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(54) **RASTER-BASED CONTOUR SWATHING FOR GUIDANCE AND VARIABLE-RATE CHEMICAL APPLICATION**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,586,537 A 6/1971 Rennick
3,596,228 A 7/1971 Reed, Jr.
(Continued)

FOREIGN PATENT DOCUMENTS

AU 2002244539 10/2002
AU 2002244539 B2 10/2002
(Continued)

OTHER PUBLICATIONS

Noh, Kwang-Mo, Self-tuning controller for farm tractor guidance, Iowa State University Retrospective Theses and Dissertations, Paper 9874, (1990).
(Continued)

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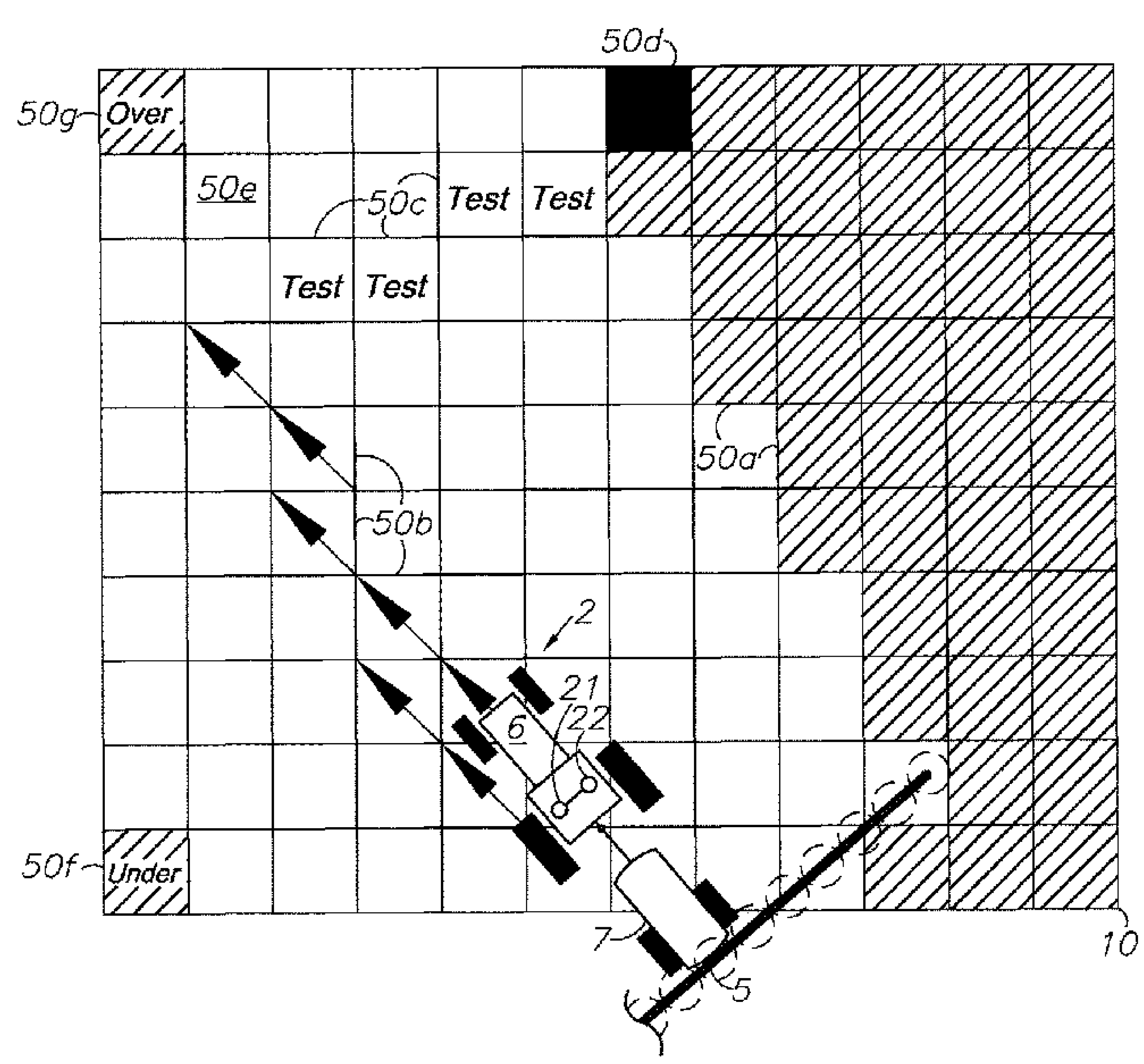
(57) **ABSTRACT**

A raster-based system for global navigation satellite system (GNSS) guidance includes a vehicle-mounted GNSS antenna and receiver. A processor provides guidance and/or autosteering commands based on GNSS-defined pixels forming a grid representing an area to be treated, such as a field. Specific guidance and chemical application methods are provided based on the pixel-defined treatment areas and preprogrammed chemical application prescription maps, which can include variable chemical application rates and dynamic control of the individual nozzles of a sprayer.

6 Claims, 9 Drawing Sheets



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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,727,710	A	4/1973	Sanders
3,815,272	A	6/1974	Marleau
3,899,028	A	8/1975	Morris
3,987,456	A	10/1976	Gelin
4,132,272	A	1/1979	Holloway
4,170,776	A	10/1979	MacDoran
4,180,133	A	12/1979	Collogan
4,398,162	A	8/1983	Nagai
4,453,614	A	6/1984	Allen
4,529,990	A	7/1985	Brunner
4,637,474	A	1/1987	Leonard
4,667,203	A	5/1987	Counselman, III
4,689,556	A	8/1987	Cedrone
4,694,264	A	9/1987	Owens
4,710,775	A	12/1987	Coe
4,714,435	A	12/1987	Stipanuk
4,739,448	A	4/1988	Rowe
4,751,512	A	6/1988	Longaker
4,769,700	A	9/1988	Pryor
4,785,463	A	11/1988	Janc
4,802,545	A	2/1989	Nystuen
4,812,991	A	3/1989	Hatch
4,813,991	A	3/1989	Hale
4,858,132	A	8/1989	Holmquist
4,864,320	A	9/1989	Munson
4,894,662	A	1/1990	Counselman
4,916,577	A	4/1990	Dawkins
4,918,607	A	4/1990	Wible
4,963,889	A	10/1990	Hatch
5,031,704	A	7/1991	Fleischer
5,100,229	A	3/1992	Lundberg
5,134,407	A	7/1992	Lorenz
5,148,179	A	9/1992	Allison
5,152,347	A	10/1992	Miller
5,155,490	A	10/1992	Spradley
5,155,493	A	10/1992	Thursby
5,156,219	A	10/1992	Schmidt
5,165,109	A	11/1992	Han
5,173,715	A	12/1992	Rodal
5,177,489	A	1/1993	Hatch
5,185,610	A	2/1993	Ward
5,191,351	A	3/1993	Hofer
5,194,851	A	3/1993	Kraning et al.
5,202,829	A	4/1993	Geier
5,207,239	A	5/1993	Schwitalia
5,239,669	A	8/1993	Mason
5,255,756	A	10/1993	Follmer
5,268,695	A	12/1993	Dentinger
5,293,170	A	3/1994	Lorenz
5,294,970	A	3/1994	Dornbusch
5,296,861	A	3/1994	Knight
5,311,149	A	5/1994	Wagner
5,323,322	A	6/1994	Mueller
5,334,987	A	8/1994	Teach
5,343,209	A	8/1994	Sennott
5,345,245	A	9/1994	Ishikawa
5,359,332	A	10/1994	Allison
5,361,212	A	11/1994	Class
5,365,447	A	11/1994	Dennis
5,369,589	A	11/1994	Steiner
5,375,059	A	12/1994	Kyrtsos
5,390,124	A	2/1995	Kyrtsos
5,390,125	A	2/1995	Sennott et al.
5,390,207	A	2/1995	Fenton
5,416,712	A	5/1995	Geier
5,430,654	A	7/1995	Kyrtsos et al.
5,442,363	A	8/1995	Remondi
5,444,453	A	8/1995	Lalezari
5,451,964	A	9/1995	Babu
5,467,282	A	11/1995	Dennis
5,471,217	A	11/1995	Hatch
5,476,147	A	12/1995	Fixemer
5,477,228	A	12/1995	Tiwari
5,477,458	A	12/1995	Loomis
5,490,073	A	2/1996	Kyrtsos
5,491,636	A	2/1996	Robertson
5,495,257	A	2/1996	Loomis
5,504,482	A	4/1996	Schreder
5,511,623	A	4/1996	Frasier
5,519,620	A	5/1996	Talbot
5,521,610	A	5/1996	Rodal
5,523,761	A	6/1996	Gildea
5,534,875	A	7/1996	Diefes
5,543,804	A	8/1996	Buchler
5,546,093	A	8/1996	Gudat
5,548,293	A	8/1996	Cohen
5,561,432	A	10/1996	Knight
5,563,786	A	10/1996	Torii
5,568,152	A	10/1996	Janky
5,568,162	A	10/1996	Samsel
5,583,513	A	12/1996	Cohen
5,589,835	A	12/1996	Gildea
5,592,382	A	1/1997	Colley
5,596,328	A	1/1997	Stangeland
5,600,670	A	2/1997	Turney
5,604,506	A	2/1997	Rodal
5,608,393	A	3/1997	Hartman
5,610,522	A	3/1997	Locatelli
5,610,616	A	3/1997	Vallot
5,610,845	A	3/1997	Slabinski
5,612,883	A	3/1997	Shaffer
5,615,116	A	3/1997	Gudat
5,617,100	A	4/1997	Akiyoshi
5,617,317	A	4/1997	Ignagni
5,621,646	A	4/1997	Enge
5,631,658	A	5/1997	Gudat et al.
5,638,077	A	6/1997	Martin
5,644,138	A	7/1997	Allen
5,646,844	A	7/1997	Gudat et al.
5,663,879	A	9/1997	Trovato et al.
5,664,632	A	9/1997	Frasier
5,673,491	A	10/1997	Brenna
5,680,140	A	10/1997	Loomis
5,684,476	A	11/1997	Anderson
5,684,696	A	11/1997	Rao
5,706,015	A	1/1998	Chen
5,717,593	A	2/1998	Gvili
5,725,230	A	3/1998	Walkup
5,731,786	A	3/1998	Abraham
5,739,785	A	4/1998	Allison
5,757,316	A	5/1998	Buchler
5,765,123	A	6/1998	Nimura
5,777,578	A	7/1998	Chang
5,810,095	A	9/1998	Orbach
5,828,336	A	10/1998	Yunck
5,838,562	A	11/1998	Gudat

