operates under the direction of a navigation control algorithm. The navigation control algorithm includes a definition of a predetermined triggering event.

Broadly described, the navigational control system, under the direction of the navigation control algorithm, monitors the movement activity of the robotic device **40**. In one embodiment, the monitored movement activity is defined in terms of the "position history" of the robotic device **40**, as described in further detail below. In another embodiment, the monitored movement activity is defined in terms of the "instantaneous position" of the robotic device **40**.

The predetermined triggering event is a specific occurrence or condition in the movement activity of the robotic device **40**. Upon the realization of the predetermined triggering event, the navigational control system operates to generate and communicate a control signal to the robotic device **40**. In response to the control signal, the robotic device **40** operates to implement or execute a conduct prescribed by the control signal, i.e., the prescribed conduct. This prescribed conduct represents a deterministic component of the movement activity of the robotic device **40**.

While the robotic device **40** is vacuuming, it will periodically approach the stationary base station **10**. Contact with the base station **10** could damage or move the base station into an area that would make docking impossible. Therefore, avoidance functionality is desirable. To avoid inadvertent contact, the base station **10** may generate an avoidance signal **60**, as depicted in FIG. **3**. The avoidance signal **60** is shown being transmitted from the emitter **18** on the top of the backstop **14**. The radial range of the avoidance signal **60** from the base station **10** may vary, depending on predefined factory settings, user settings, or other considerations. At a minimum, the avoidance signal **60** need only project a distance sufficient to protect the base station **10** from unintentional contact with the robot **40**. The avoidance signal **60** range can extend from beyond the periphery of the base station **10**, to up to and beyond several feet from the base station **10**, depending on the application.

Here, the avoidance signal **60** is depicted as an omni-directional (i.e., single plane) infrared beam, although other signals are contemplated, such as a plurality of single stationary beams or signals. If stationary beams are used, however, a sufficient number could provide adequate coverage around the base station **10** to increase the chances of the robotic device **40** encountering them. When the detector **50** of the robotic device **40** receives the avoidance signal **60** from the emitter **18**, the robotic device **40** can alter its course, as required, to avoid the base station **10**. Alternatively, if the robotic device **40** is actively or passively seeking the base station **10** (for recharging or other docking purposes), it can alter its course toward the base station **10**, such as by circling the base station **10**, in such a way to increase the chances of encountering the homing signals described with respect to FIGS. **4**A-**4**B below.

In certain embodiments, a collimated IR emitter is used, such as Waitrony p/n IE-320H. Because of potential interference from sunlight and other IR sources, most IR devices, such as remote controls, personal digital assistants and other IR communication devices, emit signals that may be modulated. Herein, the emitters **18**, **20** modulate the beams at 38 kHz. In an embodiment of the present invention, additional modulation of the beams at a frequency, for example 500 Hz, different from the frequency of common IR bit streams, prevents interference with other IR equipment. Generally, the avoidance signal **60** is coded, as are the homing signals **62**, **64**. The bit encoding method as well as binary codes are selected such that the robot **40** can detect the presence of each signal, even if the robot **40** receives multiple codes simultaneously.

Whenever measurable level of IR radiation from the avoidance signal **60** strikes the detector **50**, the robot's IR avoidance behavior is triggered. In one embodiment, this behavior causes the robot **40** to spin in place to the left until the IR signal falls below detectable levels. The robot **40** then resumes its previous motion. Spinning left is desired in certain systems because, by convention, the robot may attempt to keep all objects to its right during following operations. The robot's avoidance behavior is consistent with its other behaviors if it spins left on detecting the avoidance signal **60**. In one embodiment, the detector **50** acts as a gradient detector. When the robot **40** encounters a region of higher IR intensity, the robot **40** spins in place. Because the detector **50** is mounted at the front of the robot **40** and because the robot **40** does not move backward, the detector **50** always "sees" the increasing IR intensity before other parts of the robot **40**. Thus, spinning in place causes the detector **50** to move to a region of decreased intensity. When the robot **40** next moves forward, it necessarily moves to a region of decreased IR intensity—away from the avoidance signal **60**.

