EXHIBIT A

US006374180B1

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Slominski et al.

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(45) **Date of Patent: Apr. 16, 2002**

(54) **POINTS OF INTEREST FOR A NAVIGATION SYSTEM**

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(*) 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.: **09/661,982**

(22) Filed: **Sep. 18, 2000**

(51) **Int. Cl.**[7] **G01C 21/36**

(52) **U.S. Cl.** **701/208**; 701/209; 701/211; 340/988; 340/990

(58) **Field of Search** .... 701/208, 201, 701/207, 209, 211; 340/988, 990, 995; 73/178 R

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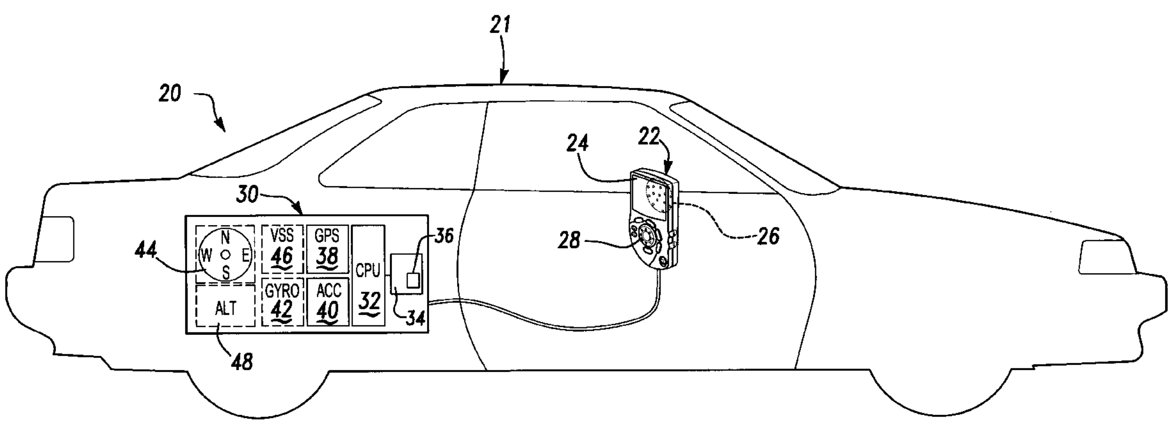
Primary Examiner—Yonel Beaulieu
(74) *Attorney, Agent, or Firm*—Carlson, Gaskey & Olds

(57) **ABSTRACT**

A navigation system that enables a user to search for points of interest across categories is provided. The user may enter a character string of a desired destination into the navigation system using a user input device. The navigation system will search for points of interest in the database for the character string. The character string may be from the first portion of the name of the point of interest or somewhere in the middle of the name of the point of interest. In this manner, the user will be able to locate a point of interest from the database while having a partially incorrect name. Additionally, the navigation system may relate the points of interest to the vehicle location, such as by vehicle direction or proximity of the points of interest to the vehicle.

18 Claims, 3 Drawing Sheets



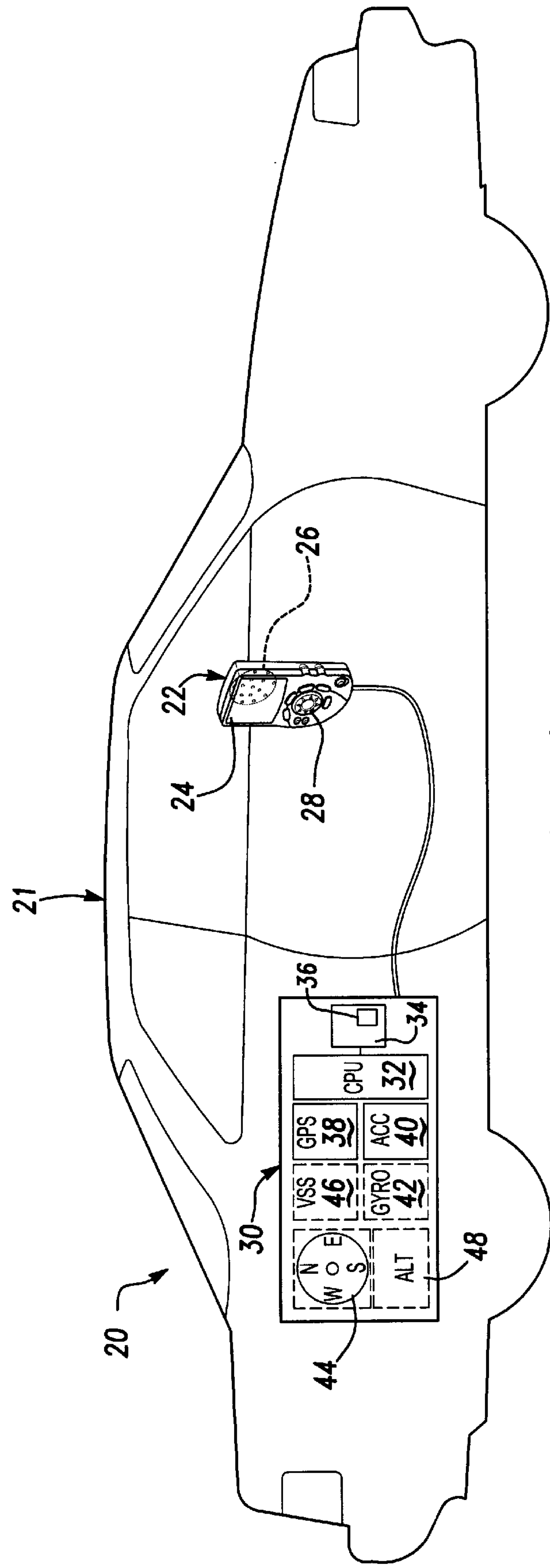

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Fig-1

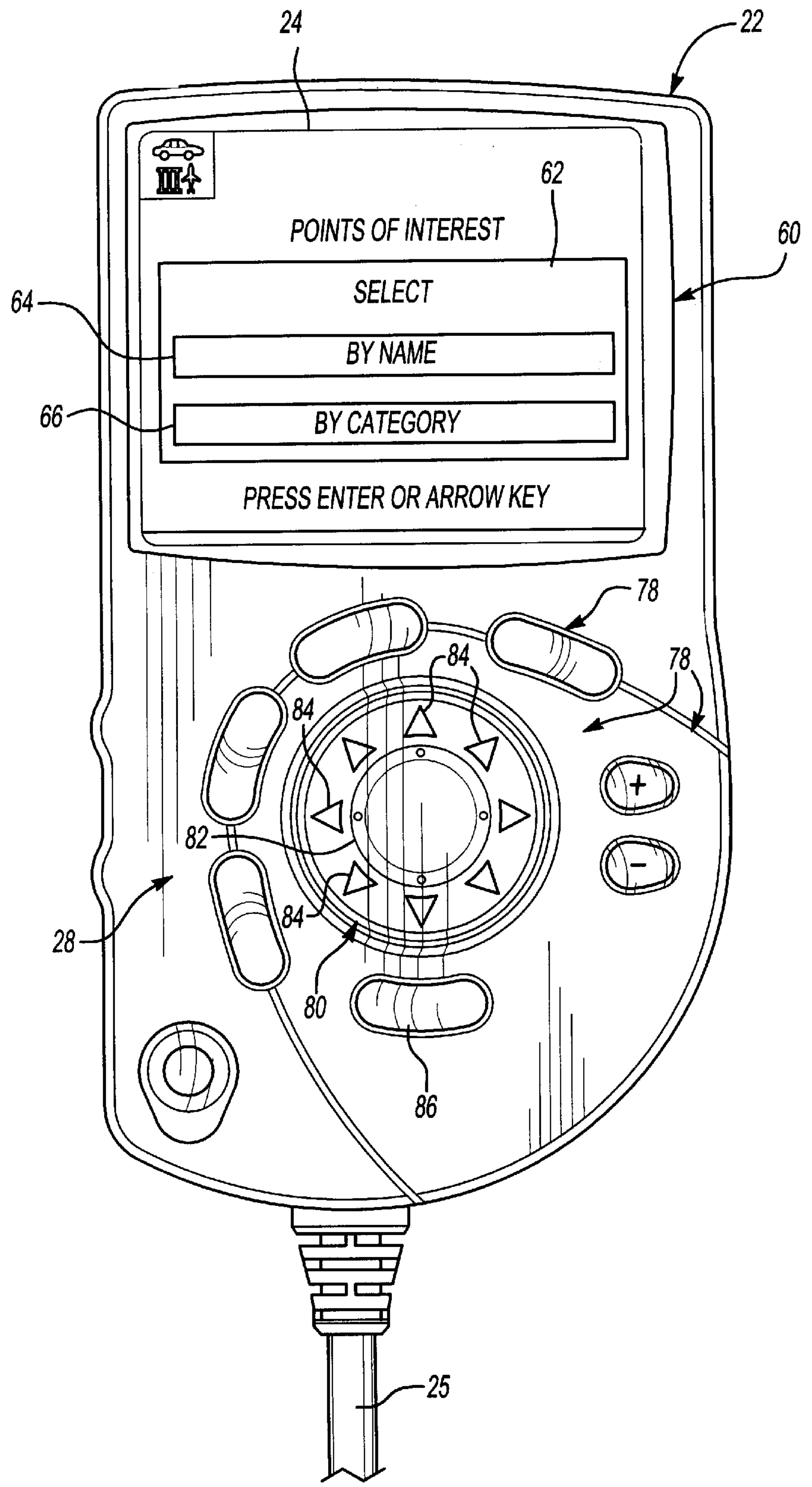
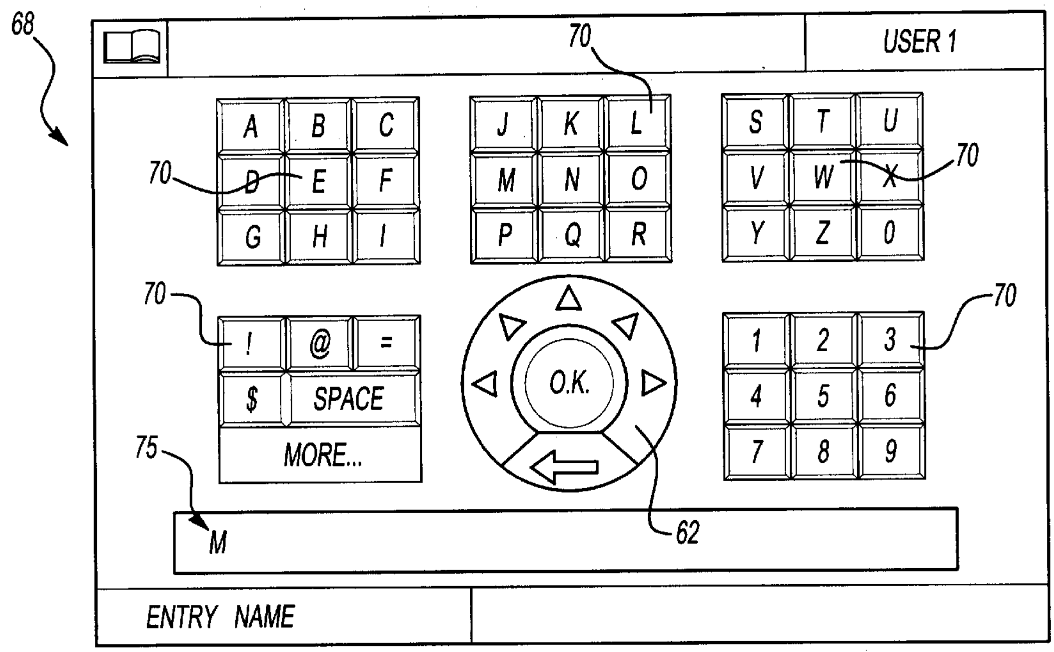