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,854,987	A	12/1998	Sekine
5,862,501	A	1/1999	Talbot
5,864,315	A	1/1999	Welles
5,864,318	A	1/1999	Cozenza
5,875,408	A	2/1999	Bendett
5,877,725	A	3/1999	Kalafus
5,890,091	A	3/1999	Talbot
5,899,957	A	5/1999	Loomis
5,906,645	A	5/1999	Kagawa
5,912,798	A	6/1999	Chu
5,914,685	A	6/1999	Kozlov
5,917,448	A	6/1999	Mickelson
5,918,558	A	7/1999	Susag
5,919,242	A	7/1999	Greatline
5,923,270	A	7/1999	Sampo et al.
5,926,079	A	7/1999	Heine
5,927,603	A	7/1999	McNabb
5,928,309	A	7/1999	Korver
5,929,721	A	7/1999	Munn
5,933,110	A	8/1999	Tang
5,935,183	A	8/1999	Sahm
5,936,573	A	8/1999	Smith
5,940,026	A	8/1999	Popeck
5,941,317	A	8/1999	Mansur
5,943,008	A	8/1999	Van Dusseldorp
5,944,770	A	8/1999	Enge
5,945,917	A	8/1999	Harry
5,949,371	A	9/1999	Nichols
5,955,973	A	9/1999	Anderson
5,956,250	A	9/1999	Gudat
5,969,670	A	10/1999	Kalafus
5,987,383	A	11/1999	Keller
6,014,101	A	1/2000	Loomis
6,014,608	A	1/2000	Seo
6,018,313	A	1/2000	Engelmayer
6,023,239	A	2/2000	Kovach
6,052,647	A	4/2000	Parkinson et al.
6,055,477	A	4/2000	McBurney
6,057,800	A	5/2000	Yang
6,061,390	A	5/2000	Meehan
6,061,632	A	5/2000	Dreier
6,062,317	A	5/2000	Gharsalli
6,069,583	A	5/2000	Silvestrin
6,070,673	A	6/2000	Wendte
6,073,070	A	6/2000	Diekhans
6,076,612	A	6/2000	Carr
6,081,171	A	6/2000	Ella
6,100,842	A	8/2000	Dreier
6,122,595	A	9/2000	Varley
6,128,574	A	10/2000	Diekhans
6,144,335	A	11/2000	Rogers
6,191,730	B1	2/2001	Nelson, Jr.
6,191,733	B1	2/2001	Dizchavez
6,198,430	B1	3/2001	Hwang
6,198,992	B1	3/2001	Winslow
6,199,000	B1	3/2001	Keller
6,205,401	B1	3/2001	Pickhard
6,212,453	B1	4/2001	Kawagoe et al.
6,215,828	B1	4/2001	Signell
6,229,479	B1	5/2001	Kozlov
6,230,097	B1	5/2001	Dance
6,233,511	B1	5/2001	Berger
6,236,916	B1	5/2001	Staub
6,236,924	B1	5/2001	Motz
6,253,160	B1	6/2001	Hanseder
6,256,583	B1	7/2001	Sutton
6,259,398	B1	7/2001	Riley
6,266,595	B1	7/2001	Greatline
6,285,320	B1	9/2001	Olster
6,292,132	B1	9/2001	Wilson
6,307,505	B1	10/2001	Green
6,313,788	B1	11/2001	Wilson
6,314,348	B1	11/2001	Winslow
6,325,684	B1	12/2001	Knight
6,336,051	B1 *	1/2002	Pangels A01B 79/005 700/207
6,336,066	B1	1/2002	Pellenc
6,345,231	B2	2/2002	Quincke
6,356,602	B1	3/2002	Rodal
6,377,889	B1	4/2002	Soest
6,380,888	B1	4/2002	Kucik
6,389,345	B2	5/2002	Phelps
6,392,589	B1	5/2002	Rogers
6,397,147	B1	5/2002	Whitehead
6,415,229	B1	7/2002	Diekhans
6,418,031	B1	7/2002	Archambeault
6,421,003	B1	7/2002	Riley
6,424,915	B1	7/2002	Fukuda
6,431,576	B1	8/2002	Viaud
6,434,462	B1	8/2002	Bevly
6,445,983	B1	9/2002	Dickson et al.
6,445,990	B1	9/2002	Manring
6,449,558	B1	9/2002	Small
6,463,091	B1	10/2002	Zhodzicshsky
6,463,374	B1	10/2002	Keller
6,466,871	B1	10/2002	Reisman
6,469,663	B1	10/2002	Whitehead
6,484,097	B2	11/2002	Fuchs
6,501,422	B1	12/2002	Nichols
6,515,619	B1	2/2003	McKay, Jr.
6,516,271	B2	2/2003	Upadhyaya
6,539,303	B2	3/2003	McClure et al.
6,542,077	B2	4/2003	Joao
6,549,835	B2	4/2003	Deguchi
6,553,299	B1	4/2003	Keller
6,553,300	B2	4/2003	Ma
6,553,311	B2	4/2003	Ahearn
6,570,534	B2	5/2003	Cohen
6,577,952	B2	6/2003	Geier
6,587,761	B2	7/2003	Kumar
6,606,542	B2	8/2003	Hauwiller
6,611,228	B2	8/2003	Toda
6,611,754	B2	8/2003	Klein
6,611,755	B1	8/2003	Coffee
6,622,091	B2	9/2003	Perlmutter
6,631,916	B1	10/2003	Miller
6,643,576	B1	11/2003	O'Connor
6,646,603	B2	11/2003	Dooley
6,657,875	B1	12/2003	Zeng
6,671,587	B2	12/2003	Hrovat
6,688,403	B2	2/2004	Bernhardt
6,703,973	B1	3/2004	Nichols
6,711,501	B2	3/2004	McClure
6,721,638	B2	4/2004	Zeitler
6,732,024	B2	5/2004	Rekow
6,744,404	B1	6/2004	Whitehead
6,754,584	B2	6/2004	Pinto
6,774,843	B2	8/2004	Takahashi
6,789,014	B1	9/2004	Rekow et al.
6,792,380	B2	9/2004	Toda
6,804,587	B1	10/2004	O Connor et al.
6,819,269	B2	11/2004	Flick
6,819,780	B2	11/2004	Benson et al.
6,822,314	B2	11/2004	Beasom
6,865,465	B2	3/2005	McClure
6,865,484	B2	3/2005	Miyasaka
6,876,920	B1	4/2005	Mailer
6,900,992	B2	5/2005	Kelly
6,922,635	B2	7/2005	Rorabaugh
6,931,233	B1	8/2005	Tso
6,967,538	B2	11/2005	Woo
6,990,399	B2	1/2006	Hrazdera
7,006,032	B2	2/2006	King
7,026,982	B2	4/2006	Toda
7,027,918	B2	4/2006	Zimmerman
7,031,725	B2	4/2006	Rorabaugh
7,089,099	B2	8/2006	Shostak
7,142,956	B2	11/2006	Heiniger et al.
7,162,348	B2	1/2007	McClure
7,191,061	B2	3/2007	McKay
7,231,290	B2	6/2007	Steichen
7,248,211	B2	7/2007	Hatch
7,271,766	B2	9/2007	Zimmerman

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,277,784	B2	10/2007	Weiss
7,277,792	B2	10/2007	Overschie
7,292,186	B2	11/2007	Miller
7,324,915	B2	1/2008	Altman
7,358,896	B2	4/2008	Gradincic
7,373,231	B2	5/2008	McClure
7,388,539	B2	6/2008	Whitehead
7,395,769	B2	7/2008	Jensen
7,428,259	B2	9/2008	Wang
7,437,230	B2	10/2008	McClure
7,451,030	B2	11/2008	Eglington
7,460,942	B2	12/2008	Mailer
7,479,900	B2	1/2009	Horstemeyer
7,505,848	B2	3/2009	Flann
7,522,100	B2	4/2009	Yang
7,571,029	B2	8/2009	Dai
7,623,952	B2	11/2009	Unruh et al.
7,689,354	B2	3/2010	Heiniger
RE41,358	E	5/2010	Heiniger et al.
8,140,223	B2	3/2012	Whitehead et al.
8,190,337	B2	5/2012	McClure
8,265,826	B2	9/2012	Feller et al.
8,386,129	B2	2/2013	Collins
8,437,901	B2	5/2013	Anderson
8,649,930	B2	2/2014	Reeve et al.
8,718,874	B2	5/2014	McClure
2002/0072850	A1	6/2002	McClure et al.
2002/0107609	A1	8/2002	Benneweis
2003/0014171	A1	1/2003	Ma
2003/0187560	A1	10/2003	Keller et al.
2003/0208319	A1	11/2003	Ell
2004/0039514	A1	2/2004	Steichen
2004/0186644	A1	9/2004	McClure et al.
2004/0212533	A1	10/2004	Whitehead
2005/0080559	A1	4/2005	Ishibashi
2005/0225955	A1	10/2005	Grebenkemper
2005/0265494	A1	12/2005	Goodings
2006/0167600	A1	7/2006	Nelson, Jr. et al.
2006/0215739	A1	9/2006	Williamson
2007/0021913	A1*	1/2007	Heiniger et al. 701/213
2007/0078570	A1	4/2007	Dai
2007/0088447	A1	4/2007	Stothert
2007/0121708	A1	5/2007	Simpson
2007/0205940	A1	9/2007	Yang
2007/0285308	A1	12/2007	Bauregger
2008/0129586	A1	6/2008	Martin
2008/0195268	A1	8/2008	Sapilewski et al.
2008/0204312	A1	8/2008	Euler
2009/0099737	A1*	4/2009	Wendte et al. 701/50
2009/0121932	A1	5/2009	Whitehead et al.
2009/0171583	A1	7/2009	DiEsposti
2009/0174597	A1	7/2009	DiLellio
2009/0174622	A1	7/2009	Kanou
2009/0177395	A1	7/2009	Stelpstra
2009/0177399	A1	7/2009	Park
2009/0259397	A1	10/2009	Stanton
2009/0259707	A1	10/2009	Martin
2009/0262014	A1	10/2009	DiEsposti
2009/0262018	A1	10/2009	Vasilyev
2009/0262974	A1	10/2009	Lithopoulos
2009/0265054	A1	10/2009	Basnayake
2009/0265101	A1	10/2009	Jow
2009/0265104	A1	10/2009	Shroff
2009/0273372	A1	11/2009	Brenner
2009/0273513	A1	11/2009	Huang
2009/0274079	A1	11/2009	Bhatia
2009/0274113	A1	11/2009	Katz
2009/0276155	A1	11/2009	Jeergage
2009/0295633	A1	12/2009	Pinto
2009/0295634	A1	12/2009	Yu
2009/0299550	A1	12/2009	Baker
2009/0322597	A1	12/2009	Medina Herrero
2009/0322598	A1	12/2009	Fly
2009/0322600	A1	12/2009	Whitehead
2009/0322601	A1	12/2009	Ladd
2009/0322606	A1	12/2009	Gronemeyer
2009/0326809	A1	12/2009	Colley
2010/0013703	A1	1/2010	Tekawy
2010/0026569	A1	2/2010	Amidi
2010/0030470	A1	2/2010	Wang
2010/0039316	A1	2/2010	Gronemeyer
2010/0039318	A1	2/2010	Kmiecik
2010/0039320	A1	2/2010	Boyer
2010/0039321	A1	2/2010	Abraham
2010/0060518	A1	3/2010	Bar-Sever
2010/0063649	A1	3/2010	Wu
2010/0084147	A1	4/2010	Aral
2010/0085249	A1	4/2010	Ferguson
2010/0085253	A1	4/2010	Ferguson
2010/0103033	A1	4/2010	Roh
2010/0103034	A1	4/2010	Tobe
2010/0103038	A1	4/2010	Yeh
2010/0103040	A1	4/2010	Broadbent
2010/0106414	A1	4/2010	Whitehead
2010/0106445	A1	4/2010	Kondoh
2010/0109944	A1	5/2010	Whitehead
2010/0109945	A1	5/2010	Roh
2010/0109947	A1	5/2010	Rintanen
2010/0109948	A1	5/2010	Razoumov
2010/0109950	A1	5/2010	Roh
2010/0111372	A1	5/2010	Zheng
2010/0114483	A1	5/2010	Heo
2010/0117894	A1	5/2010	Velde
2010/0185364	A1	7/2010	Collins
2010/0312428	A1	12/2010	Roberge et al.
2011/0015817	A1	1/2011	Reeve
2011/0018765	A1	1/2011	Whitehead et al.
2011/0054729	A1	3/2011	Whitehead et al.
2011/0270495	A1	11/2011	Knapp
2012/0174445	A1	7/2012	Jones et al.
2013/0179026	A1	7/2013	McClure et al.