In other embodiments, the base station **10** includes multiple coded emitters at different power levels or emitters that vary their power level using a system of time multiplexing. These create concentric coded signal rings which enable the robot **40** to navigate towards the base station **10** from far away in the room. Thus, the robot **40** would be aware of the presence of the base station **10** at all times, facilitating locating the base station **10**, docking, determining how much of the room has been cleaned, etc. Alternatively, the robot **40** uses its motion through the IR field to measure a gradient of IR energy. When the sign of the gradient is negative (i.e., the detected energy is decreasing with motion), the robot **40** goes straight (away from the IR source). When the sign of the gradient is positive (energy increasing), the robot **40** turns. The net effect is to implement a "gradient descent algorithm," with the robot **40** escaping from the source of the avoidance signal **60**. This gradient method may also be used to seek the source of emitted signals. The concentric rings at varying power levels facilitate this possibility even without a means for determination of the raw signal strength.

A flowchart of one embodiment of the control logic of the avoidance behavior **100** is shown in FIG. **6**A. The robot **40** determines whether the signal **110** detected by the detector **50** is an avoidance signal **60**. If an avoidance signal **60** is detected, the robot **40** chooses a turning direction **120**. The robot **40** then begins to turn in the chosen direction until the avoidance signal **60** is no longer detected **130**. Once the avoidance signal **60** is no longer detected, the robot **40** continues turning for an additional amount **140**, such as 20°, or the robot may turn randomly between 0° and 135°.

While in flowchart step **120**, the direction selection algorithm **120***a*, illustrated in the flowchart shown in FIG. **6**B, is used. The robot's control logic keeps track of the robot's discrete interactions with the beam. The robot **40** first increments a counter by one **122**. On odd numbered interactions, the robot **40** chooses a new turning direction randomly **124**, **126**; on even numbered interactions, the robot **40** again uses its most recent turning direction. In the alternative, the robot **40** may choose which direction to turn at random. It will continue to turn in that direction until it has moved a sufficient distance.

In other embodiments, the robot **40** can always turn in a single direction or choose a direction randomly. When the robot **40** always turns in one direction, it may get stuck in a loop by turning away from the beam, bumping into another obstacle in a room, turning back toward the beam, seeing the beam again, turning away, bumping again, ad infinitum. Moreover, when the robot **40** only turns in a single direction, it consequently may fail to vacuum certain areas of the floor. Thus, where the robot's task is to complete work evenly throughout a room, a single turning direction may not be optimal. If the direction is chosen purely randomly, the robot **40** may turn back and forth often, as it encounters the beam.

Again referring to FIG. **6**A, in the embodiment of step **140**, the robot **40** turns an additional 20° from the point at which the avoidance signal **60** is lost. The arc of the turn can be varied for the particular robot **40** and application. The additional turn helps to prevent the robot **40** from re-encountering the avoidance signal **60** immediately after first encountering it. For various applications, the amount of additional movement (linear or turning) can be a predetermined distance, angle or time, or in the alternative may include a random component. In still other embodiments, the robot's avoidance behavior may include reversing the robot's direction until the avoidance signal **60** is no longer detected, or as described above, the robot may turn randomly between 0° and 135° after losing the avoidance signal **60**.

FIGS. **4**A-**4**C depict the robotic device **40** in various stages of seeking the base station **10** by using the homing signals **62**, **64**. The robotic device **40** may seek the base station **10** when it detects the need to recharge its battery, or when it has completed vacuuming the room. As described above, once the robotic device **40** detects the presence of the avoidance signal **60** (and therefore the base station **10**), it can move as required to detect the homing signals **62**, **64**. As with the avoidance signal **60** above, the projected range and orientation of the homing signals **62**, **64** may be varied, as desired. It should be noted however, that longer signals can increase the chance of the robot **40** finding the base station **10** efficiently. Longer signals can also be useful if the robotic device **40** is deployed in a particularly large room, where locating the base station **10** randomly could be inordinately time consuming. Homing signal **62**, **64** ranges that extend from approximately six inches beyond the front of the base plate **12**, to up to and beyond several feet beyond the base plate **12** are contemplated, depending on application. Naturally, the angular width of the homing signals **62**, **64** may vary depending on application, but angular widths in the range of 5° to up to and beyond 60° are contemplated. A gradient behavior as described above can also be used to aid the robot in seeking out the base station.

In addition to operating as navigational beacons, horning signals **62**, **64** (and even the avoidance signal **60**) may also be used to transmit information, including programming data, fail safe and diagnostic information, docking control data and information, maintenance and control sequences, etc. In such an embodiment, the signals can provide the control information, dictating the robot's reactions, as opposed to the robot **40** taking certain actions upon contacting certain signals from the base station **10**. In that case, the robot **40** functions as more of a slave to the base station **10**, operating as directed by the signals sent.