24
22
62
POINTS OF INTEREST
60
SELECT
64
BY NAME
66
BY CATEGORY
PRESS ENTER OR ARROW KEY
78
84
78
84
+
82
−
84
28
80
86
25

Fig-2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G H I
J K L
M N O
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V W X
Y Z 0
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! @ =
$ SPACE
MORE...
O.K.
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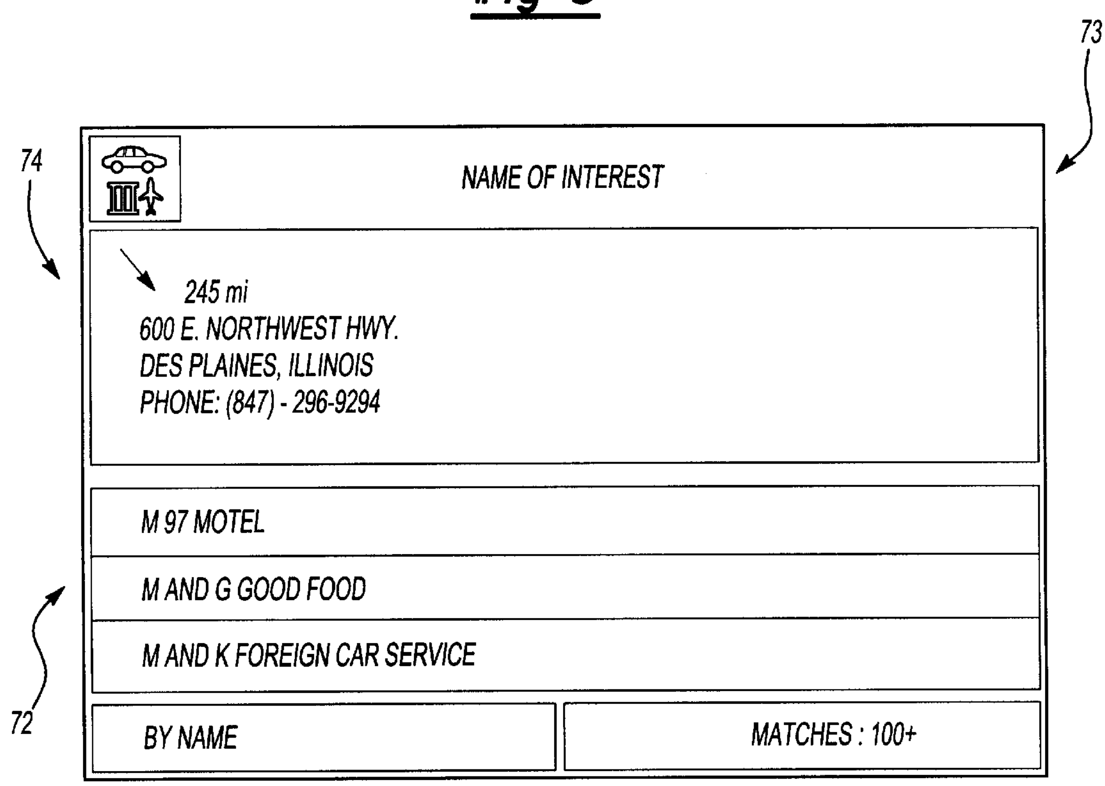
7 8 9
75
M
62
ENTRY NAME

Fig-3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74
NAME OF INTEREST
245 mi
600 E. NORTHWEST HWY.
DES PLAINES, ILLINOIS
PHONE: (847) - 296-9294
M 97 MOTEL
M AND G GOOD FOOD
M AND K FOREIGN CAR SERVICE
72
BY NAME
MATCHES : 100+

Fig-4

POINTS OF INTEREST FOR A NAVIGATION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to navigation systems, and more particularly, to navigation systems using an improved method of finding points of interest.

Navigation systems generally provide a recommended route from a starting point to a desired destination. Typically, one or both of the starting points and the desired destination are selected from a large database of roads and particular locations or points of interest that are stored in a mass media storage. When the user desires directions to a particular location, the user may conduct a search for the desired destination from the database and then select the destination from a hit list to generate the map thereto. The points of interest have typically been organized in the database by categories, such as restaurants and hotels. Most navigation systems have been limited in that the user was only able to search a particular category at a time. That is, the user would have to preselect the category prior to searching for the point of interest. Frequently, a particular destination may be stored in a category other than the category anticipated by the user. As a result, after the user conducted a search in the category, the desired destination would not be found.

An improved method of searching for points of interest has been developed in which the user is able to search across categories enabling the user to find the particular point of interest regardless of how the point of interest is classified in the database. While the ability to search across categories for a point of interest is an improvement over the prior art, several problems remain in searching for a point of interest. For example, the name entered by the user may not be the first name used for the point of interest in the database and, therefore, the point of interest will not be found by the user. Another problem is that a name search across categories will yield a greater number of results or hits. As a result, it is difficult for the user to find the potentially more relative points of interest from the generated list, which is often the points of interest closest to the vehicle location. Therefore, what is needed is an improved navigation system which enables the user to search for points of interest across categories while enabling the user to search within the name of the points of interest and relate the point of interest to the vehicle location.

SUMMARY OF THE INVENTION

The present invention provides a navigation system that enables a user to search for points of interest across categories. The user may enter a character string of a desired destination into the navigation system using a user input device. The navigation system searches for points of interest in the database having the character string. The character string may be from the first portion of the name of the point of interest or somewhere in the middle of the name of the point of interest. In this manner, the user is able to locate a point of interest from the database while having a partially incorrect name.

The navigation system may also relate the points of interest to the location of the vehicle. The navigation system senses the vehicle travel information such as vehicle position or vehicle direction. The points of interest are organized relative to the vehicle information. A hit list is generated and displayed in a manner that relates to vehicle location. For example, the closest points of interest to the vehicle location may be organized at the top of the hit list. Alternatively, the points of interest may be organized relative to the direction of the vehicle travel. That is, the points of interest closest to the vehicle and in the direction of the vehicle travel would be displayed at the top of the hit list.

Accordingly, the present invention searches a larger amount of the database to ensure that the user is able to locate the desired destination. The present invention also ensures that the information is organized in a manner such that the potentially most relative information is easily accessible to a user.

BRIEF DESCRIPTION OF THE DRAWINGS

Other advantages of the present invention can be understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. **1** is a schematic view of a navigation system with the graphical user interface of the present invention installed in a vehicle;

FIG. **2** is a plan view of a displayed device having multiple user inputs and a display screen; and

FIG. **3** is a character input display screen.

FIG. **4** is a display screen of one embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

The navigation system **20** of the present invention is shown schematically in FIG. **1** installed in a vehicle **21**. The navigation system **20** includes an Operator Interface Module ("OIM") **22** including input and output devices. The OMI **22** includes a display **24**, such as a high resolution LCD or flat panel display, and an audio speaker **26**. The OIM **22** also includes input devices **28**, preferably a plurality of buttons and directional keypad, but alternatively including a mouse, keyboard, keypad, remote device or microphone. Alternatively, the display **24** can be a touch screen display.

The navigation system **20** further includes a computer module **30** connected to the OIM **22**. The computer module **30** includes a CPU **32** and storage device **34** connected to the CPU **32**. The storage device **34** may include a hard drive, CD-ROM, DVD, RAM, ROM or other optically readable storage, magnetic storage or integrated circuit. The storage device **34** contains a database **36** including a map of all the roads in the area to be traveled by the vehicle **21** as well as the locations of potential destinations, such as addresses, hotels, restaurants, or previously stored locations. The software for the CPU **32**, including the graphical user interface, route guidance, operating system, position-determining software, etc may also be stored in storage device **34** or alternatively in ROM, RAM or flash memory.

The computer module **30** preferably includes navigation sensors, such as a GPS receiver **38** and an inertial sensor, which is preferably a multi-axis accelerometer **40**. The computer module **30** may alternatively or additionally include one or more gyros **42**, a compass **44**, a wheel speed sensor **46** and altimeter **48**, all connected to the CPU **32**. Such position and motion determining devices (as well as others) are well known and are commercially available.

The navigation system **20** propagates the position of the vehicle **21** relative to the map database **36**, i.e. relative to road segments and intersections. The navigation system **20** also determines the current location of the vehicle **21** in terms of latitude and longitude. Generally, the CPU **32** and position and motion determining devices determine the position of the vehicle **21** relative to the database **36** of roads utilizing dead reckoning, map matching, etc. Further, as is known in navigation systems, the user can select a destination relative to the database **36** of roads utilizing the input device **28** and the display **24**. The navigation system **20** then calculates and displays a recommended route directing the driver of the vehicle **21** to the desired destination. Preferably, the navigation system **20** displays turn-by-turn instructions on display **24** and gives corresponding audible instructions on audio speaker **26**, guiding the driver to the desired destination.

FIG. **2** is a perspective view of one disclosed embodiment of the display device **24** and directional input device **26**, preferably designed as an integral unit attached to the CPU by connection **25**. The display device **24** includes a screen such as a high resolution LCD or flat panel display. The directional input device **26** includes a multiple of input buttons **78** including, preferably, an eight-way button shown generally at **80** and a selection key **86** such as an "Enter" key. Although an eight-way button is shown, it will be realized that other input devices, such as a joystick, mouse or roller ball can be employed.

The internal disk **82** is pivotally mounted in the eight-way button **80** and is capable of moving in the direction of any one of the directional arrows **84**. Movement of the internal disk **82** in the direction of one of the directional arrows **84** transmits a directional signal.

A point of interest screen **60** is shown on display device **24** in FIG. **2**. The user may select between the search type option **62** by using the input button **78**. Specifically, the user may use the eight-way button **80** to arrow up or down between the search type option **62**. The user may conduct a name search by selecting the "By Name" option **64**, or the user may conduct a category search by selecting the "By Category" option **66**. The "By Category" search option **64** will limit category that is selected by the user in a subsequent display screen (not shown), as in the prior art. Once the search option has been selected, the user may press the enter key **86** to continue the search. The navigation system **20** may have search options other than described above.

Once the search option has been selected a character entry screen **68** will appear on the display device as shown in FIG. **3**. The user selects characters **70** by using the eight-way button **80** and enter key **86** to build a search string **75** that represents a portion of the name of the point of interest or desired destination. The user may enter just a portion of the name or the entire name. Once the desired character string **75** has been entered the CPU **32** will search the database **36** across the categories for points of interest containing the character string **75**. In accordance with one feature of the present invention, the CPU **32** will search across the categories for the character string **75** anywhere in the name of the points of interest. That is, the search will not be limited to points of interest beginning with the character string entered by the user. For example, a particular destination may have a name other than the name commonly used to refer to the location. For example, when searching for a Wendy's fast food restaurant, a prior art search would not reveal a Wendy's listed under the proprietor's name such as Bob's Wendy's. With the present invention, all Wendy's would be found in the database. The results are organization into a hit list and displayed on the display device **24** preferably in alphabetical order beginning with the name starting with the character string **75**. All other points of interest are preferably organized alphabetically for names not starting with the character string. The hit list screen **71** is shown in FIG. **4** displaying a hit list **72** including points of interest **73**. When a particular point of interest is selected using the eight-way button **80**, location information **74** is displayed on the display device **24** above the hit list **72**.