FOREIGN PATENT DOCUMENTS

AU	2002325645	B2	3/2003
AU	2002325645		9/2007
JP	07244150		9/1995
WO	2000/024239	A1	5/2000
WO	2003/019430	A1	3/2003
WO	2005/119386	A1	12/2005
WO	2008/080193	A1	7/2008
WO	WO-2008080193		7/2008
WO	2009/066183	A2	5/2009
WO	2009/126587	A1	10/2009
WO	2009/148638	A1	12/2009
WO	2010/005945	A1	1/2010
WO	WO-2010005945		1/2010

OTHER PUBLICATIONS

Van Zuydam,. R.P., Centimeter-Precision Guidance of Agricultural Implements in the Open Field by Means of Real Tim Kinematic DGPS, ASA-CSSA-SSSA, pp. 1023-1034 (1999).
"ARINC Engineering Services, Interface Specification IS-GPS-200, Revision D", Online [retrieved on May 18, 2010]. Retrieved from the Internet: <http://www.navcen.uscg.gov/gps/geninfo/IS-GPS-200D.pdf> Dec. 7, 2004; p. 168, para [0001].
"Eurocontrol, PEGASUS Technical Notes on SBAS", report [online], Dec. 7, 2004 [retrieved on May 18, 2010]. Retrieved from the Internet: <http://www.icao.int/icao/en/ro/nacc/meetings/2004/gnss/documentation/Pegasus/tn.pdf> Dec. 7, 2004; p. 89, paras [0001]-[0004].
"ISO", 11783 Part 7 Draft Amendment 1 Annex, Paragraphs B.6 and B.7 ISO 11783-7 2004 DAM1, ISO; Mar. 8, 2004.
"Orthman Manufacturing Co., www.orthman.com/htm;guidance.htm", 2004, regarding the "Tracer Quick-Hitch.".
Bevly, David M., "Comparison of INS v. Carrier-Phase DGPS for Attitude Determination in the Control of Off-Road Vehicles"; ION 55th Annual Meeting; Jun. 28-30, 1999; Cambridge, Mass; p. 497-504.

(56) **References Cited**

OTHER PUBLICATIONS

Han, Shaowel et al., "Single-Epoch Ambiguity Resolution for Real-Time GPS Attitude Determination with the Aid of One-Dimensional Optical Fiber Gyro". GPS Solutions, vol. 3, No. 1; pp. 5-12 (1999); John Wiley & Sons, Inc.
International Search Report and Written Opinion for PCT/162008/003796 dated Jul. 15, 2009.
International Search Report and Written Opinion for PCT/US2004/015678 dated Jun. 21, 2005.
International Search Report and Written Opinion for PCT/US2009/063594 dated Jan. 11, 2010.
International Search Report and Written Opinion for PCT/US2010/021334 dated Mar. 12, 2010.
International Search Report for PCT/AU2008/000002 dated Feb. 28, 2008.
International Search Report for PCT/US2009/033567 dated Feb. 9, 2009.
International Search Report for PCT/US2009/033693 dated Mar. 30, 2009.
International Search Report for PCT/US2009/039686 dated May 26, 2009.
International Search Report for PCT/US2009/049776 dated Aug. 11, 2009.
International Search Report for PCT/US2009/060668 dated Dec. 9, 2009.
International Search Report for PCT/US2009/067693 dated Jan. 26, 2010.
International Search Report for PCT/US2010/026509 dated Apr. 20, 2010.
International Search Report for PCT/US209/034376 dated Nov. 2, 2009.
Irsigler, M. et al., "PPL Tracking Performance in the Presence of Oscillator Phase Noise", GPS Solutions, vol. 5, No. 4; pp. 45-57; 2002.
Kaplan, E.D. "Understanding GPS: Principles and Applications"; Artech House, MA; 1996.
Keicher, R. et al. "Automatic Guidance for Agricultural Vehicles in Europe", Computers and Electronics in Agriculture, vol. 25, Jan. 2000; pp. 169-194.
Last, J.D. et al., "Effect of skyware interference on coverage of radio beacon stations", IEEE Proc.-Radar, Sonar Navig., vol. 14, No. 3; Jun. 1997; pp. 163-168.
Lin, Dai et al., "Real-time Attitude Determination for Microsatellite by Lamda Method Combined with Kalman Filtering", A collection of the 22nd AIAA International Communications Satellite Systems Conference and Exhibit Technical Papers vol. 1, Monterey, CA, American Institute of Aeronautics and Astronautics, Inc.; May 2004; 136-143.
Park, Chansik et al., "Integer Ambiguity Resolution for GPS Based Attitude Determination System", SICE Jul. 29-31, 1998, Shiba, 1115-1120.
Parkinson, Bradford W., et al., "Global Positioning System: Theory and Applications, vol. II"; Bradford W. Parkinson and James J. Spiker, Jr., eds., Global Positioning System: Theory and Applications, vol. II: 1995, AIAA, Reston, VA, USA; pp. 3-50; (1995), 3-50.
Rho, Hyundho et al., "Dual-Frequency GPS Precise Point Positioning with WADGPS Corrrections", [retrieved on May 18, 2010]. Retrieved from the Internet: <http://gauss.gge.unb.ca/papers.pdf/iongnss2005.rho.wadgps.pdf> Jul. 12, 2006.
Schaer, et al., "Determination and Use of GPS Differential Code Bias Values", Presentation [online]. Retrieved on May 18, 2010. Retrieved from the Internet: <http://nng/esoc.esa.de/ws2006/REPR2.pdf> May 8, 2006.
Takac, Frank et al., "SmartRTK: A Novel Method of Processing Standardized RTCM Network RTK information for High Precision Positioning"; Proceedings of ENC GNSS 2008, Toulouse, France; Apr. 22, 2008.
Ward, Phillip, W., "Performance Comparisons Between FLL, PLL and a Novel FLL-Assisted-PLL Carrier Tracking Loop Under RF Interference Conditions", 11th Int. Tech Meeting of the Satellite Division of the US Inst. Of Navigation, Nashville, TN; Sep. 15018, 1998; p. 783-795.
Xu, Jiangning et al., "An EHW Architecture for Real-Time GPS Attitude Determination Based on Parallel Genetic Algorithm", the Computer Society Proceedings of the 2002 NASA/DOD Conference on Evolvable Hardware (EH '02)(2002).