The robot **40** performs its docking with the base station **10** accurately and repeatably, without the need for gross mechanical guidance features. The two homing signals **62**, **64** are distinguishable by the robotic device, for example as a red signal **62** and a green signal **64**. IR beams are generally used to produce the signals and, as such, are not visible. The color distinction is given for illustrative purposes only, and any "color" (i.e., signal bit pattern) may be used, provided the robotic device **40** recognizes which signal to orient a particular side. Alternatively, the signals **62**, **64** may be distinguished by using different wavelengths or by using different carrier frequencies (e.g., 380 kHz versus 38 kHz, etc.).

Thus, when the robotic device **40** wants or needs to dock, if the detector **50** receives the red signal **62** transmitting from the base station **10**, it moves to keep the red signal **62** on the robot's right side; if it detects the green signal **64** transmitting from the base station **10**, it moves to keep the green signal **64** on the robot's left side. Where the two signals overlap (the "yellow" zone **66**), the robot **40** knows that the base station **10** is nearby and may then dock. Such a system may be optimized to make the yellow zone **66** as thin as practicably possible, to ensure proper orientation and approach of the robot **40** and successful docking. Alternatively, the red signal **62** and green signal **64** may be replaced by a single signal, which the robot **40** would follow until docked.

FIGS. **4**A-**4**C depict, at various stages, a docking procedure utilizing two signals. In FIG. **4**A, the detector **50** is in the green or left signal **64** field, and thus the robotic device **40** will move towards the right, in direction M_R in an effort to keep that green signal **64** to the left of the robot **40** (in actuality, the robot **40** moves to keep the green signal **64** to the left of the detector **50**). Similarly, in FIG. **4**B, the detector **50** is in the red or right signal **62** field, and thus the robotic device **40** will move towards the left, in direction M_L in an effort to keep that red signal **64** to the right of the detector **50**. Last, in FIG. **4**C, the detector **50** has encountered yellow zone **66**. At this point, the robotic device **40** will move in direction M_F directly towards the base station **10**. While approaching the base station **10**, the robotic device **40** may slow its speed of approach and/or discontinue vacuuming, or perform other functions to ensure trouble-free docking. These operations may occur when the robot **40** detects the avoidance signal **60**, thus recognizing that it is close to the base station **10**, or at some other predetermined time, e.g., upon a change in the signal from the emitters **62**, **64**.

Various methods are contemplated for ensuring that the robot **4**Q correctly docks with base station **10**. For example, the robot **40** can continue to move toward the base station **10** (within the yellow zone **66**) until the bumper **48** is depressed, signaling the robot **40** that it has contacted the base station **10**. Another embodiment overlaps the horning signals **62**, **64** such that the yellow zone **66** terminates at a point calibrated such that the robot **40** will contact the charging contacts **16** upon reaching the termination point. Other embodiments simply stop the robot **40** when its electrical contacts touch the electrical contacts **16** on the base station **10**. This would guarantee that the robot **40** is moving over the contacts **16**, providing a wiping action that cleans the contacts **16** and improves the electrical integrity of the connection. This also enables the base station **10** to be lighter, since it does not have to resist the force necessary to depress the robot's bumper **48**. FIG. **5** shows the robotic device **40** completely docked with

the base station **10**. Naturally, this procedure may also utilize detector **52** or a combination of both detectors.

While this embodiment of the invention describes use of IR signals for both avoidance and homing, the system and method of the present invention can use other signals to accomplish the goals. Other types of waves may have drawbacks, however. For example, radio waves are more difficult and expensive to make directional, and visible light suffers from interference from many sources and may be distracting to users. Sound waves could also be used, but it is similarly difficult to make sound purely directional and such waves tend to scatter and reflect more.