In another aspect of the present invention, the points of interest containing the character string **75** are organized relative to vehicle travel information, such as vehicle position and vehicle direction. Vehicle travel information is sensed using the position and motion determining devices described above. In one embodiment, the points of interest are organized and displayed in order of closest point of interest to the vehicle position to farthest point of interest to the vehicle position. This list may be further refined by limiting the displayed hit list to points of interest within a predetermined radius from the vehicle. Alternatively, the radius may be selected by the user. In this manner, the hit list may be limited to the potentially most useful number of points of interest.

In another embodiment, the points of interest are organized and displayed relative to the direction of the vehicle. That is, the closest points of interest in the direction that the vehicle is traveling are displayed at the top of the list while points of interest that are farther in the direction of vehicle travel are displayed further down. Points of interest in the opposite direction of vehicle travel may still be displayed further down the list. For example, if the vehicle is traveling northbound on Interstate-**75** the user is not as interested in points of interest in which the vehicle would have to turn around and travel southbound on Interstate-**75**. In this manner, the most potentially relative points of interest are displayed at the top of the list.

The present invention provides expanded searching capability of the database **36** while maintaining a hit list containing the potentially most relative points of interest. The invention has been described in an illustrative manner, and it is to be understood that the terminology that has been used is intended to be in the nature of words of description rather than of limitation. Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A method of finding a desired destination in a navigation system comprising the steps of:

a) entering a character string of a desired destination into the navigation system;

b) searching points of interest in a database for the character string;

c) sensing vehicle travel information;

d) organizing a hit list including the points of interest containing the character string with reference to the vehicle travel information; and

e) displaying the hit list.

2. The method according to claim **1**, wherein the character string includes at least one character.

3. The method according to claim **1**, wherein the points of interest are organized by categories, and step b) includes searching across the categories.

4. The method according to claim **1**, wherein the vehicle travel information includes vehicle position, and step d) includes organizing the hit list in order of closest point of interest to the vehicle position to farthest point of interest to the vehicle position within a predetermined radius.

5. The method according to claim **1**, wherein the vehicle travel information includes vehicle direction, and step d) includes organizing the hit list in order of closest point of interest in the direction of the vehicle direction and approximately perpendicular thereto to the farthest point of interest within a predetermined radius in the direction of the vehicle direction and approximately perpendicular thereto.

6. The method according to claim **5**, wherein step d) includes further organizing the hit list within a predetermined radius in order of closest point of interest in the direction opposite of the vehicle direction and approximately perpendicular thereto to farthest point of interest in the direction opposite of the vehicle direction and approximately perpendicular thereto.

7. The method according to claim **1**, wherein the desired destination is represented by a name, and step b) includes searching for the character string anywhere in the name.

8. The method according to claim **1**, wherein step c) occurs at predetermined intervals for sensing new vehicle travel information, and the method further includes the steps of:

f) updating the hit list including the points of interest containing the character string with reference to the new vehicle travel information; and

g) displaying an updated hit list.

9. A vehicle navigation system comprising:

a user input device for entering a character string from a portion of a name of a desired destination;

a database having points of interest organized by categories;

at least one navigation sensor for detecting vehicle travel information including vehicle position and vehicle direction;

a display device; and

a CPU connected to said input and output devices, said at least one navigation sensor, and said database, said CPU generating a hit list including points of interest containing said character string and organized with reference to said vehicle travel information, said hit list displayed on said display device in response to said character string.

10. The system according to claim **9**, wherein the CPU organizes the hit list in order of closest point of interest to the vehicle position to farthest point of interest to the vehicle position within a predetermined radius.

11. The system according to claim **9**, wherein the CPU organizes the hit list in order of closest point of interest in the direction of the vehicle direction and approximately perpendicular thereto to farthest point of interest within a predetermined radius in the direction of the vehicle direction and approximately perpendicular thereto.

12. The system according to claim **11**, wherein the CPU further organizes the hit list within a predetermined radius in order of closest point of interest in a direction opposite of the vehicle direction and approximately perpendicular to the farthest point of interest in the direction opposite of the vehicle direction and approximately perpendicular thereto.

13. The system according to claim **9**, wherein the points of interest are organized by categories, and the CPU searches across the categories.

14. The system according to claim **9**, wherein said desired destination is represented by a name, and said CPU searches for said character string anywhere in said name.

15. The method according to claim **1**, wherein the vehicle travel information includes vehicle position, and step d) includes displaying the hit list in order of closest point of interest to the vehicle position to farthest point of interest to the vehicle.

16. The method according to claim **1**, wherein the vehicle travel information includes vehicle direction, and step d) includes displaying the hit list in order of closest point of interest in the direction of the vehicle direction.

17. The method according to claim **16**, wherein step d) includes displaying the hit list in order of closest point of interest in the direction of the vehicle direction and approximately perpendicular thereto to farthest point of interest.

18. The method according to claim **17**, wherein step d) includes displaying the hit list in order of closest point of interest in the direction of the vehicle direction and approximately perpendicular thereto to farthest point of interest in the direction of the vehicle direction and approximately perpendicular thereto.

* * * * *

EXHIBIT B

US006178380B1

(12) United States Patent
Millington

(10) Patent No.: US 6,178,380 B1
(45) Date of Patent: Jan. 23, 2001

(54) STREET IDENTIFICATION FOR A MAP ZOOM OF A NAVIGATION SYSTEM

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(73) Assignee: **Magellan, DIS, Inc.**, Rochester Hills, MI (US)

(*) Notice: Under 35 U.S.C. 154(b), the term of this patent shall be extended for 0 days.

(21) Appl. No.: **09/176,630**

(22) Filed: **Oct. 22, 1998**

(51) **Int. Cl.**[7] **G08G 1/0969**; G09B 29/00; G01C 21/00

(52) **U.S. Cl.** **701/212**; 701/208; 701/211; 340/990; 340/995

(58) **Field of Search** 701/25, 201, 208, 701/211, 212; 340/990, 995

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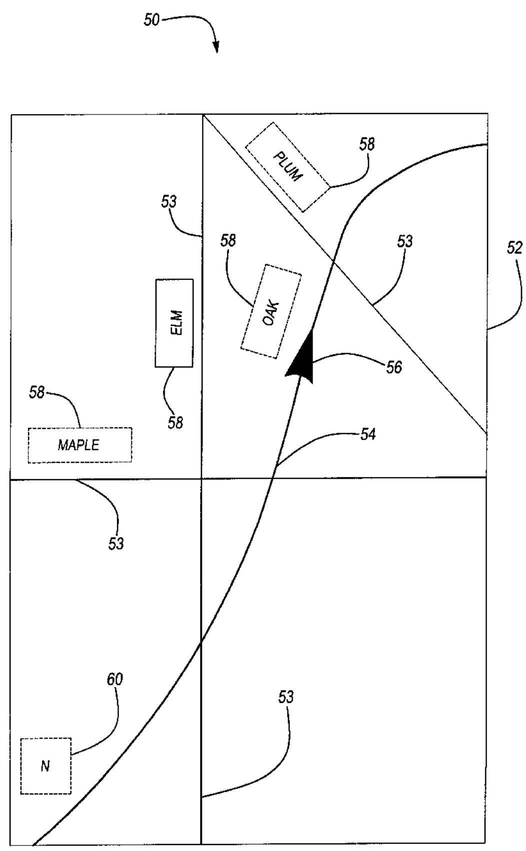
Primary Examiner—Ian J. Lobo
(74) *Attorney, Agent, or Firm*—Carlson, Gaskey & Olds

(57) **ABSTRACT**

A vehicle location display for a navigation or route guidance system is disclosed. The vehicle location display provides information to a user regarding the current location of the vehicle on a map even when the scale of the map is large. In a preferred embodiment, the map includes a current location field that displays a road segment name associated with the current road segment that the vehicle is located on. In an alternative embodiment, the vehicle location display displays a large scale map wherein the current road segment is highlighted by displaying it in a color and the name of the current road segment is displayed in a current location field on the map.