* cited by examiner

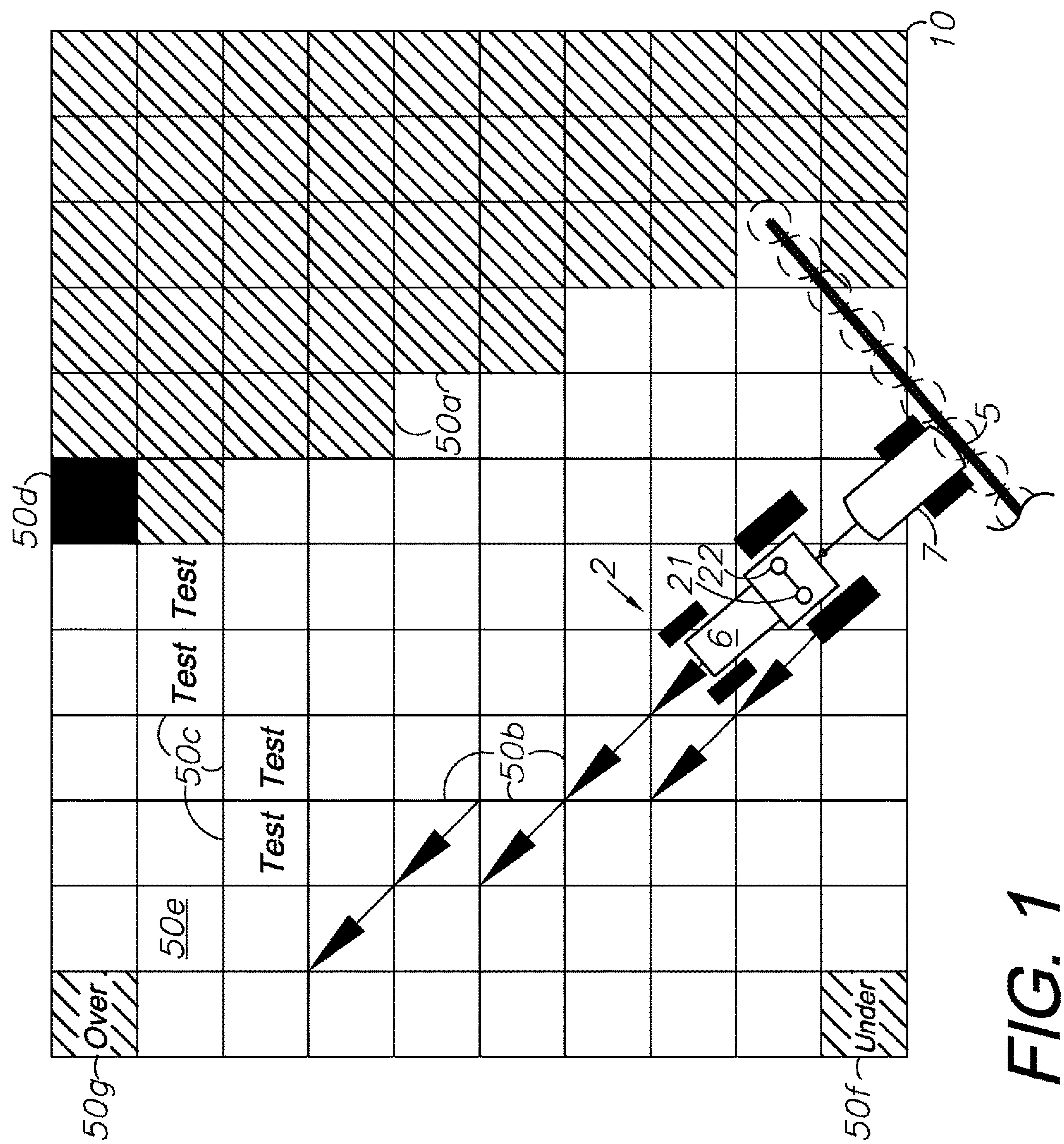

10
50a
50d
2
21
22
6
5
7
Test
Test
Test
Test
50c
50b
50e
Over
Under
50g
50f

FIG. 1

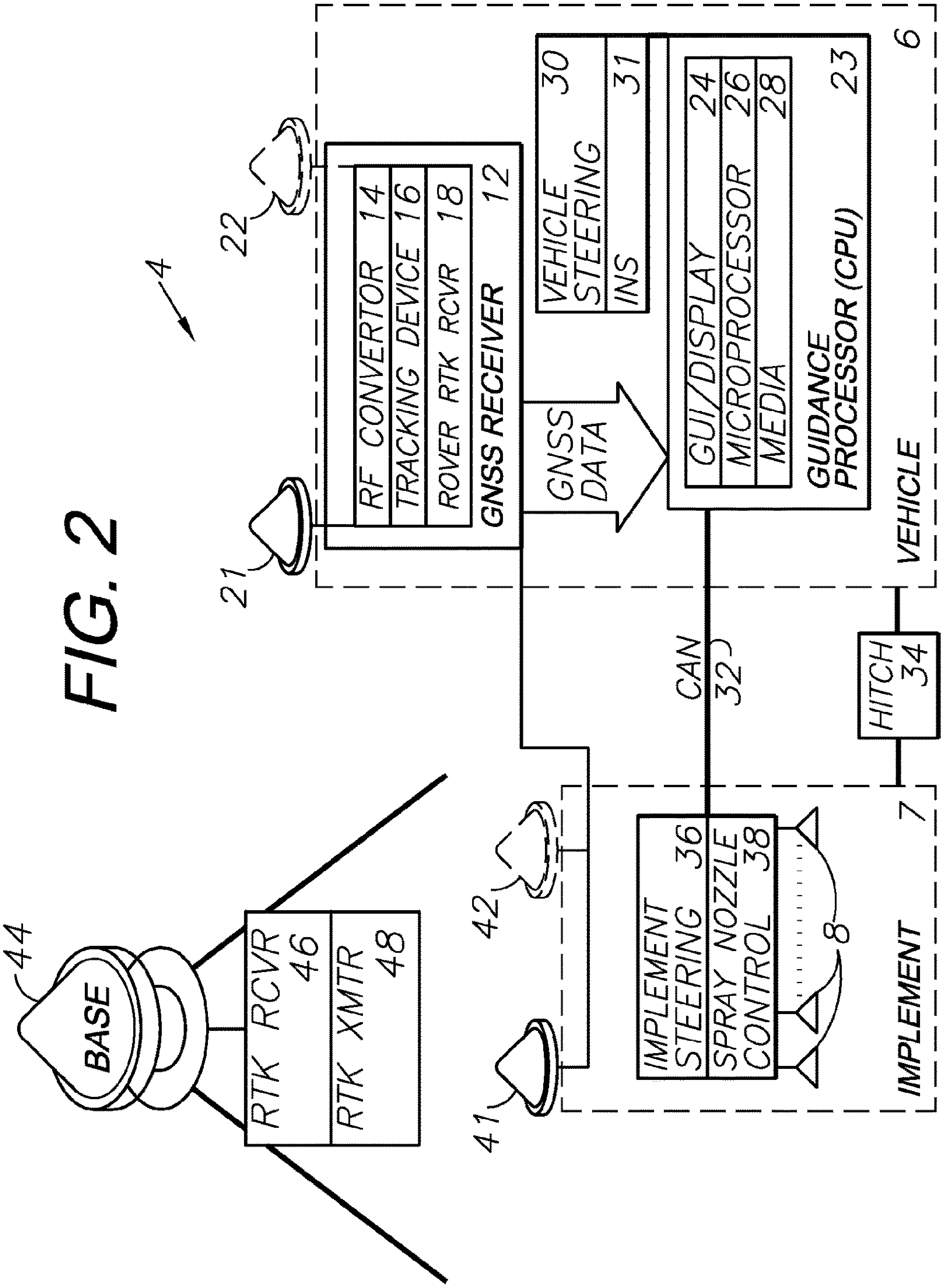
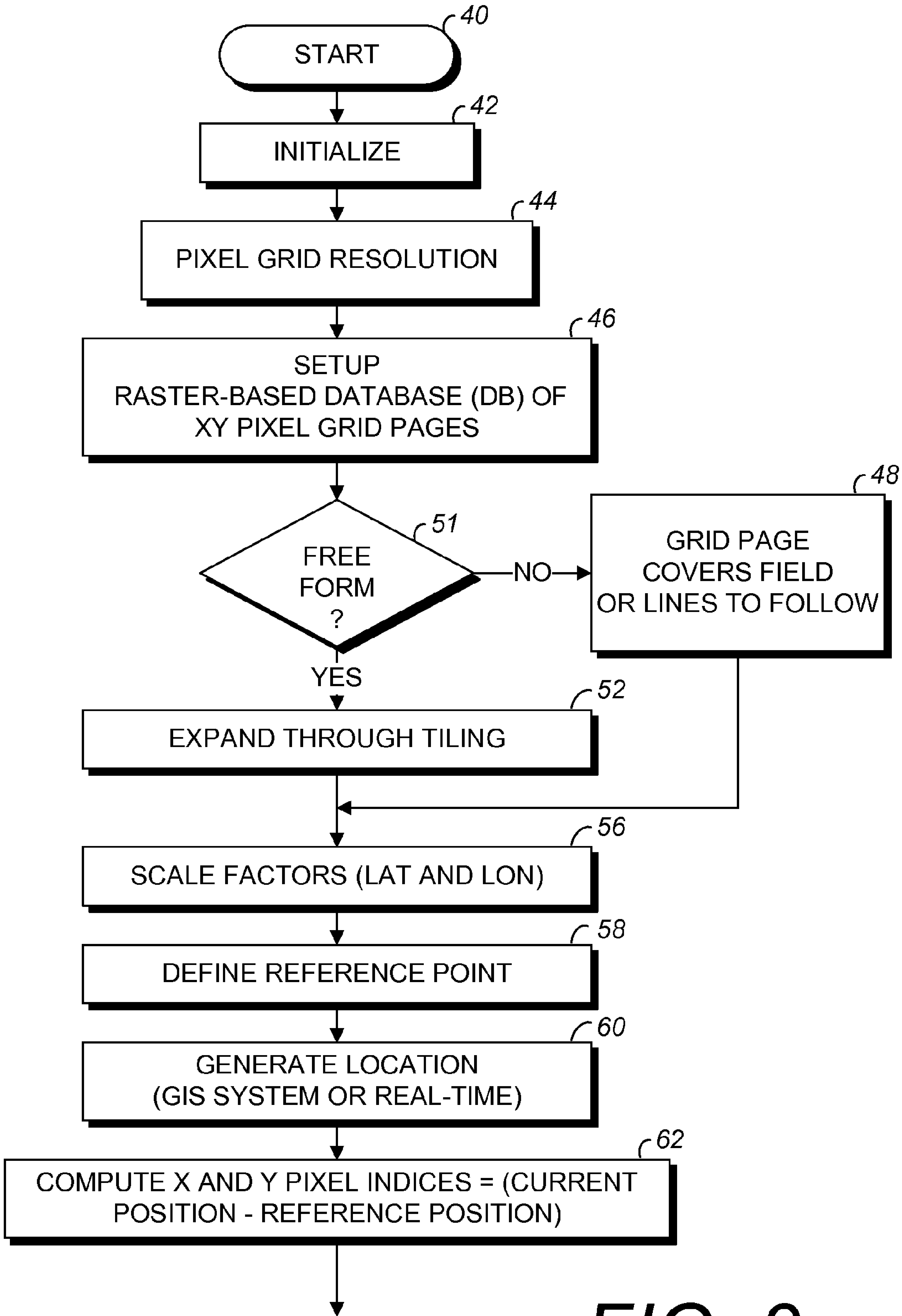

4
22
21
RF CONVERTOR 14
TRACKING DEVICE 16
ROVER RTK RCVR 18
GNSS RECEIVER 12
GNSS DATA
VEHICLE STEERING 30
INS 31
GUI/DISPLAY 24
MICROPROCESSOR 26
MEDIA 28
GUIDANCE PROCESSOR (CPU) 23
6
VEHICLE
CAN 32
HITCH 34
BASE
44
RTK RCVR 46
RTK XMTR 48
42
41
IMPLEMENT STEERING 36
SPRAY NOZZLE CONTROL 38
8
7
IMPLEMENT

FIG. 2



CONTINUED ON FIG. 3b

FIG. 3a

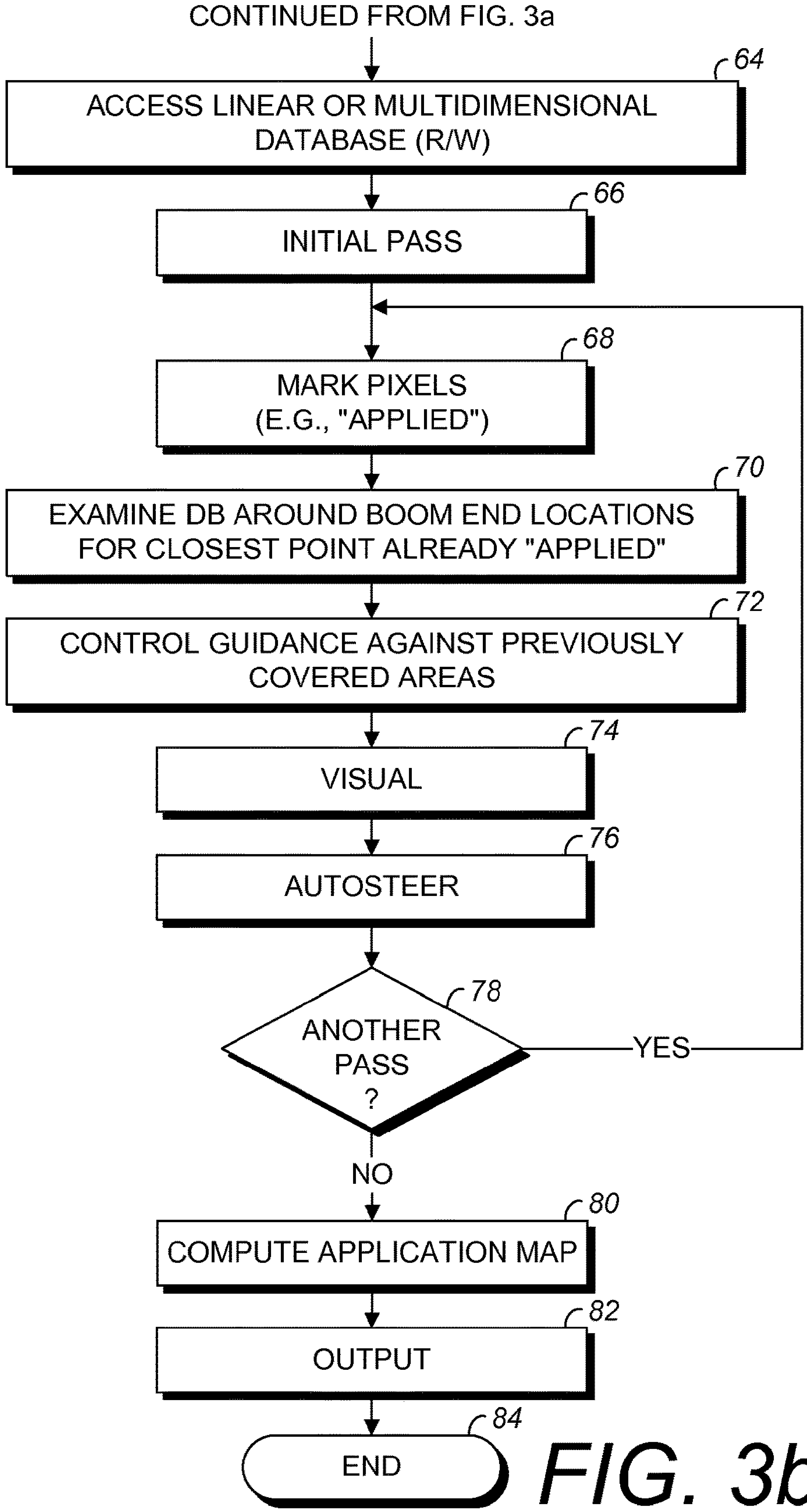

CONTINUED FROM FIG. 3a
64
ACCESS LINEAR OR MULTIDIMENSIONAL DATABASE (R/W)
66
INITIAL PASS
68
MARK PIXELS (E.G., "APPLIED")
70
EXAMINE DB AROUND BOOM END LOCATIONS FOR CLOSEST POINT ALREADY "APPLIED"
72
CONTROL GUIDANCE AGAINST PREVIOUSLY COVERED AREAS
74
VISUAL
76
AUTOSTEER
78
ANOTHER PASS ?
YES
NO
80
COMPUTE APPLICATION MAP
82
OUTPUT
84
END