FIG. **7** depicts a schematic diagram which shows the control sequence **200** of the robotic device **40** during vacuuming. Generally, the control sequence **200** includes three subsequences based on the measured energy level of the robotic device **40**. Those are referenced generally as a high energy level **210**, a medium energy level **220**, and a low energy level **230**. In the high energy level subsequence **210**, the robotic device **40** performs its predetermined task, in this case, vacuuming (utilizing various behavioral modes as described above), while avoiding the base station **212**. When avoiding the base station **212**, the robotic device **40** performs its avoidance behavior and continues to operate normally. This process continues while the robotic device **40** continually monitors its energy level **214**. Various methods are available to monitor the energy level **214** of the power source, such as coulometry (i.e., the measuring of current constantly entering and leaving the power source), or simply measuring voltage remaining in the power source. Other embodiments of the robotic device **40** may simply employ a timer and a look-up table stored in memory to determine how long the robotic device **40** can operate before it enters a different energy level subsequence. Still other embodiments may simply operate the robot **40** for a predetermined time period before recharging, without determining which energy level subsequence it is operating in. If the robot **40** operates on a liquid or gaseous fuel, this level may also be measured with devices currently known in the art.

Once the energy remaining drops below a predetermined high level, the robot **40** enters its medium energy level sequence **220**. The robot **40** continues to vacuum and monitor its energy level **224**, employing methods indicated in step **214** above. In the medium energy level **220**, however, the robot **40** "passively seeks" **222** the base station **10**. While passively seeking **222** the base station **10**, the robot **40** does not alter its travel characteristics; rather, it continues about its normal behavioral mode until it fortuitously detects the avoidance signal **60** or a homing signal **62**, **64**, each of which tray be followed until the robot **40** ultimately docks with the base station **10**. In other words, if the robot detects the avoidance signal **60** while passively seeking **222**, rather than avoiding the base station **10** as it normally would, it alters its travel characteristics until it detects the homing signals **62** or **64**, thus allowing it to dock.

Alternatively, the robot **40** continues operating in this medium energy level subsequence **220** until it registers an energy level **224** below a predetermined low level. At this point, the robot **40** enters the low level subsequence **230**, characterized by a change in operation and travel characteristics. To conserve energy, the robot **40** may discontinue powering all incidental systems, and operations, such as vacuuming, allowing it to conserve as much energy as possible for "actively searching" **232** for the base station **10**. While actively searching **232**, the robot **40** may alter its travel characteristics to increase its chances of finding the base station **10**. It may discontinue behavioral modes such as those employing a spiral movement, which do not necessarily create a higher chance of locating the base station, in favor of more deliberate modes, such as wall-following. This deliberate seeking will continue until the robot **40** detects the presence of the base station **10**, either by detecting the avoidance signal **60** or the homing signals **62**, **64**. Clearly, additional subsequences may be incorporated which sound alarms when the power remaining reaches a critical level, or which reconstruct the route the robot **40** has taken since last contacting the base station **10** to aid in relocating the station **10**.

The robot **40** may also dock because it has determined that it has completed its assigned task (e.g., vacuuming a room). The robot **40** may make this determination based on a variety of factors, including considerations regarding room size, total run time, total distance traveled, dirt sensing, etc. Alternatively, the robot may employ room-mapping programs, using the base station **10** and/or walls and large objects as points of reference. Upon determining that it has completed its task, the robot **40** will alter its travel characteristics in order to find the base station **10** quickly.

Once the robot **40** contacts the base station **10**, it can recharge itself autonomously. Circuitry within the base station **10** detects the presence of the robot **40** and then switches on the charging voltage to its contacts **16**. The robot **40** then detects the presence of the charging voltage and then switches on its internal transistor power switch to allow current flow into the battery. In one embodiment, the base station **10** contains a constant-current type switching charger. Maximum current is limited to approximately 1.25 amps even under a short circuit condition. Maximum unloaded terminal voltage is limited to approximately 22Vdc. This constant-current charging circuit is used to charge the battery in the robot **40** via the electrical connections provided by the contacts **16** on the base station **10** and those on the undercarriage **54** of the robot **40**. One embodiment of this charging sequence is detailed below.

Generally, while the robot **40** is away from the base station **10**, the charging contacts **16** will present five volts, limited to 1 mA maximum short circuit current flow. This low voltage/low current "sense" condition limits the amount of available energy at the contacts **16**, thus rendering them safe in the event they are contacted by humans, animals, and electrically conductive objects. The contacts on the undercarriage **54** of the robot **40**, when contacting the contacts **16** on the base station **10**, present a precise resistive load that, along with a resistor in the base station **10**, creates a high impedance voltage divider. A microprocessor that constantly monitors the voltage across the contacts **16** recognizes this lower voltage. This voltage divider creates a specific voltage, plus or minus a known tolerance. When the microprocessor determines that the voltage has fallen into the specific range, it detects that the robot **40** is present. The microprocessor then turns on a transistor switch that delivers a higher voltage/current charge (capable of charging the robot's internal battery) to the charging contacts **16**. Alternatively, the robot **40** and/or base station **10** can verify the integrity of the charging circuit by sending signals through the IR beams, thereby confirming that the robot **40** has, in fact, docked.