31 Claims, 5 Drawing Sheets



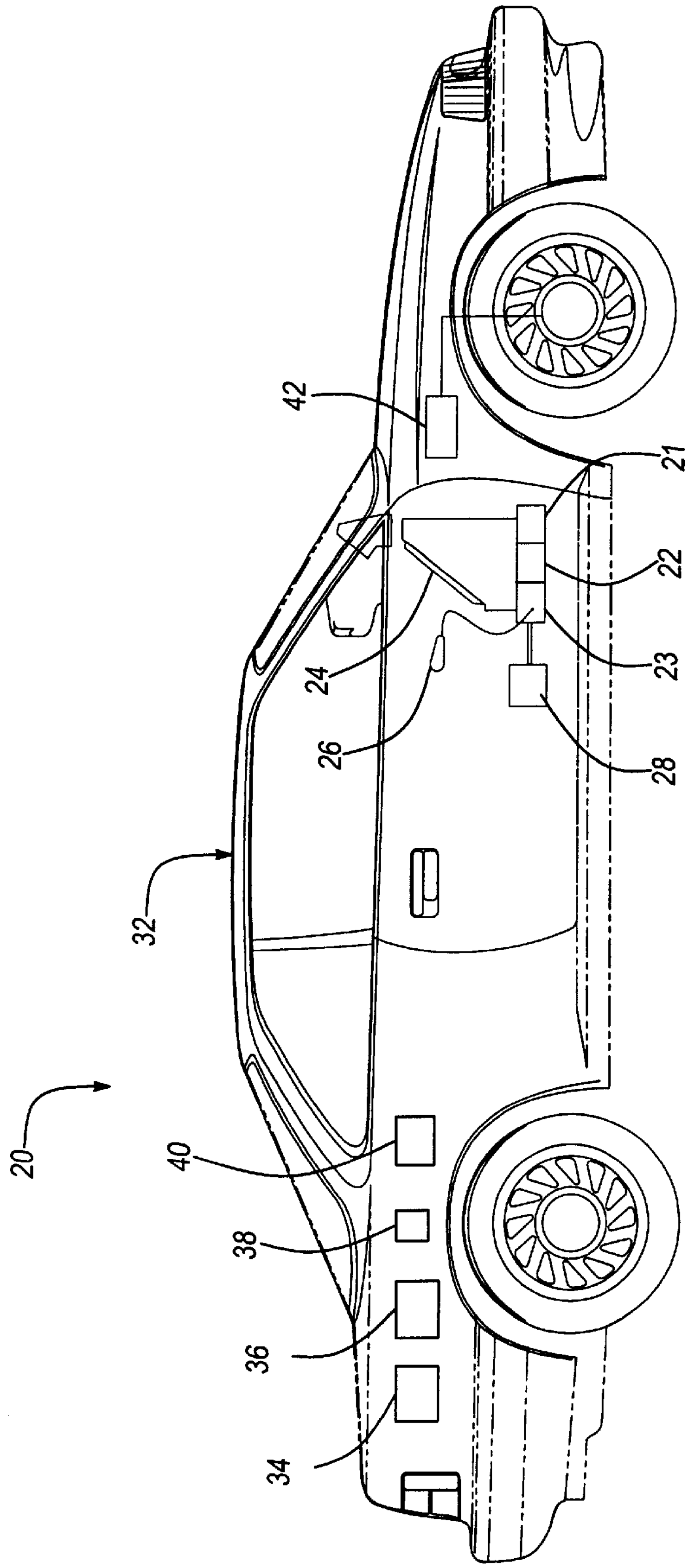


Fig-1

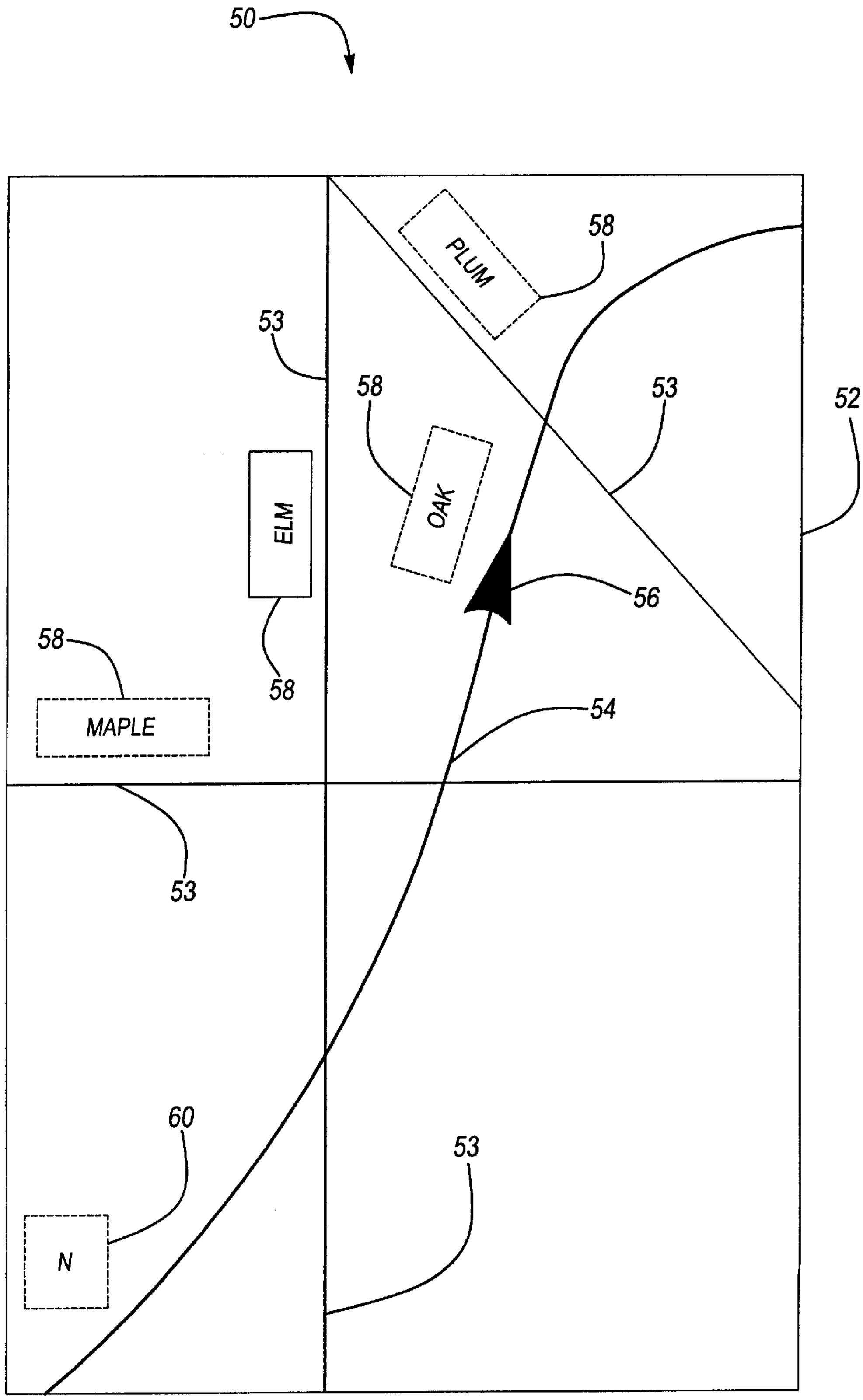


Fig-2

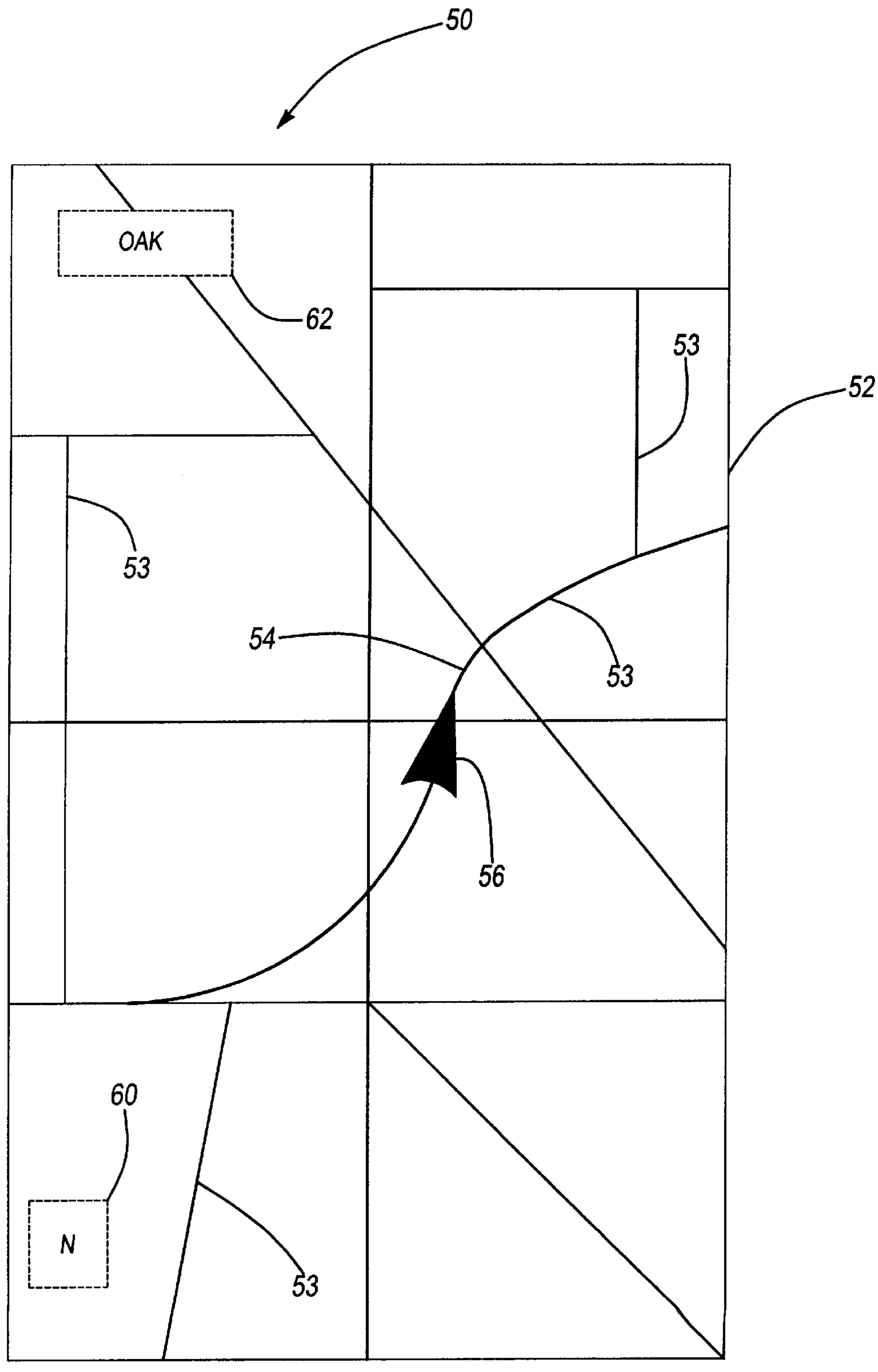


Fig-3

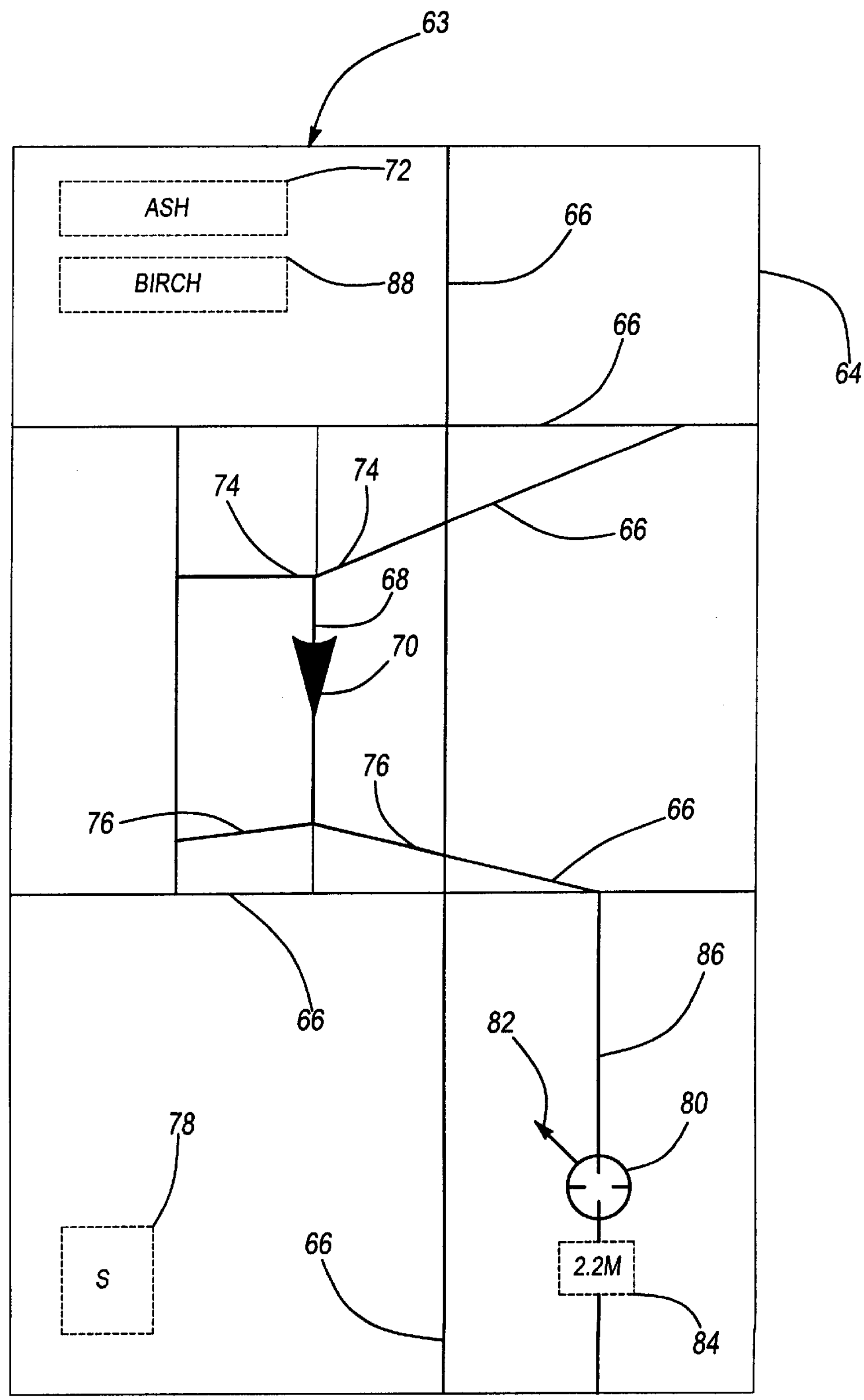

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Fig-4

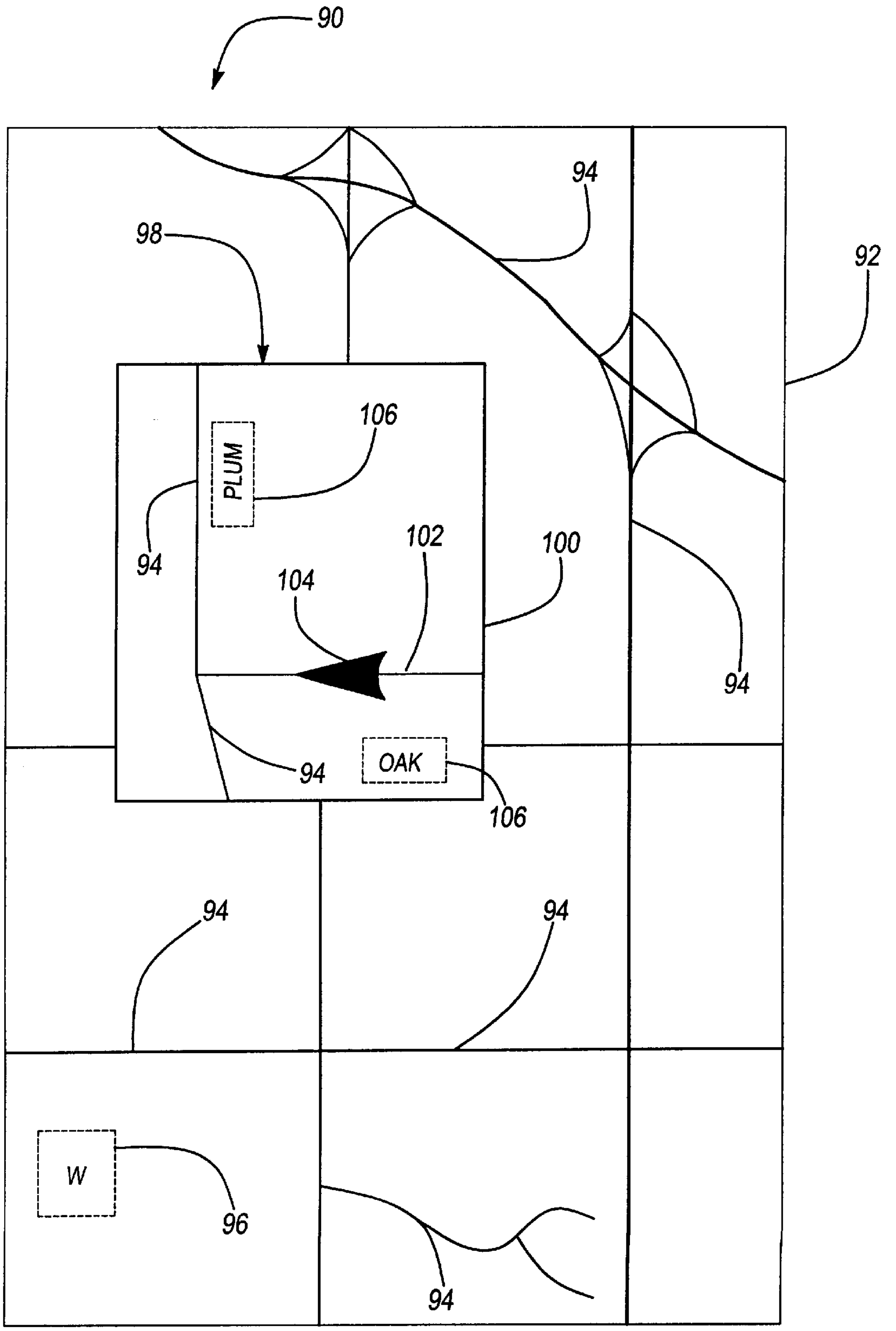

Fig-5

STREET IDENTIFICATION FOR A MAP ZOOM OF A NAVIGATION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to a navigation or route guidance system and, more particularly, to a vehicle location display for a route guidance system.

Navigation systems generally provide a recommended route from a starting point to a desired destination. Generally, the starting point and desired destination are selected from a large database of roads stored in a mass media storage, such as a CD ROM or hard drive, which includes the roads in the area to be travelled by the user. The navigation system can be located in a personal computer or it can be installed in a vehicle. If the navigation system is installed in a vehicle, the starting point is typically the current position of the vehicle, which can be input to the navigation system by an associated position determining system that usually includes a GPS (Global Positioning System) receiver.

The navigation system determines a route from the starting point to the destination utilizing an algorithm well-known to those in the art and currently in use in many navigation systems. Usually there are many potential routes between the selected starting point and the desired destination. Typical navigation systems select a recommended route based upon certain "cost" values associated with each segment of road in the road database. These cost values include the length of the road segment and the estimated time of travel through the road segment. The navigation system selects the potential route with the lowest total cost to be the recommended route. Depending upon the predetermined algorithm of the navigation system, the navigation system will recommend the route with the shortest total length, the lowest total time, or some weighted average of length and time.

The recommended route is then displayed to the user as a map showing the starting point, desired destination and highlighting the recommended route. Preferably, if the navigation system is installed in a vehicle, the navigation system displays the current location of the vehicle and provides turn-by-turn instructions to the driver, guiding the driver to the selected destination.

The typical navigation system provides the current vehicle location to the user by displaying either a textual guidance mode screen having a set of instructions and the current location or a guidance mode map showing the starting point, desired destination, current location and highlighting the recommended route. When a user has not determined a route, the typical navigation system displays a map showing the current vehicle location and all of the surrounding streets. Such a system is described in U.S. Pat. No. 6,049,755 filed Jul. 13, 1998, which claims benefit of provisional application Ser. No. 60/084,292, filed May 5, 1998. The disclosures of U.S. Pat. No. 6,049,755 and 60/084,292 referenced above are hereby incorporated by reference in full.

The typical navigation system also permits a user to adjust the scale of a displayed map. Frequently a user desires to "zoom out" by increasing the map scale to enable the user to see a larger area of the database. One disadvantage of current map zoom functions is that when a user zooms out it can be difficult, because of the complexity of a larger scale map, to see the current vehicle location on the large scale map. Also, in a current navigation system when a smaller scale map is displayed the user is provided with the name of

streets on the map, this information can not be provided on the larger scale display.

The typical navigation system also permits a user to pan the map to areas other than the current location. One disadvantage when panning a large scale map is that the user is not provided with a street name of a panned street.

Thus, it is desirable to provide a vehicle location display for a navigation system that permits a user to alter the scale of a displayed map to a large scale while still providing the user with information concerning the current vehicle location. In addition, it is desirable to provide information to a user regarding a panned street when the scale of a displayed map is large.

SUMMARY OF THE INVENTION

In general terms, this invention provides a vehicle location display for a navigation system.

In one embodiment the vehicle location display comprises a database of a plurality of road segments each having an associated road segment name. The vehicle location display also includes a display that displays a map at a variable scale and comprising a plurality of the road segments including the current road segment. The display displays an associated road segment name adjacent the current road segment when the variable scale is below a threshold scale. The display displays the associated road segment name of the current road segment in a current location field on the display not adjacent the current road segment when the scale is above the threshold scale.

In a preferred embodiment the vehicle location display accents the current road segment and the associated road segment name when the variable scale is above the threshold scale by displaying them in a first color on the display. In a most preferred embodiment the vehicle location display includes a map scaler that adjusts the scale of the map in response to input from a user input device.

These and other features and advantages of this invention will become more apparent to those skilled in the art from the following detailed description of the presently preferred embodiment. The drawings that accompany the detailed description can be described as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of a navigation system with a vehicle location display designed according to the present invention installed in a vehicle;

FIG. **2** is a screen display of one embodiment of the vehicle location display illustrating a map having a scale below a threshold scale;

FIG. **3** is a screen display of the vehicle location display shown in FIG. **2** when the map has a scale above the threshold scale;