FIG. 3b

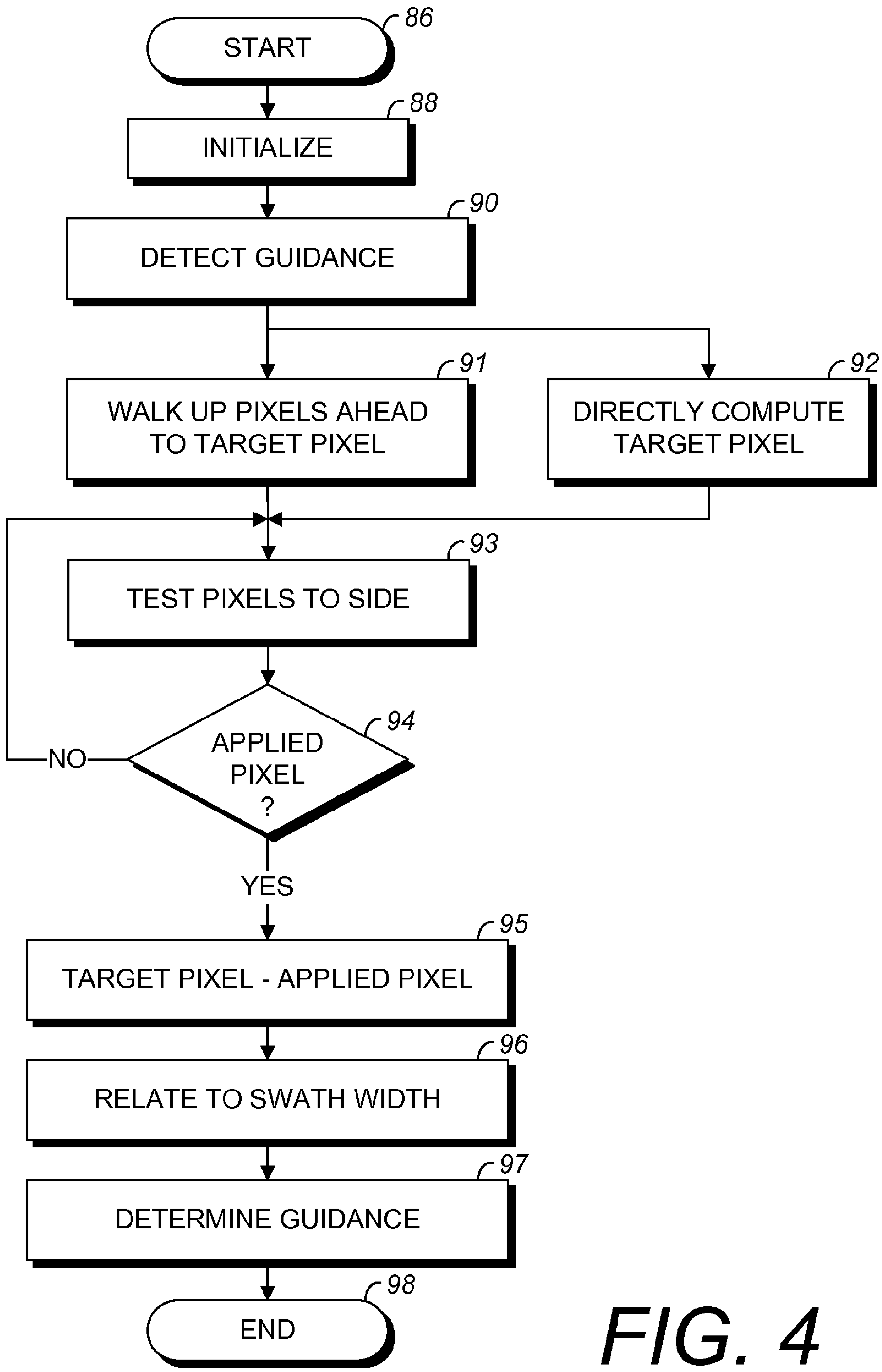

START
86
INITIALIZE
88
DETECT GUIDANCE
90
WALK UP PIXELS AHEAD TO TARGET PIXEL
91
DIRECTLY COMPUTE TARGET PIXEL
92
TEST PIXELS TO SIDE
93
APPLIED PIXEL ?
94
NO
YES
TARGET PIXEL - APPLIED PIXEL
95
RELATE TO SWATH WIDTH
96
DETERMINE GUIDANCE
97
END
98

FIG. 4

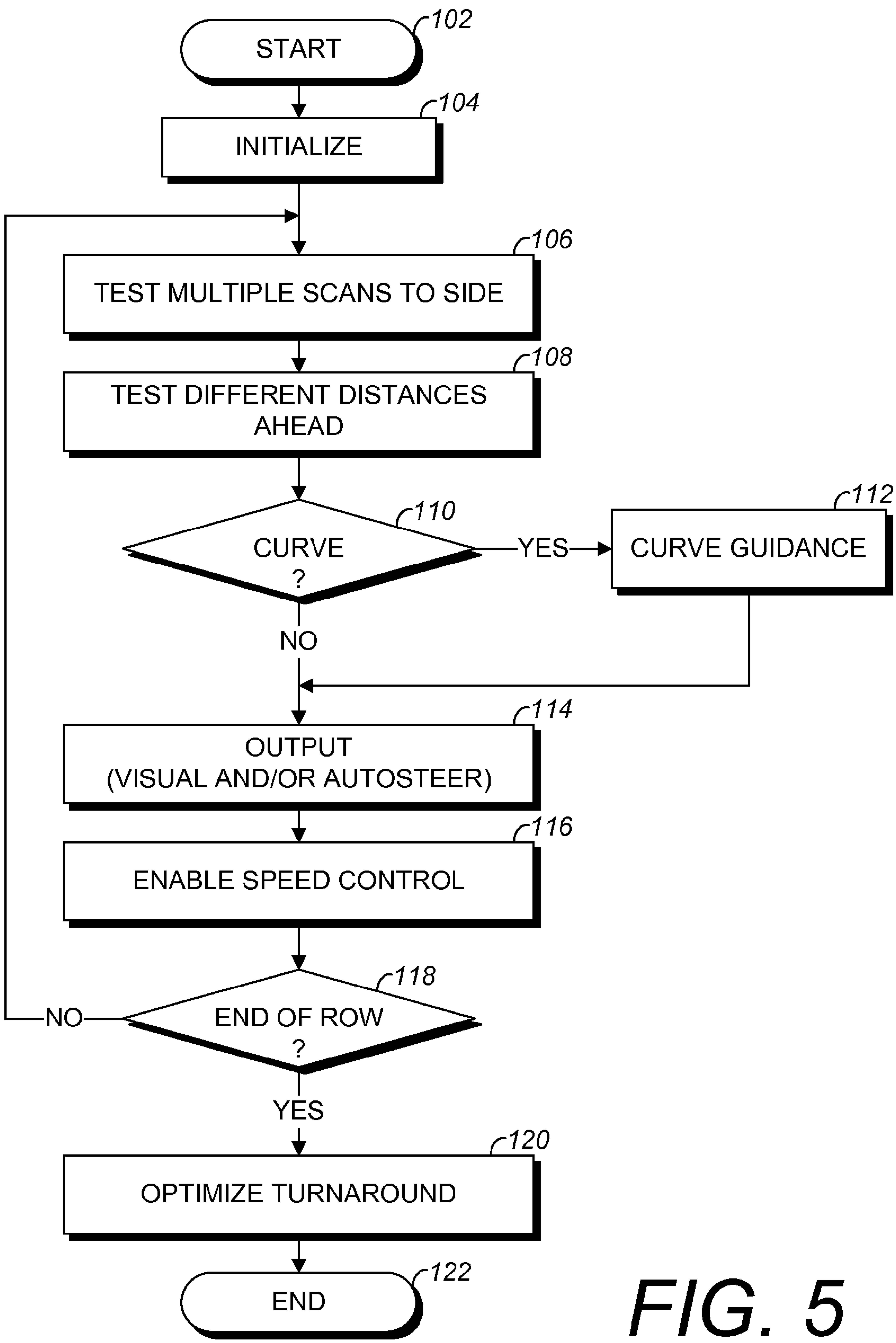

START
102
INITIALIZE
104
TEST MULTIPLE SCANS TO SIDE
106
TEST DIFFERENT DISTANCES AHEAD
108
CURVE ?
110
YES
CURVE GUIDANCE
112
NO
OUTPUT (VISUAL AND/OR AUTOSTEER)
114
ENABLE SPEED CONTROL
116
END OF ROW ?
118
NO
YES
OPTIMIZE TURNAROUND
120
END
122

FIG. 5

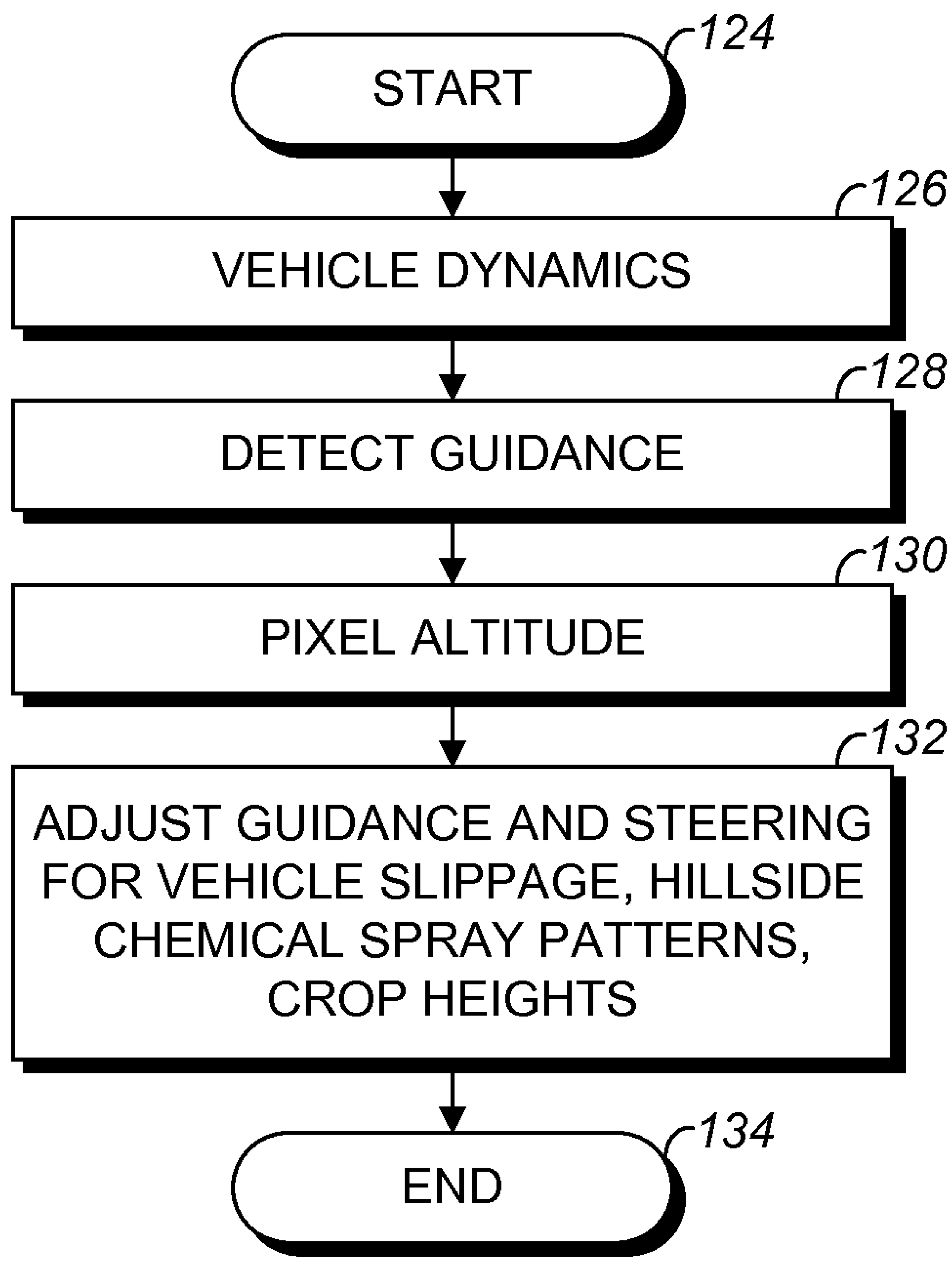

START
124
VEHICLE DYNAMICS
126
DETECT GUIDANCE
128
PIXEL ALTITUDE
130
ADJUST GUIDANCE AND STEERING FOR VEHICLE SLIPPAGE, HILLSIDE CHEMICAL SPRAY PATTERNS, CROP HEIGHTS
132
END
134