FIG. **8** depicts an embodiment of the charger circuitry schematic. With five volts being presented by the base station, it is the job of resistor dividers R**101** and R**116** to hold Q**48** and Q**5** off when J**25** is in contact with the initial low voltage state. This divider also provides the known impedance of R**101** plus R**116** in parallel with R**224** plus the base-emitter diode drop of Q**48**. This Thevenin impedance is in series with a resistor in the docking station thus forming a voltage divider. A window comparator circuit within the docking

station looks for a specific voltage created by the divider. Once the base station has determined this impedance is likely the robot (not some other conductive body), it then delivers the full 22 volt capable, 1.25 Amp charging voltage to the robot.

At the onset of this higher voltage, the divider of R**101** and R**224** are such that the requirements are met to turn on Q**48** and Q**5** respectively. It is this combination of transistors that then allows current to flow to the on-board robot electronics only, allowing the robot's processor to become active if in fact it was inoperative due to a depleted battery.

Once operative, the robot's processor is then able to detect the presence of the base station voltage via R**113** and D**15** and if driving, turn off its drive motors. Once stable on the charging contacts, it becomes the job of the robot processor to measure the internal robot battery and decide when and what type of charging control cycle is needed when allowing current to flow into the battery. For example, if the battery is at 12 volts, then it is acceptable to turn on Q**45** and Q**47** via processor control, in order to allow current to flow through FET U9 to the battery on a continuous basis.

If, however, the battery voltage is deemed less than 5 volts, it generally would not be desirable to allow the full current to flow to the battery on a continuous basis. The reason this condition is of concern lies in the fact that the power source within the DOC is a constant current charger, which will adjust its output voltage to be slightly higher than the battery voltage in order to flow 1.25 A into the battery. In some cases, this might be millivolts higher than the battery voltage itself and in the case of the battery at low voltage, for example, 3 volts, would cause the output voltage to drop below the necessary 5 volt level needed to operate the on board base station and robot electronics suite.

In this case, the robot processor then delivers a pulse width modulation to the charger control line pertaining to Q**47**, such that the energy storage capacitors in both the robot and base station maintain enough charge to keep their respective electronics working properly throughout the charge pulse. The energy storage capacitors are then replenished during the off time of the pulse width modulation charging cycle, ready to then sustain the next charge pulse. This scenario continues until the battery has been charged to the point where a continuous charge is no longer able to bring the supply voltage down to a critical level and the charge control can become a static level.

Since this pulse width modulation process in this embodiment relies on software control, health monitoring of the processor, both within the base station and robot, are important. The requirement then set fourth for charging is for a charger "watchdog" be incorporated via Q**45** such that a static high or low state on this signal line will disable current flow into the battery. It is a requirement of the robot processor to continuously pulse this control line in order for any current to flow, therefore eliminating most cases of processor latch up due to electrostatic discharge or other battery related events from mistreating the charging profile. Naturally, other control and related fail safe schemes could be utilized.

The described charging sequence provides particular safety features, even though the charging contacts **16** are exposed and energized. Because a specific resistance required to create a specific voltage drop across the contacts **16** when the 5-volt sense voltage is present (i.e., when the robot **40** is not docked) there is no danger of electric shock due to accidental contact because the low sense current is harmless. Also, the base station **10** will never switch to the higher voltage/current level, because the sense current has not entered the predetermined range. When the base station **10** does determine that the robot **40** is present, it delivers the charging voltage/current. This charging current is limited to approximately 22 volts/1.25 amps maximum. Even if inadvertent contact occurred during delivery of the charging current—which is unlikely, since the robot chassis **44** effectively blocks the contacts **16**—the voltage delivered would not present a serious shock hazard, as it is relatively low.

Another level of safety is afforded by the base station **10** checking for the robot **40** at regular intervals, from as little as once per minute to as much as 10 times per second or more. Thus, in the event that the robot **40** is dislodged from the base station **10** (either by an animal or human), the charging current could be shut down immediately. This same condition applies if the contacts **16** are short circuited with the robot **40** docked (either intentionally or accidentally, for example, if the robot **40** drags debris onto the charging contacts **16**).