FIG. **4** is a screen display of another embodiment of the vehicle location display illustrating a map having a scale above the threshold scale; and

FIG. **5** is a screen display of another embodiment of the vehicle location display illustrating a second map within a first map when the first map has a scale above the threshold scale.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The navigation system **20** of the present invention is shown schematically in FIG. **1**. The navigation system **20** includes a CPU **22** (Central Processing Unit) having a route determination system **21** and a map scaler **23**. Preferably, the route determination system **21** and the map scaler **23** are implemented in software on the CPU **22**. The CPU **22** is connected to a display device **24**, such as a high resolution LCD or flat panel display. The CPU **22** is also connected to a user input device **26**. The navigation system **20** further includes a database **28** connected to the CPU **22**. The database **28** is a mass media storage device, such as a CD ROM or hard drive, which includes data of all the roads in the area to be travelled by the user. The navigation system **20** can display a map on display device **24** based on the data in the database **28**. The scale of the map, for example 1:265,000, is a variable scale that can be altered by a user through the user input device **26** and the map scaler **23**.

Each road in the database is divided into road segments, each having an associated set of cost values, which indicate the "cost" of traveling that road segment. For example, the cost values may include the length of the road segment, the estimated time to travel the road segment, and the type of road (i.e., highway, secondary road, toll road, one way, etc.). Each road segment also has a road segment name associated with it. Generally, each road segment comprises the portion of a road between adjacent cross roads to the road.

Using algorithms well known in the art, route determination system **21** determines a route on the road segments from a beginning point to a user selected destination point. Preferably, the beginning point is the current vehicle location as determined by the CPU **22** and one of the position determining devices discussed below. The determined route is preferably based on the cost values. Preferably, the navigation system **20** displays the determined route on display device **24** and provides turn by turn instructions to the user.

Each road segment in the database **28** has a rank associated with it. The rank, for example, may be a number from zero to four, with four being the highest rank. The rank of a road segment is determined by a number of factors including: road geometry, such as the number of lanes; speed limit of the road segment; and type of road segment, such as freeway, primary street or subdivision street. Generally, the rank divides road segments from highest rank to lowest rank into a freeway, a primary street, a secondary street, and a subdivision street with a freeway being the highest rank. The rank of a given road segment can not be altered by a user. The CPU **22** associates a unique rank color with each of the ranks. The display device displays each road segment in its associated rank color. Thus, for example, a highway, which has the highest rank may have a rank color of red and a subdivision street, which has the lowest rank may have a rank color of gray.

The navigation system **20** can, but need not, be installed in a vehicle **32**. The navigation system can be used in conjunction with position determining devices, such as a GPS receiver **34**, a gyroscope **36**, a compass **38**, an orthogonal multi-axis accelerometer **40** and a vehicle speed sensor **42**, all connected to the CPU **22** (connections not shown for simplicity). Such position determining devices are well-known and are commercially available. Preferably, a combination of these position determining devices is utilized. Using known software algorithms and technologies, such as dead-reckoning or map-matching or others, the CPU **22** in combination with the position determining device comprises a position determining system that determines the current position of the navigation system **20** or the vehicle **32** relative to the map database **28**. The current position determination includes a determination of a current road segment and a current vehicle location on the current road segment.

FIG. **2** is a screen display of one embodiment of a vehicle location display shown generally at **50**. Vehicle location display **50** includes a map **52** displayed on display device **24**. Map **52** is comprised of a plurality of road segments **53** and includes a current road segment **54**, which is determined by the position determining system, described above. A vehicle cursor **56** is located at a current vehicle location, also determined by the position determining system, on current road segment **54**. A road segment name field **58**, shown in phantom, is located adjacent at least one road segment **53** of each road including current road segment **54**. A road segment name associated with the adjacent road segment **53** is displayed in each road segment name field **58**. Vehicle location display **50** also includes a current heading field **60**, shown in phantom, that displays a current compass heading of vehicle **32**. As discussed above, map **52** is comprised of a plurality of road segments **53**, generally each road segment **53** comprises the portion of a road between adjacent cross roads of that road. If there is a long distance between cross roads, then a road segment may be a portion of a road that is not defined by cross roads. Preferably each road segment **53**, and the current road segment **54** are displayed in their associated rank color, described above. In FIG. **2** the scale of map **52** is below a threshold scale, thus vehicle location display **50** operates in a first mode and map **52** displays associated names in the road segment name fields **58**. The threshold scale is preferably set at a scale that displays a map **52** that is not overly complex or detailed and represents a fully zoomed in view.