FIG. 6

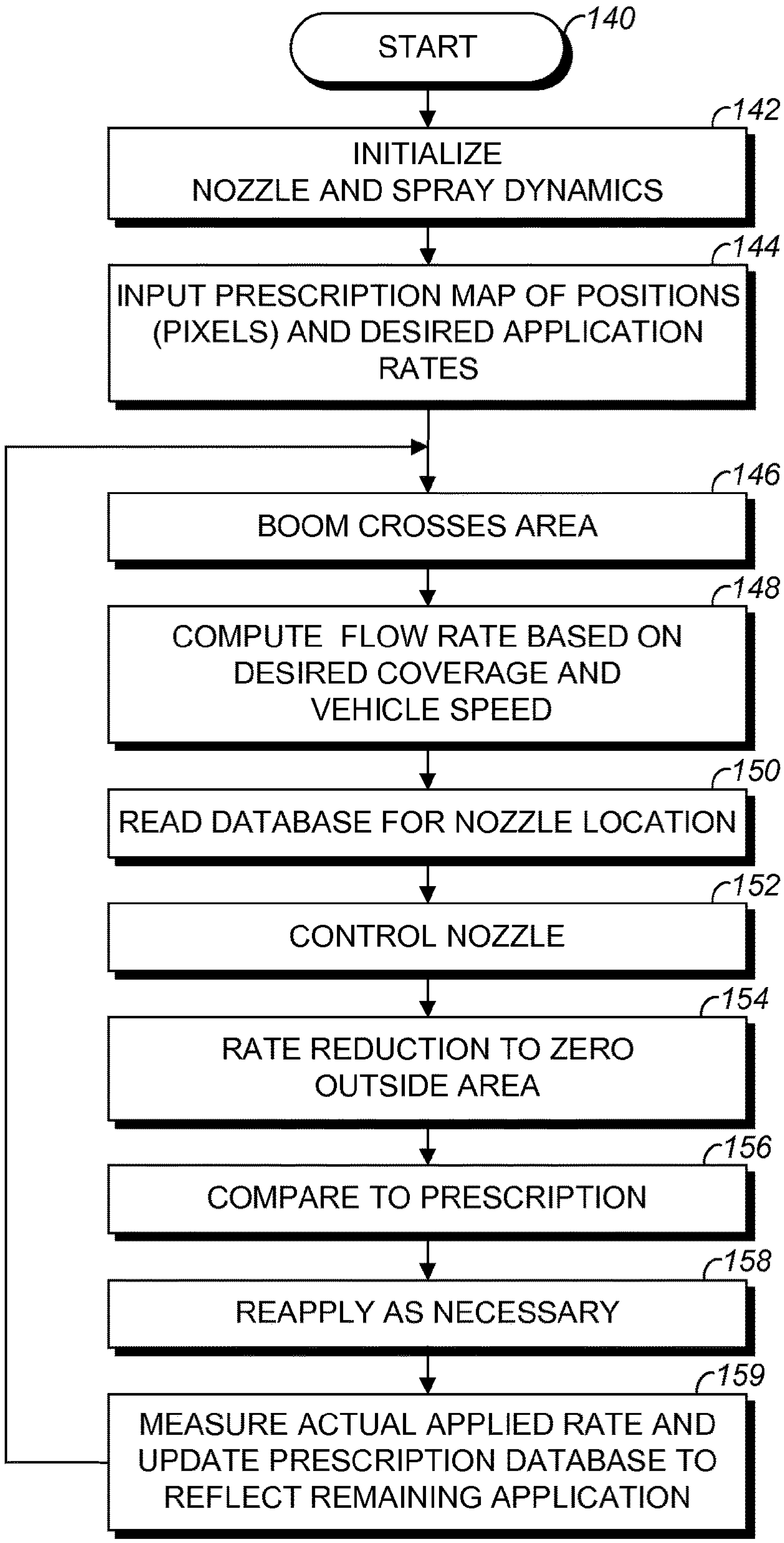

START
140
INITIALIZE NOZZLE AND SPRAY DYNAMICS
142
INPUT PRESCRIPTION MAP OF POSITIONS (PIXELS) AND DESIRED APPLICATION RATES
144
BOOM CROSSES AREA
146
COMPUTE FLOW RATE BASED ON DESIRED COVERAGE AND VEHICLE SPEED
148
READ DATABASE FOR NOZZLE LOCATION
150
CONTROL NOZZLE
152
RATE REDUCTION TO ZERO OUTSIDE AREA
154
COMPARE TO PRESCRIPTION
156
REAPPLY AS NECESSARY
158
MEASURE ACTUAL APPLIED RATE AND UPDATE PRESCRIPTION DATABASE TO REFLECT REMAINING APPLICATION
159

FIG. 7

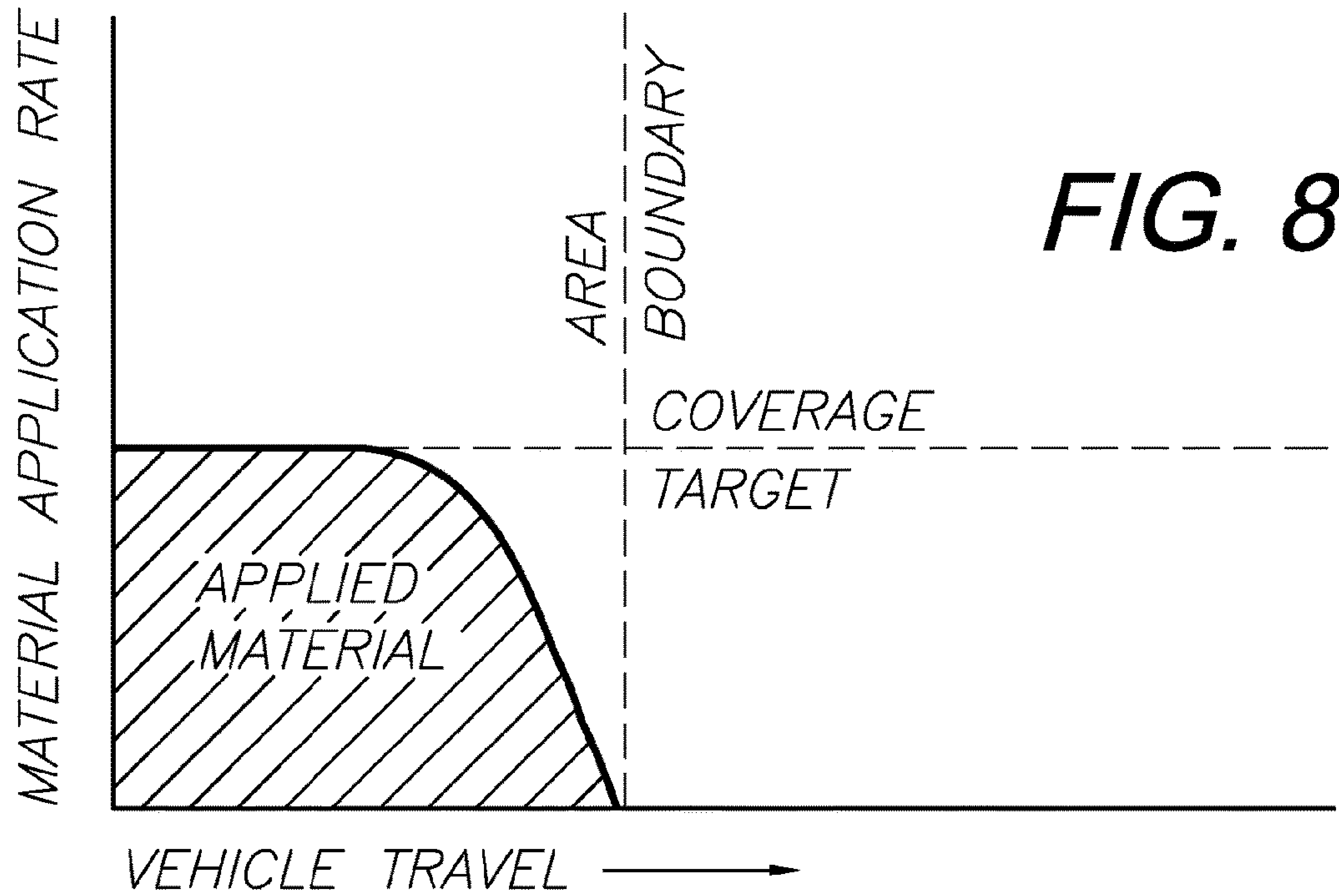

MATERIAL APPLICATION RATE
AREA
BOUNDARY
COVERAGE
TARGET
APPLIED
MATERIAL
VEHICLE TRAVEL

FIG. 8a

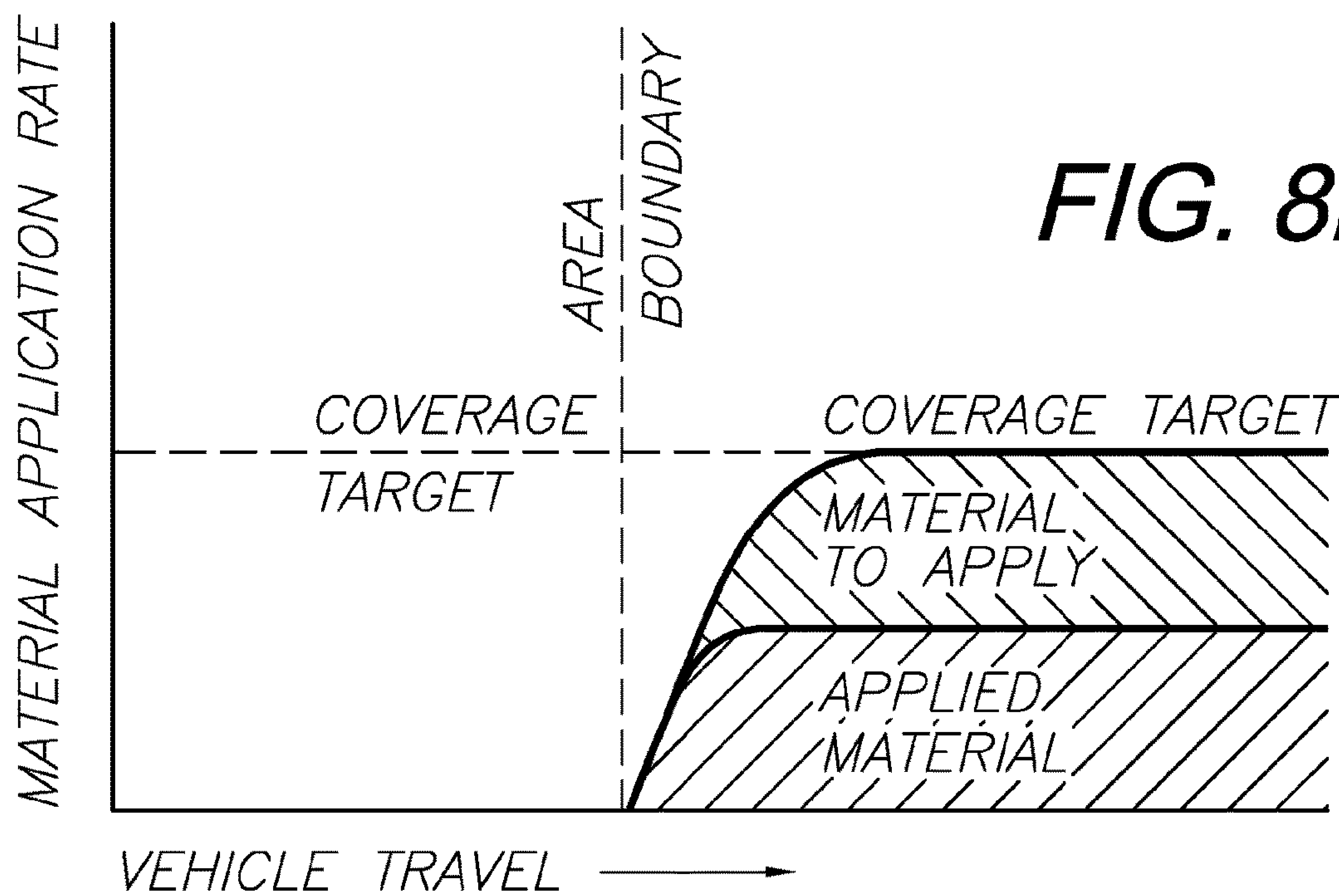

MATERIAL APPLICATION RATE
AREA
BOUNDARY
COVERAGE
TARGET
COVERAGE TARGET
MATERIAL
TO APPLY
APPLIED
MATERIAL
VEHICLE TRAVEL

FIG. 8b

RASTER-BASED CONTOUR SWATHING FOR GUIDANCE AND VARIABLE-RATE CHEMICAL APPLICATION

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATIONS

[This application is a continuation of and claims priority in U.S. patent application Ser. No. 12/689,184, filed Jan. 18, 2010, now U.S. Pat. No. 8,386,129, issued Feb. 26, 2013, which claims priority in U.S. Provisional Patent Application Ser. No. 61/145,542, filed Jan. 17, 2009, both of which are incorporated herein by reference.**]** *This application is a reissue of U.S. patent application Ser. No. 13/776,512, filed Feb. 25, 2013, now U.S. Pat. No. 8,718,874, issued May 6, 2014, which is a continuation of and claims priority to U.S. patent application Ser. No. 12/689,184, filed Jan. 18, 2010, now U.S. Pat. No. 8,386,129, issued Feb. 26, 2013, which claims priority in U.S. Provisional Patent Application Ser. No. 61/145,542, filed Jan. 17, 2009, all of which are incorporated by reference in their entireties.*

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to automated equipment control using a raster-based database, including vehicle navigation and guidance using global navigation satellite system (GNSS), inertial navigation system (INS) and other positioning inputs, and machine control functions such as variable-rate chemical applications in agricultural spraying.