An additional safety feature of this charging sequence prevents overheating of contacts **16** due to intentional shorting or oxidation. A thermal circuit breaker or similar device can be employed to perform this task, as well as a microprocessor equipped with a temperature measuring subroutine. The circuit breaker, however, provides the advantage of controlling contact temperature in the event of a microprocessor or software failure. Additionally, the base station **10** circuitry can also incorporate a timer to reset the temperature measuring subroutine or circuit breaker in the event of system failure. These safety controls may be incorporated into the "watchdog" described above.

While docked with the base station **10**, the robot **40** can also perform other maintenance or diagnostic checks. In certain embodiments, the robot **40** can completely recharge its power source or only partially charge it, based on various factors. For example, if the robot **40** determines, through the use of route-tracking subroutines, that only a small portion of the room still requires vacuuming, it may take only a minimal charge before returning to complete cleaning of the room. If, however, the robot **40** requires a full charge before returning to clean the room, that option is also available. If the robot **40** has completed its vacuuming of the room prior to docking, it may dock, fully recharge, and stand by to await a signal (either internal or external) to begin its next cleaning cycle. While in this stand-by mode, the robot **40** may continue to measure its energy levels and may begin charging sequences upon reaching an energy level below a predetermined amount. Alternatively, the robot **40** may maintain a constant or near-constant trickle charge to keep its energy levels at or near peak. Other behaviors while in the docking position such as diagnostic functions, internal mechanism cleaning, communication with network, or data manipulation functions may also be performed.

While there have been described herein what are to be considered exemplary and preferred embodiments of the present invention, other modifications of the invention will become apparent to those skilled in the art from the teachings herein. The particular methods of manufacture and geometries disclosed herein are exemplary in nature and are not to be considered limiting. It is therefore desired to be secured in the appended claims all such modifications as fall within the spirit and scope of the invention. Accordingly, what is desired to be secured by Letters Patent is the invention as defined and differentiated in the following claims.

What is claimed is:

1. An autonomous cleaning robot, comprising:

an undercarriage;

a wheel extending from the undercarriage toward a ground surface to support at least a portion of the mobile device above the ground surface;

an energy storage unit supported by the undercarriage and configured to be charged while the robot is positioned at a base station;

a navigational control system configured to direct the robot about a room, including mapping the room with respect to walls and objects as points of reference, and to monitor an amount of room remaining to be cleaned;

wherein the robot is configured to control charging as a function of the amount of room remaining to be cleaned.

2. The autonomous cleaning robot of claim **1**, wherein the control system is configured to track a cleaning route of the robot and to thereby monitor the amount of room remaining to be cleaned.

3. The autonomous cleaning robot of claim **1**, wherein the control system is configured to use a known position of the base station as a point of reference in mapping the room.

4. The autonomous cleaning robot of claim **1**, wherein the control system is configured to alter a travel characteristic of the robot upon determining that the robot has completed a task, to direct the robot to the base station for charging.

5. The autonomous cleaning robot of claim **1**, wherein the robot is configured to control charging at the base station by only partially charging the energy storage unit before leaving the base station.

6. The autonomous cleaning robot of claim **5**, wherein the robot is configured to leave the base station and continue cleaning the room upon determining that the energy storage unit has reached a minimum amount of stored energy necessary to complete cleaning of the room.

7. The autonomous cleaning robot of claim **1**, wherein the robot is configured to control charging at the base station by remaining at the base station and continuing to monitor remaining energy of the energy storage unit upon determining that the robot has completed cleaning the room.

8. The autonomous cleaning robot of claim **1**, wherein the robot is configured to return to the base station when a quantity of energy remaining in the energy storage unit falls to a predetermined threshold.

9. The autonomous cleaning robot of claim **8**, wherein the navigational control system is configured to direct the robot to the base station by seeking a base station homing signal.

10. The autonomous cleaning robot of claim **8**, wherein the robot is configured to determine the quantity of energy in the energy storage unit using at least one of coulomtery and operating time.

11. The autonomous cleaning robot of claim **1**, wherein the robot is configured to disable a cleaning function while returning to the base station for charging.

12. The autonomous cleaning robot of claim **1**, wherein the energy storage unit comprises a battery.

13. The autonomous cleaning robot of claim **1**, wherein the energy storage unit comprises electrical contacts arranged to make electrical contact with the base station during charging.

* * * * *