In FIG. **3** vehicle location display **50** is shown when the scale of map **52** is above the threshold scale, in other words, the user has zoomed out The scale of map **52** is variable and can be adjusted through user input device **26** and map scaler **23**. When the scale of map **52** exceeds the threshold scale vehicle location display **50** operates in a second mode and further includes a current location field **62**. Current location field **62** displays the road segment name associated with current road segment **54**. Preferably, when the variable scale exceeds the threshold scale map **52** no longer displays the associated names in the current road segment name field **58**.

When map **52** is at a scale above the threshold scale the current road segment **54** is accented or highlighted. Preferably, current road segment **54** is accented by displaying current road segment **54** in a first color wherein the first color is not one of the rank colors, described above. Accenting could also comprise flashing current road segment **54** or changing its intensity. Preferably, first color comprises a magenta color. In addition, preferably the road segment name associated with current road segment **54** is displayed in current location field **62** in the first color. Preferably the current location field **62** is displayed in a fixed location on display device **24** that is independent of the location of vehicle cursor **56** and current road segment **54**.

FIG. **4** is display device **24** showing another embodiment of a vehicle location display **63** operating in the second mode when the scale exceeds a threshold scale. In FIG. **4** vehicle location display **63** includes a map **64** comprised of a plurality of road segments **66**, **68**, **74**, **76**, and **86** including a current road segment **68**. Preferably road segments **66** are displayed in their associated rank color. A vehicle cursor **70** is located on current road segment **68** at the current vehicle location as determined by the position determining system, described above. The scale of map **64** as shown is above the threshold scale, and thus the road segment names are not displayed adjacent any of road segments **66**. Map **64** includes a current location field **72** which displays the road segment name associated with current road segment **68**.

Preferably, current location field **72** is displayed in a fixed location on display device **24**. Current road segment **68** is accented or highlighted, preferably, by displaying current road segment **68** in the first color, described above, wherein the first color is not one of the rank colors. In addition, current road segment name is displayed in current location field **72** in the first color.

A previous cross street **74** and a next cross street **76**, selected based on the database **28** and the current vehicle location, are also displayed on map **64**. As used in this specification and the accompanying claims, a cross street is defined as a street that is connected to the current road segment **68** in any fashion or that crosses over or under the current road segment **68**. In FIG. **4**, both the previous cross street **74** and the next cross street **76** are connected to the current road segment **68**. A portion of both the previous cross street **74** and next cross street **76** are accented on map **64**. Preferably, the portions of previous cross street **74** and next cross street **76** are accented by displaying them in a second color, wherein the second color is different from the first color and the rank colors. Most preferably the portions are displayed in a turquoise color. A current heading field **78** displays the current compass heading of the vehicle **32**.

Map **64** further includes a map panning cursor **80**. Through user input device **26** a user can pan map panning cursor **80** over map **64**. Map panning cursor **80** includes a directional indicator **82** that points toward vehicle cursor **70** relative to map panning cursor **80**. The directional indicator **82** is updated as the user pans over map **64**. A distance field **84** shows the distance between the map panning cursor **80** and the current vehicle location. A user can select to have distance field **84** display the distance as either the straight line distance or the distance between map panning cursor **80** and the vehicle cursor **70** on a determined route. The map panning cursor **80** is more fully described in co-pending U.S. patent application Ser. No. 09/100,683, allowed, filed Jun. 19, 1998, which claims benefit of U.S. Provisional application Ser. No. 60/084,294, filed May 5, 1998. Both U.S. patent application Ser. No. 09/100,683, filed Jun. 19, 1998, and Provisional application Ser. No. 60/084,294, filed May 5, 1998 are hereby incorporated in full by reference.

The CPU **22** continuously calculates the heading between the map panning cursor **80** and the vehicle cursor **70** using the latitude and longitude coordinates of each. In addition, the CPU **22** continuously calculates the distance between the map panning cursor **80** and the current vehicle location either on a straight line basis or on a determined route.

Based on the heading calculated between the map panning cursor **80** and the vehicle cursor **70**, the CPU **22** indexes an array of pre-rendered bitmap symbols that define the position of the directional indicator **82** on the map panning cursor **80** and displays the bitmap symbol on map **64**. Preferably, the array of pre-rendered bitmaps includes at least eight bitmaps one each for the compass headings of north, northeast, east, southeast, south, southwest, west and northwest. Thus, a heading of approximately 315° between the map panning cursor **80** and the vehicle cursor **70** is represented by a bitmap having the directional indicator **82** positioned as shown in FIG. **4**. When the heading changes, due to a change in the location of either the vehicle cursor **70** or the map panning cursor **80**, the CPU **22** indexes the array and displays a new bitmap as appropriate.

Most preferably, each bitmap would correspond to a range of compass headings. By way of example, a heading between approximately 337.5° to 22.5° would correspond to a directional indicator positioned at a compass position of north on the map panning cursor **80**. As would be understood by one of ordinary skill in the art, the number of pre-rendered bitmaps could be much larger than the eight compass headings described above to provide higher resolution of the heading.

When map panning cursor **80** is panned over a road segment **66** that road segment becomes a panned road segment **86**. Panned road segment **86** is accented on map **64**. Preferably, panned road segment **86** is accented by displaying panned road segment **86** in a pan color, wherein the pan color is not the first color, second color or any of the rank colors. Preferably the panned color is a yellow. Map **64** further includes a panned road segment field **88**. The road segment name associated with panned road segment **86** is displayed in panned road segment field **88**, preferably in the pan color. Preferably the panned road segment field **88** is displayed in a fixed location adjacent current location field **72** independent of panned road segment **86** location.

FIG. **5** shows display device **24** displaying another embodiment of a vehicle location display **90**. Vehicle location display **90** includes a first map **92** having a variable first scale that displays a plurality of road segments **94** based on a current vehicle location and database **28**. Road segments **94** are preferably displayed in the rank color associated with their rank. Vehicle location device **90** also includes a current heading field **96** which displays the current compass heading of vehicle **32**.

When the first scale of first map **92** exceeds a threshold scale vehicle location device **90** displays in a second mode that includes a second map **98** displayed within first map **92**. Thus, in FIG. **5** the first scale of first map **92** is above the threshold scale. As would be understood by one of ordinary skill in the art, second map **98** does not need to be displayed within first map **92**. Second map **98** could be displayed adjacent first map **92**. The second map **98** displays, at a lower scale, a portion of first map **92** including a current road segment **102**. Generally, second map **98** moves around first map **92** as the current vehicle location changes so that a vehicle cursor **104** remains displayed in second map **98**. Second map **98** includes a border **100** surrounding second map **98**. Preferably, the color of border **100** is selected to contrast with the rank colors. Within second map **98** a plurality of road segments **94** are displayed, including the current road segment **102**. Current road segment **102** also includes the vehicle cursor **104** located at the current vehicle location on current road segment **102**. Adjacent road segments **94** and current road segment **102** in second map **98** are road segment name fields **106**, which display the road segment names associated with each. The scale of second map **98** is below the threshold scale.

Most preferably, map scaler **23** enables a user to select from a plurality of scales to go from fully zoomed in to fully zoomed out. Preferably the threshold scale is set at the most zoomed in scale. As a user zooms out beyond the threshold scale vehicle location displays **50**, **63**, and **90** first stop displaying road segment names, then they stop displaying lower rank road segments, finally, at highest zoom out, only high ranking road segments are displayed in addition to the current, panned, and cross road segments.

The present invention has been described in accordance with the relevant legal standards, thus the foregoing description is exemplary rather than limiting in nature. Variations and modifications to the disclosed embodiment may become apparent to those skilled in the art and do come within the scope of this invention. Accordingly, the scope of legal protection afforded this invention can only be determined by studying the following claims.

I claim:

1. A vehicle location display of a navigation system comprising:

a database of a plurality of road segments each having an associated road segment name;

a display displaying a map at a variable scale, said map comprising a plurality of said road segments including a current road segment;

said display displaying an associated road segment name adjacent said current road segment when said variable scale is below a threshold scale;

said display displaying said associated road segment name of said current road segment in a current location field on said display not adjacent said current road segment when said variable scale is above said threshold scale.

2. A vehicle location display of a navigation system as recited in claim **1** further including a position determining system, said position determining system determining said current road segment and a current vehicle location on said current road segment; and

said display displaying a vehicle cursor at said current vehicle location.

3. A vehicle location display of a navigation system as recited in claim **1** further including a user input device; and

a map scaler, said map scaler changing said variable scale of said map in response to input from said user input device.

4. A vehicle location display of a navigation system as recited in claim **1** wherein said current location field is in a fixed location on said display independent of the location of said current road segment on said display.

5. A vehicle location display of a navigation system as recited in claim **1** wherein said display accents said current road segment when said variable scale is above said threshold scale.

6. A vehicle location display of a navigation system as recited in claim **5** wherein accenting said current road segment includes displaying said current road segment in a first color different from the color of other road segments; and

said display displaying said associated road segment name of said current road segment in said current location field in said first color when said variable scale is above said threshold scale.

7. A vehicle location display of a navigation system as recited in claim **6** further comprising:

said database including a plurality of ranks, each of said ranks associated with at least one of said road segments;

each of said ranks associated with one of a plurality of rank colors, none of said plurality of rank colors being said first color;

said display displaying each of said road segments except said current road segment of said map in an associated rank color.

8. A vehicle location display of a navigation system as recited in claim **1** further comprising:

a previous cross street and a next cross street of said current road segment;

said display accenting a portion of said previous cross street and said next cross street.

9. A vehicle location display of a navigation system as recited in claim **8** wherein accenting said portion of said previous cross street and said next cross street includes displaying said portion of said previous cross street and said next cross street in a second color different from the color of other road segments.

10. A vehicle location display of a navigation system as recited in claim **1** further including a map panning cursor, said map panning cursor movable about said map in response to input from a user input device; and

said display accenting a panned road segment, said panned road segment selected with said map panning cursor.

11. A vehicle location display of a navigation system as recited in claim **10** wherein accenting said panned road segment comprises displaying said panned road segment in a pan color different from the color of other road segments.

12. A vehicle location display of a navigation system as recited in claim **10** wherein said display displays said road segment name associated with said panned road segment in a panned road segment field on said display in a pan color when said scale is above said threshold scale.

13. A vehicle location display of a navigation system as recited in claim **10** wherein said map panning cursor includes a directional indicator, said directional indicator indicating a direction from said map panning cursor to a current vehicle location.

14. A vehicle location display of a navigation system as recited in claim **10** wherein said display displays a distance field, said distance field displaying a distance between said map panning cursor and a current vehicle location.

15. A vehicle location display of a navigation system as recited in claim **1** wherein said display further includes a current heading field, said current heading field displaying a current compass heading of a vehicle.

16. The vehicle location display of a navigation system as recited in claim **1** wherein the display does not display the associated road segment name adjacent the current road segment when the variable scale is above a threshold scale.

17. The vehicle location display of a navigation system of claim **16** wherein the display does not display the associated road name of the current road segment in the current location field when the variable scale is below said threshold scale.