2. Description of the Related Art

GNSS technology advanced vehicle and machine guidance and control in various technical fields, including the field of agricultural guidance by enabling reliable, accurate systems, which are relatively easy to use. GNSS guidance systems are adapted for displaying directional guidance information to assist operators with manually steering the vehicles. For example, the OUTBACK® steering guidance system, which is available from Hemisphere GPS LLC of Calgary, Alberta, Canada and is covered by U.S. Pat. Nos. 6,539,303 and 6,711,501 (incorporated herein by reference), includes an on-board computer capable of storing various straight-line and curved ("contour") patterns. An advantage of this system is its ability to retain field-specific cultivating, planting, spraying, fertilizing, harvesting and other patterns in memory. This feature enables operators to accurately retrace such patterns. Another advantage relates to the ability to interrupt operations for subsequent resumption by referring to system-generated logs of previously treated areas. The OUTBACK S steering guidance system, and related product offerings from Hemisphere GPS LLC, utilize "near point search method" technology, which logs GPS-defined positions along swath edges, the nearest of which are located for placing the edge of the next swath against the last.

Another type of GPS guidance utilizes "form line following," wherein vectors, which can be straight-line (A-B) or curved (contour), are computed based on equipment widths offset from the previously-driven form lines. A disadvantage with this type of system is that initial form lines must be driven and delineated based upon which subsequent form lines must be computed and followed. Significant computer overhead can be occupied with such tasks, whereby trade-offs are required between component costs and system responsiveness.

GNSS vehicle guidance equipment using the above techniques is available as a steering guide with a graphical user interface (GUI) for manually-steered vehicles, and also with an autosteer function for automatically steering the vehicle along all or part of its travel path. Automated systems can also control an agricultural procedure or operation, such as spraying, planting, tilling, harvesting, etc. Examples of such equipment are shown in U.S. Pat. No. 7,142,956, which is incorporated herein by reference. U.S. Patent Application Publication No. 2004/0186644 shows satellite-based vehicle guidance control in straight and contour modes, and is also incorporated herein by reference. U.S. Pat. No. 7,162,348 is incorporated herein by reference and discloses an articulated equipment position control system and method whereby a working component, such as an implement, can be guided independently of a motive component, such as a tractor. The implement can optionally be equipped with its own GNSS antenna and/or receiver for interacting with a tractor-mounted GNSS system.

Ideally crops would be planted in perfectly straight, evenly-spaced rows. Guidance through such fields would consist of following relatively simple straight-line patterns. Such guidance modes are commonly referred to as straight line or "A-B" in reference to the equipment traveling in a straight line from point A to point B in a repeating pattern in order to cover an entire field, which is typically flat and rectangular and therefore efficiently divided into multiple, parallel swaths. However, field conditions in many areas are not suitable for A-B guidance. For example, hilly terrain sometimes requires the formation of constant-elevation terraces.

Guidance systems accommodate such irregular conditions by operating in "contour following" modes consisting of curvilinear tracks defined by multiple GNSS points along which the equipment is guided. Initial planting passes made with manual and visually-guided navigation, which may or may not be supplemented with GNSS navigational aids, can cause crop rows to deviate from straight lines. Accommodating such irregular crop rows in subsequent operations (e.g., spraying and harvesting) may require the equipment to deviate from straight-line passes.

"Tramline" (sometimes referred to as "match tracks") is another operating mode available with some modern GNSS guidance systems. In tramline operating mode the existing crop rows are relatively well protected because the equipment follows or "matches" the previously-driven passes. The equipment wheels or tracks are thus confined between the crop rows. Machine damage from running over crops is thus avoided, or at least minimized.

Preferably a system embodying an aspect of the present invention would avoid the drawbacks inherent in the previous systems described above and be adaptable to various machine control applications, including variably controlling the output of individual nozzles in agricultural sprayers. In particular, raster (e.g., bitmap) data bases can be used with previously-defined world geodetic systems, such as WGS 84, thereby eliminating overhead-intensive tasks such as continuously running extensive searches for points along the edges of previously-driven swaths or computing form lines.

Heretofore there has not been available a raster-based contour swathing system and method with the advantages and features of the present invention.

SUMMARY OF THE INVENTION

In the practice of the present invention, a system and method are provided for automatically guiding and controlling vehicles and equipment using GNSS for defining a raster-based database of pixels defining either an entire area to be treated, or a subset through which a vehicle travels. For example, agricultural equipment comprising a tractor and an implement can be equipped with a vector position and heading sensor subsystem including a GNSS receiver and antennas and an optional inertial navigational system (INS) with X, Y and Z axis sensors for sensing equipment attitude changes through six degrees of freedom. Such sensors typically comprise gyroscopes and/or accelerometers. A 2D map array comprises an XY grid of pixels, which is scalable according to the requirements of a particular operation. Guidance operations are accomplished by marking pixels as "applied" when treated on an equipment pass. Subsequent passes can guide off of the applied pixel areas, using "target" aim point pixels and/or swath-width spacing to one side or the other of the applied areas. Moreover, machine control functions can actuate certain operations based on equipment position. For example, spray nozzles on a sprayer implement can be selectively and individually actuated over areas to be sprayed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of agricultural equipment equipped with GNSS and (optionally) INS guidance and control systems, shown in operation on a field defined by an XY array of pixels.

FIG. **2** is a block diagram of a GNSS/INS/RTK tractor and implement system for implementing the raster-based guidance system and method.

FIGS. **3**a and **3**b show a flowchart of a raster-based guidance method.

FIG. **4** is a flowchart of another aspect of the raster-based guidance method using target pixels.

FIG. **5** is a flowchart of another aspect of the raster-based guidance method.

FIG. **6** is a flowchart of another aspect of the raster-based guidance method.

FIG. **7** is a flowchart of another aspect of the raster-based guidance method including spray nozzle control.

FIG. **8**a is a diagram of material application parameters on exiting a treated area.

FIG. **8**b is another diagram of material application parameters on entering an area to be treated.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. Introduction and Environment

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed structure.

Certain terminology will be used in the following description for convenience in reference only and will not be limiting. For example, up, down, front, back, right and left refer to the invention as oriented in the view being referred to. The words "inwardly" and "outwardly" refer to directions toward and away from, respectively, the geometric center of the embodiment being described and designated parts thereof Global navigation satellite systems (GNSS) are broadly defined to include GPS (U.S.), Galileo (proposed), GLONASS (Russia), Beidou (China), Compass (proposed), IRNSS (India, proposed), QZSS (Japan, proposed) and other current and future positioning technology using signals from satellites, using single or multiple antennae, with or without augmentation from terrestrial sources. Inertial navigation systems (INS) include gyroscopic (gyro) sensors, accelerometers and similar technologies for providing output corresponding to the inertia of moving components in all axes, i.e. through six degrees of freedom (positive and negative directions along transverse X, longitudinal Y and vertical Z axes). Yaw, pitch and roll refer to moving component rotation about the Z, X and Y axes respectively. Said terminology will include the words specifically mentioned, derivatives thereof and words of similar meaning.

II. Guidance and Control System **4**

Referring to the drawings in more detail, the reference numeral **2** generally designates a piece of agricultural equipment, which is equipped with a raster-based guidance and control system **4** embodying an aspect of the present invention. Without limitation on the generality of equipment **2**, a motive component **6** is connected to a working component **7** through an optional articulated connection or hitch **34** (collectively comprising the equipment or vehicle **2**). Also by way of example, the motive component **6** can comprise a tractor or other vehicle and the working component **7** can comprise a ground-working implement. However, the system **4** can be applied to other equipment configurations for a wide range of other applications. Such applications include equipment and components used in road construction, road maintenance, earthworking, mining, transportation, industry, manufacturing, logistics, etc.

FIG. **1** shows the equipment **2** operating on a portion of a field **10** with an array of XY pixels **50**, which are used for providing guidance and controlling the operation of the implement **7**, which can comprise a sprayer with individual nozzles **8**.

FIG. **2** is a schematic block diagram showing the components of the GNSS guidance/control system **4**. The tractor **6** components include a GNSS receiver **12** including a first vehicle antenna **21**, an optional second vehicle antenna **22**, an RF (down) converter **14**, a tracking device **16** and an optional rover RTK receiver **18**. A guidance processor CPU **23** includes a GUI display **24**, a microprocessor **26** and a media storage device **28**. Vehicle steering **30** and INS components **31** (e.g., gyroscopes and/or accelerometers) are connected to the guidance processor **23**. GNSS-derived data is transferred from the GNSS receiver **12** to the guidance processor CPU **23**. The implement **7** can include a first implement antenna **41** and an optional second implement antenna **42**, which are connected to the vehicle GNSS receiver **12** and provide GNSS data thereto.

An implement steering subsystem **36** receives steering commands from the guidance processor CPU **23** via a CAN bus **32** or some other suitable connection, which can be wireless. The implement **7** is mechanically connected to the vehicle **6** by a hitch **34**, which can be power-driven for active implement positioning in response to implement steering commands, or a conventional mechanical linkage. The hitch

34 can be provided with sensors for determining relative attitudes and orientations between the vehicle **6** and the implement **7**. Examples of such an articulated connection and an implement steering system are described in U.S. Pat. Nos. 6,865,465, 7,162,348 and 7,460,942, which are incorporated herein by reference. The implement **8** can comprise any of a wide range of suitable implements, such as planting, cultivating, harvesting and spraying equipment. For example, spraying applications are commonly performed with a boom **5**, which can be equipped for automatic, selective control of multiple nozzles **8** and other boom operating characteristics, such as height, material dispensed, etc. By way of example and without limitation, the implement **7** can comprise an agricultural sprayer with a spray nozzle control **38** connected to the guidance processor CPU **23** by the CAN bus **32** for individually controlling the spray nozzles **8**.

The GNSS/INS guidance and control system **4** can be configured in various combinations of components and thereby accommodate a wide range of guidance and control operations. For example, RTK guidance can be accommodated with a base **44** including an RTK receiver **46** and an RTK transmitter **48**, which can be mounted at a fixed-position reference point in the general vicinity of fields being worked by the equipment **2**. Moreover, various combinations of receivers and antennas can be used on the vehicle **6** and/or the implement **7**, including single frequency (L1 only) and dual frequency (L1 and L2). Various forms of signal correction can also be utilized, including Satellite Based Augmentation System (SBAS), Wide Area Augmentation System (WAAS) and private subscription services.

The GNSS receiver **12** disclosed herein can be adapted for various satellite navigational systems, and can utilize a variety of SBAS technologies. Technology is also available for continuing operation through satellite signal interruptions, and can be utilized with the system **4**. The antennas **21**, **22** can be horizontally aligned transversely with respect to a direction of travel of the tractor **6**, i.e. parallel to its transverse X axis. The relative positions of the antennas **21**, **22** with respect to each other can thus be processed for determining yaw, i.e. rotation with respect to the vertical Z axis. The INS **31** can include inertial sensors (e.g., gyroscopes and accelerometers) for detecting and measuring inertial movement with respect to the X, Y and Z axes corresponding to yaw, roll and pitch movements in six degrees of freedom. Signals from the receiver **12** and the INS sensors are received and processed by the microprocessor **26** based on how the system **4** is configured and programmed

III. Raster-based Guidance and Control Method

FIGS. **3**a and **3**b show a method of raster-based guidance and control according to an aspect of the present invention. From a start **40** the system **4** is initialized at **42**, including setting a pixel grid resolution at **44**. Without limitation, pixel grid resolution in the approximate range of 0.05 meters to 5 meters can be useful for various operations, depending on the desired accuracy.