18. A vehicle location display of a navigation system comprising:

a database of a plurality of road segments;

a position determining system, said position determining system determining a current road segment and a current vehicle location on said current road segment;

a display displaying a first map at a first scale and comprising a plurality of said road segments including said current road segment;

said display displaying a second map and said first map simultaneously, said second map comprising a plurality of said road segments including said current road segment, said second map having a second scale less than said first scale.

19. A vehicle location display of a navigation system as recited in claim **18** further comprising:

a user input device; and

a map scaler, said map scaler changing said first scale of said first map in response to input from said user input device.

20. A vehicle location display of a navigation system as recited in claim **18** wherein said display displays a road segment name adjacent said current road segment and a vehicle cursor at said current vehicle location on said first map when said first scale of said first map is below a threshold scale.

21. A vehicle location display of a navigation system as recited in claim **18** wherein said display displays a road segment name adjacent said current road segment on said second map.

22. A vehicle location display of a navigation system as recited in claim **18** wherein said display displays said second map within said first map.

23. A vehicle location display of a navigation system as recited in claim **18** further comprising:

said database including a plurality of ranks, each of said ranks associated with at least one of said road segments;

each of said ranks associated with one of a plurality of rank colors;

said display displaying each of said road segments of said first map and said second map in an associated rank color.

24. A vehicle location display of a navigation system as recited in claim **18** wherein said second map further includes a border, said border surrounding said second map and having a color other than said plurality of rank colors.

25. A vehicle location display of a navigation system as recited in claim **18** wherein said display further includes a current heading field, said current heading field displaying a current compass heading of a vehicle.

26. A method for displaying a current vehicle location on a display of a navigation system comprising the steps of:

a.) determining a current vehicle location relative to a database of road segments;

b.) displaying a plurality of said road segments and said current vehicle location;

c.) adjusting a scale of said display; and

d.) displaying in a first mode when said scale is below a threshold scale and displaying in a second mode when said scale is above said threshold.

27. A method as recited in claim **26** wherein:

step b.) further comprises displaying said plurality of said road segments and said current vehicle location on a map;

step c.) further comprises adjusting a scale of said map; and

step d.) further comprises in said first mode displaying a road segment name associated with said current vehicle location adjacent said current vehicle location and in said second mode displaying said road segment name associated with said current vehicle location in a current location field.

28. A method as recited in claim **26** wherein:

step b.) further comprises displaying said plurality of said road segments and said current vehicle location on a first map;

step c.) further comprises adjusting a scale of said first map; and

step d.) further comprises in said first mode displaying on said first map said current vehicle location and in said second mode displaying said first map and a second map, said second map having a scale below said threshold and including said current vehicle location.

29. A vehicle location display of a navigation system comprising:

a database of a plurality of road segments;

a position determining system, said position determining system determining a current vehicle location relative to said database;

a display having a variable scale and displaying a plurality of said road segments and said current vehicle location in a first mode when said variable scale is below a threshold and displaying a plurality of said road segments and said current vehicle location in a second mode when said variable scale is above a threshold.

30. A vehicle location display of a navigation system as recited in claim **29** wherein said display displays a map including said plurality of said road segments and said current vehicle location;

in said first mode said display displays an associated road segment name adjacent said current vehicle location on said map; and

in said second mode said display displays said associated road segment name in a current location field on said display.

31. A vehicle location display of a navigation system as recited in claim **29** wherein:

said display displays a first map at said variable scale and including said plurality of said road segments and said current vehicle location when said display is in said first mode; and

said display displaying a second map and said first map when said display is in said second mode, said second map comprising a plurality of said road segments including said current road segment and a vehicle cursor displayed at said current vehicle location, said second map having a scale less than said threshold scale.

* * * * *

EXHIBIT C

US006029111A

United States Patent [19]

Croyle

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[45] **Date of Patent:** ***Feb. 22, 2000**

[54] **VEHICLE NAVIGATION SYSTEM AND METHOD USING GPS VELOCITIES**

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[*] Notice: This patent is subject to a terminal disclaimer.

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[52] **U.S. Cl.** .... **701/207**; 701/213; 701/214; 701/216; 701/221; 73/178 R

[58] **Field of Search** .... 364/460, 461, 364/450, 454, 453, 447, 448, 443, 444.1, 449.1, 449.2, 449.7; 340/988, 990, 995; 73/178 R; 342/357, 457, 352, 451; 701/200, 201, 207, 208, 213, 214, 215, 216, 217, 221

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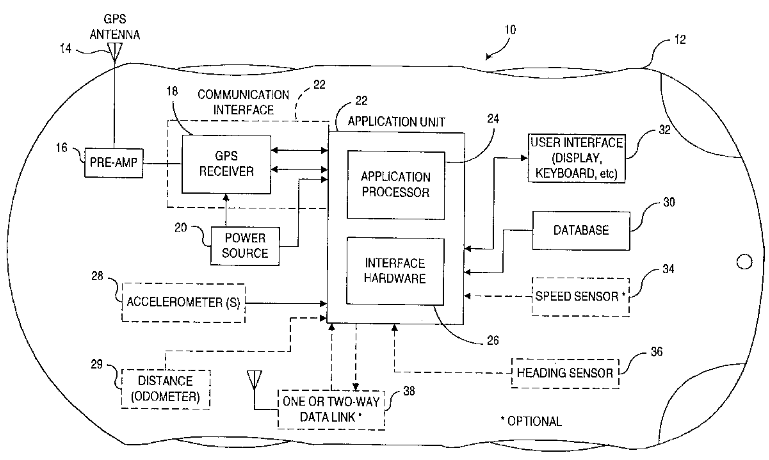
[57] **ABSTRACT**

The improved vehicle navigation system can take advantage of the recent availability of low cost micro-machined and piezoelectric sensors, and partially overcomes the low dynamics and line of sight limitations of GPS receivers without resorting to the hard wired approach described above. The low cost sensors introduce system level errors due to their inherent DC offset and drift rates. The improved vehicle navigation system minimizes both the sensor induced errors and GPS low dynamic limitations by using a zero motion detection system as a self contained (within the navigation system), vehicle independent device.

28 Claims, 12 Drawing Sheets



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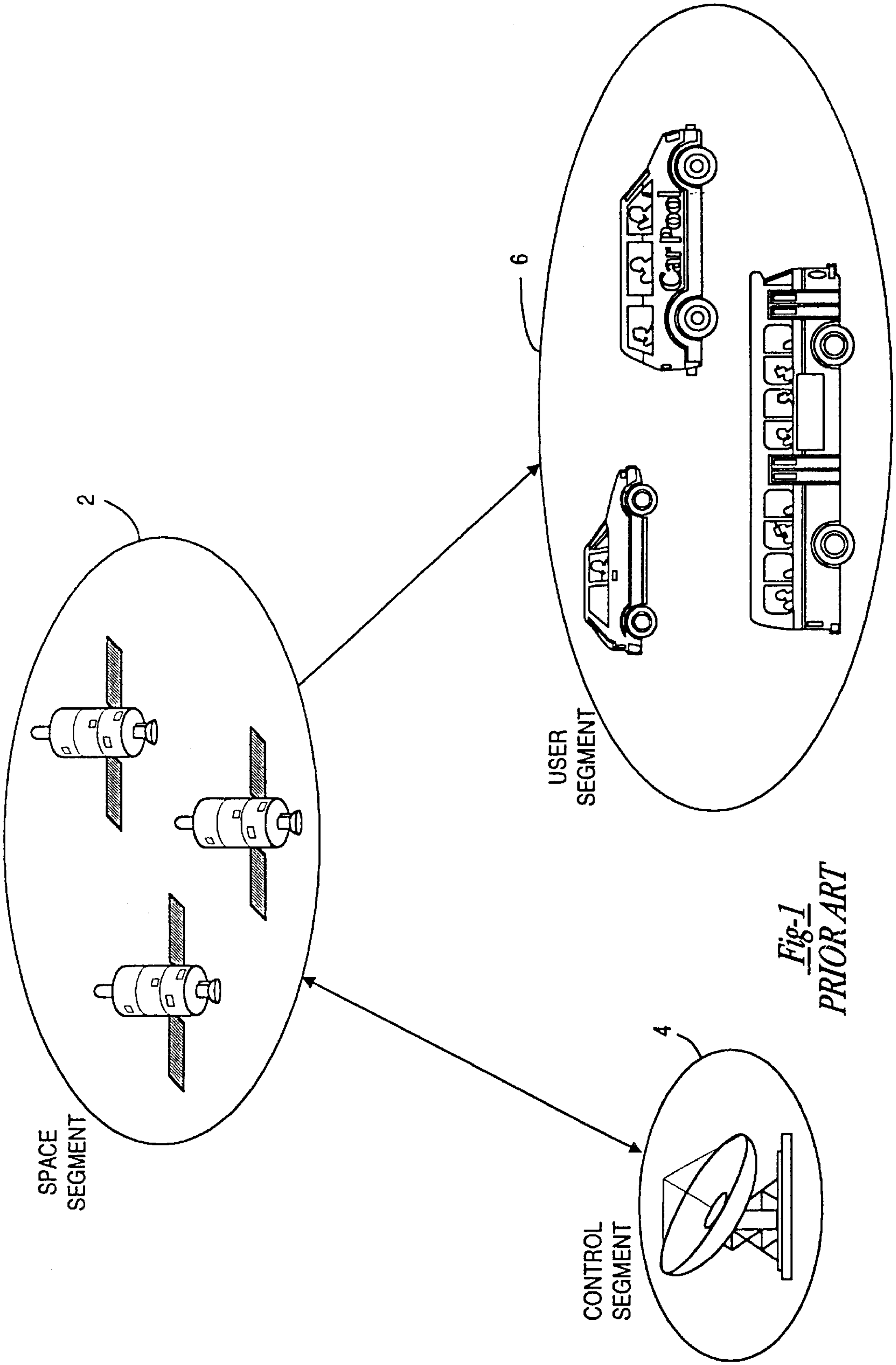