Setup of a raster-based database (DB) of XY pixel grid pages **48** occurs at **46**. An example of a pixel grid page **48** is shown in FIG. **1** and includes multiple pixels **50**. Pixel grid pages can cover entire fields, or, alternatively from decision box **51**, can be freeform and automatically expandable in any direction through a tiling method at step **52**. An exemplary preferred method is to use a rectangular grid based on WGS 84 comprising GPS-based coordinates for generating a grid page at **48**. Scale factors for latitude and longitude are set at **56** and an initial reference point is defined at **58**. A location in the grid area can be generated at **60** on a GIS system, such as the Map Star™ program available from Hemisphere GPS of Calgary, Alberta, Canada, or in real-time in the field on the guidance system **4**. Locations in the grid area are defined by the number of pixels east-west (EW) and north-south (NS) from the reference location at **62**. *X and Y pixel indicies are computed in 62 where X and Y indicies=(Current Position−Reference position).* A linear or multidimensional database is accessed at **64** using the XY pixel indices computed at **62**. The database can be accessed and read and/or written to (R/W) at **64**.

In an exemplary field spraying operation using the sprayer **7**, the equipment **2** is driven in an initial pass at **66** in a "swath" mode with its swath width comprising one of the operating parameters whereby all pixels covered by the spray boom **5** are marked as "applied" (**50**a in FIG. **1**) at step **68**. On a subsequent adjacent pass, the database around the spray boom end locations is examined for the closest applied pixel **50**a at **70**, which is designated **50**d (tested and applied) in FIG. **1**, and is then used for instantaneous guidance control at **72**, either through a visual GUI at **74** and/or an autosteering function at **76**.

As shown in FIG. **1**, the operator can thereby drive against previously covered (applied) pixels **50**a. The database can be programmed for "unapplied" **50**e and "applied" **50**a pixel status conditions. Other pixel status conditions can include "vehicle track" **50**b, "unapplied test" **50**c, "applied test" **50**d, "unapplied" **50**e, "under-applied" **50**f and "over-applied" **50**g (FIG. **1**). The process continues via a loop through the "another pass" decision box **78** until complete or interrupted, whereafter an application map showing database values, pixel status, equipment positions and headings is computed at **80** and output at **82** with the operation ending at **84**.

FIG. **4** shows another method of guidance using the vehicle **6** location, swath (e.g., spray boom **5**) width and direction of travel. From start **86**, initialize **88** and detect guidance **90**, vehicle track/target pixels **50**b (FIG. **1**) ahead of the equipment **2** are "walked up" from the center of the vehicle **6** to a *target pixel* point ahead using either a Bresenham-type algorithm at **91** or by directly computing a track/target pixel **50**b ahead at **92**. Then the unapplied test pixels **50**c to the side of the track/target pixel **50**b are tested for "applied" status at **93**. Upon detecting an applied test pixel **50**d at **94**, its distance away from the track/target pixel **50**b relative to the implement swath width (i.e. "offset" generally equal to half of the swath width) is obtained at **95**, related to swath width at **96**, used to determine guidance at **97** and the method ends at **98**.

As shown in FIG. **5**, a similar method can be used for computing guidance using two dimensions (2D). From start **102** and initialize **104**, multiple scans to the side of the vehicle and different distances ahead of it are tested at **106**, **108** respectively to detect previously-applied areas along curves at **110** and to implement curve guidance at **112**. The output can be provided visually via a GUI **24** and/or used in an autosteering algorithm at **114**. Speed control at **116** and end-of-row turnaround at **118**, **120** can be enabled and optimized. The method ends at **122**.

FIG. **6** shows a variation comprising a 3D method using the altitudes of the different pixels for adjusting guidance and steering. From a start **124** vehicle dynamics are input as operating parameters at **126**, guidance is detected at **128** and pixel altitudes are input at **130**. For example, the method can compensate by remaining closer to the applied area to adjust for vehicle downhill slippage and hillside chemical spray patterns at **132**. Such 3D information can also correspond to crop heights with the system making suitable adjustments, also at **132**. The method ends at **134**.

FIG. **7** shows another method of the invention involving sprayer nozzle control. From a start **140** the nozzle and spray dynamics are initialized at **142**. A chemical spray prescription map including the positions represented by pixels and target chemical application rates (e.g. gallons per acre) is input at **144**. Operation commences as the spray boom crosses an area at **146** and flow rate is computed based on desired coverage (i.e. prescription database value) and vehicle speed at **148**. The database is read for the locations of the spray nozzles at **150** whereby their pixel-defined locations are used for determining chemical applications and nozzle control at **152**. At **154** the dispensing rate for one or more of the nozzles **8** is reduced to zero if the equipment **2** travels outside the predetermined application area, e.g., field **10**. A comparison with the prescription occurs at **156** followed by reapplication as necessary at **158** followed by measure actual applied rate and update prescription database to reflect remaining application at **159** followed by a loop back to **146**. The process shown in FIG. **7** is continuous in the sense that the operator can start and stop at any time and the sprayer will only dispense when located over a pixel **50** with a non-zero prescription database value. Thus, the field **50** is completely treated when all of its pixels **50** have zero prescription database values, and the system will no longer dispense.

In conjunction with the methods described above, variable rate control can be accomplished using multiple channels for individual nozzle control of chemical applications. For example, the CAN bus **32** communicates individual nozzle control commands from the processor **23** to the spray nozzles **8**, which can be monitored and boom pressure controlled thereby for correct calibration. Individual nozzle flow rate control across the entire spray boom accommodates swath overlaps whereby spray nozzle output would be reduced or shut off. Nozzles **8** can also be shut off upon entry into previously-applied areas and no-spray areas, such as outside the field boundaries.

The pixel status in the method of the present invention includes information on the chemical(s) application rates(s). As the spray boom **5** crosses the treatment area the database is read for each nozzle **8** location and the desired rates per area, e.g. gallons per acre. The nozzle flow rate is then adjusted to the required output, e.g., in gallons per minute (GPM) based on the current nozzle speed. The amount of coverage during turning of the vehicle can also vary according to the nozzle locations in the turn, with the outermost nozzle **8** traveling fastest (requiring the greatest flow rate) and the innermost nozzle traveling slowest (requiring the least flow rate). Such speeds can vary considerably in turns and are accommodated by the system **4**.

Alternative algorithms can be utilized for managing chemical application. For example, in a "rate reduction to zero" algorithm the application rates can be progressively reduced on one or more passes as required to "zero out" the applied material quantities across the boom widths whereby on subsequent passes the applied rate will be zero gallons per acre. Alternatively, in an "as applied map" algorithm the application rates can be read back in real time from the processor **23** and subtracted from the desired target rate per pixel and written back as the remaining desired rates with a flag indicating partial application marking the partially-treated (under-applied) pixels **50**f. The real time database display reflects the remaining rates required for each pixel, the remaining chemical required for the completion of the field area and the remaining quantities available.

Various output information can be provided to an operator, e.g., indicating pixel status originally and currently, "as applied" mapping and remaining chemical application rates by pixel for job completion. By individually controlling the flow rates at the nozzles **8**, the desired prescription map area rate can be achieved, thereby optimizing variable rate coverage for increased crop production. Less-experienced operators can be accommodated because the system **4** reduces the likelihood of over-application or application outside the field perimeter.

FIGS. **8**a and **8**b show conditions encountered at field perimeters (i.e. area boundaries). FIG. **8**a shows a preemptive shut off as the vehicle approaches the area boundary. Programming the system **4** with such "look-ahead" capabilities can prevent chemical application beyond the area boundary. FIG. **8**b shows commencing application upon entering a coverage area, which can occur in phases with a first applied material quantity, from which the remaining quantity of material to be applied can be determined in order to achieve the target chemical application.

It is to be understood that the invention can be embodied in various forms, and is not to be limited to the examples discussed above. *The different methods described above may be combined together.*

What is claimed and desired to be secured by Letters Patent is as follows:

1. A method of *using a processor for* guiding an agriculture [sprayer] vehicle including a motive component and a [spray] *working* component [with a spray boom having opposite ends and multiple spray nozzles mounted in spaced relation between said ends, said components being interconnected by a power hitch adapted for laterally shifting said working component relative to said motive component, which method comprises the steps of]*, comprising*:

providing an XY pixel grid *page* corresponding to [the] *an* area*, the grid page including pixels associated with different portions of the area*;

[providing a raster-based database page comprising said XY pixel grid for said area;

providing a processor on the vehicle;

providing a GNSS guidance system connected to the processor on the vehicle;

receiving GNSS positioning signals with said guidance system;

providing said GNSS positioning signals as input to said processor;

computing GNSS-based positioning for said vehicle with said processor;

defining a GNSS-defined reference point on said area and storing the reference point coordinates with said processor;

computing X and Y pixel indices based on said GNSS-defined vehicle position in relation to said reference point with said processor;

treating portions of said area with said working component;

with said processor marking pixels in said treated area portions as treated;

guiding said vehicle over said area utilizing said treated pixel information;

defining additional raster-based XY pixel grid pages in said area;

expanding said database by tiling said pixel grid pages over said area;

generating X and Y scale factors for said database;

relating said X and Y scale factors to latitude and longitude respectively;

computing X and Y pixel indices based on the difference between current GNSS-defined position coordinates and the reference position coordinates;

creating with said processor a linear or multidimensional database comprising said pixel grid pages;

accessing with said processor said database;

marking pixels in said database as treated;

defining a swath coverage area with said working component ends forming opposite edges of said swath;

with said GNSS system and said processor seeking pixels in proximity to said swath edges;

with said GNSS system and said processor guiding said vehicle along said swath edges;

providing an autosteer system on said vehicle;

with said processor generating steering commands using the marked pixel information and said XY pixel page database;

outputting said steering commands to said autosteer system for automatically steering said vehicle over said area;

with said processor and said GNSS system laterally shifting said working component relative to said motive component for maintaining said working component generally within said swath;

computing an application map for said area corresponding to treatments of pixels therein with said working component;

guiding said vehicle with said application map while treating said pixels; and]

guiding the agricultural vehicle in an initial pass over the area corresponding to the grid page;

during the initial pass of the area marking the pixels in the XY pixel grid page associated with the portions of the area treated by the working component as applied pixels;

during another pass of the area, detecting a vehicle [direction of travel] *path* with [said] *a* GNSS system;

walking up [the] pixels in the *XY pixel grid page along the* vehicle [direction of travel] *path* to a target pixel *in the XY pixel grid page*;

testing *the* pixels [in multiple scans] *in the XY pixel grid page* alongside [said] *the* vehicle path for [treated conditions] *the applied pixels* based on a swath width of [said] *the* working component; *and*

guiding [said] *the* vehicle towards [said] *the* target pixel [using said treated condition pixel information] *based on the applied pixels identified* alongside [said] *the* vehicle path[;

testing multiple distances ahead for treated pixels;

detecting a curve condition defined by treated pixels;

guiding said vehicle alongside said curve using said treated pixel information;

preprogramming said processor with variables corresponding to vehicle performance dynamics;

determining altitudes of said pixels with said GNSS system; and

adjusting guidance and steering for vehicle slippage, sloping surface chemical spray patterns and crop heights using said vehicle performance dynamics and said pixel altitudes].

2. The method of claim 1, including:

testing, with the processor, multiple distances ahead for the applied pixels;

detecting, with the processor, a curve defined by the applied pixels; and

guiding, with the processor, the vehicle alongside the curve defined by the applied pixels.

3. The method of claim 1, including:

determining altitudes for the portions of the area;

assigning the altitudes to the pixels associated with the portions of the area; and

adjusting guidance and steering of the vehicle based on the altitudes assigned to the pixels associated with the portions of the area covered by the working component.

4. The method of claim 1, including:

defining additional XY pixel grid pages; and

combining the additional XY pixel grid pages with the provided XY pixel grid page.

5. The method of claim 1, including:

identifying a swath coverage area with swath edges corresponding with opposite ends of the working component;

identifying the pixels in proximity to the swath edges; and

steering the vehicle based on the pixels in proximity to the swath edges.

6. The method of claim 1, including:

assigning chemical prescription rate values to the pixels;

compute amounts of a chemical applied to the portions of the area;

compare the amounts of the chemical applied to the portions of the area with the chemical prescription rate values assigned to the pixels associated with the portions of the area; and

adjusting the amounts of additional chemical output from individual spray nozzles of the working component on the portions of the area based on the comparisons of the amounts of the chemical previously applied to the portions of the area and the chemical prescription rate values assigned to the pixels associated with the portions of the areas.

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