Fig-1
PRIOR ART

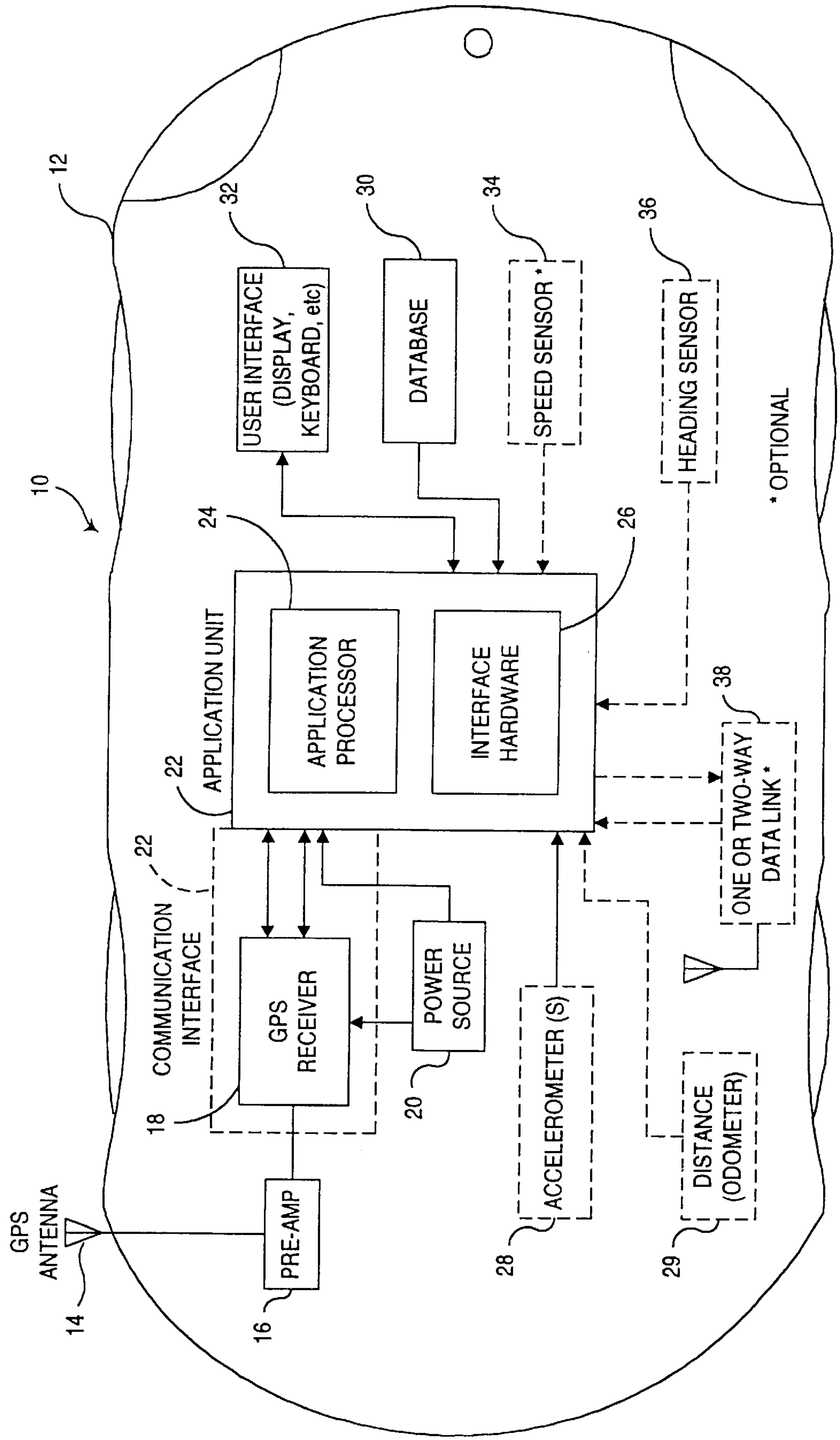

12
10
32
USER INTERFACE (DISPLAY, KEYBOARD, etc)
30
DATABASE
34
SPEED SENSOR *
36
HEADING SENSOR
* OPTIONAL
24
26
APPLICATION UNIT
APPLICATION PROCESSOR
INTERFACE HARDWARE
22
38
ONE OR TWO-WAY DATA LINK *
22
COMMUNICATION INTERFACE
GPS RECEIVER
POWER SOURCE
ACCELEROMETER (S)
DISTANCE (ODOMETER)
18
20
GPS ANTENNA
PRE-AMP
28
29
14
16

Fig-2

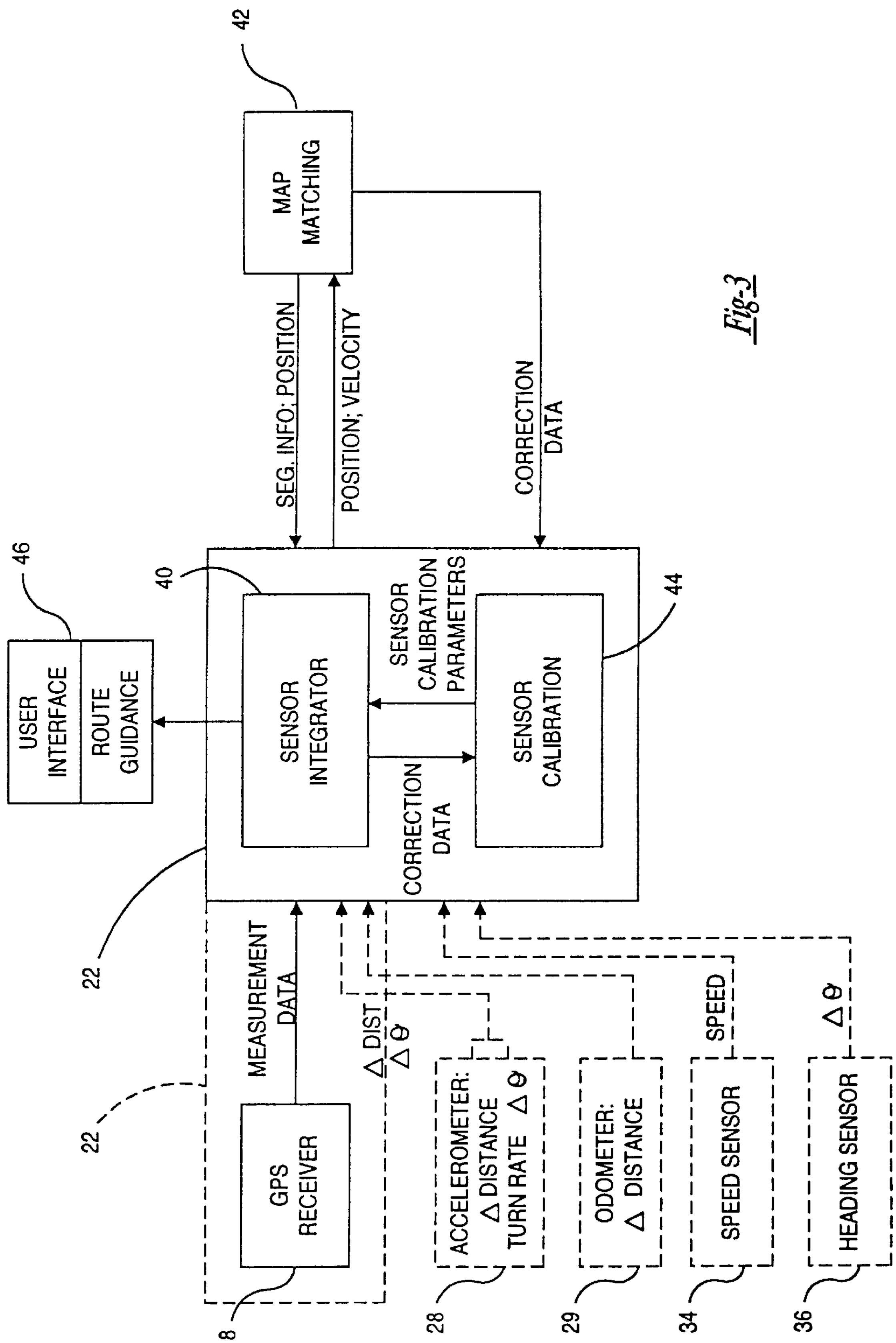

MAP MATCHING
42
SEG. INFO; POSITION
POSITION; VELOCITY
CORRECTION DATA
USER INTERFACE
ROUTE GUIDANCE
46
40
SENSOR INTEGRATOR
SENSOR CALIBRATION PARAMETERS
SENSOR CALIBRATION
44
CORRECTION DATA
22
MEASUREMENT DATA
Δ DIST
Δ θ
22
GPS RECEIVER
18
ACCELEROMETER: Δ DISTANCE TURN RATE Δ θ
28
ODOMETER: Δ DISTANCE
29
SPEED
SPEED SENSOR
34
Δ θ
HEADING SENSOR
36

Fig-3

Fig-4A

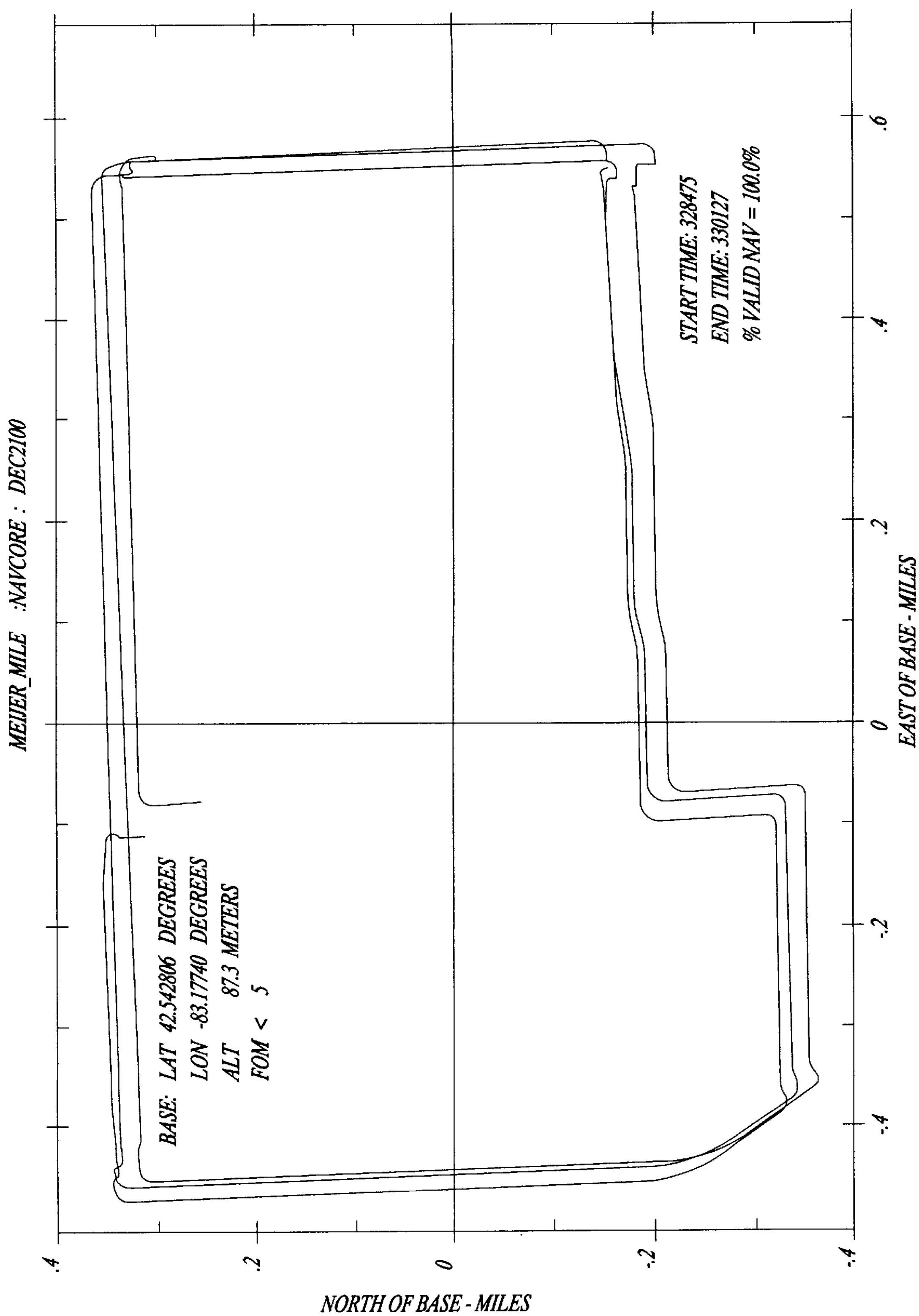

MEIJER_MILE :NAVCORE : DEC2100
BASE: LAT 42.542806 DEGREES
LON -83.17740 DEGREES
ALT 87.3 METERS
FOM < 5
START TIME: 328475
END TIME: 330127
% VALID NAV = 100.0%
.4
.2
0
-.2
-.4
NORTH OF BASE - MILES
.6
.4
.2
0
-.2
-.4
EAST OF BASE - MILES

Fig-4B

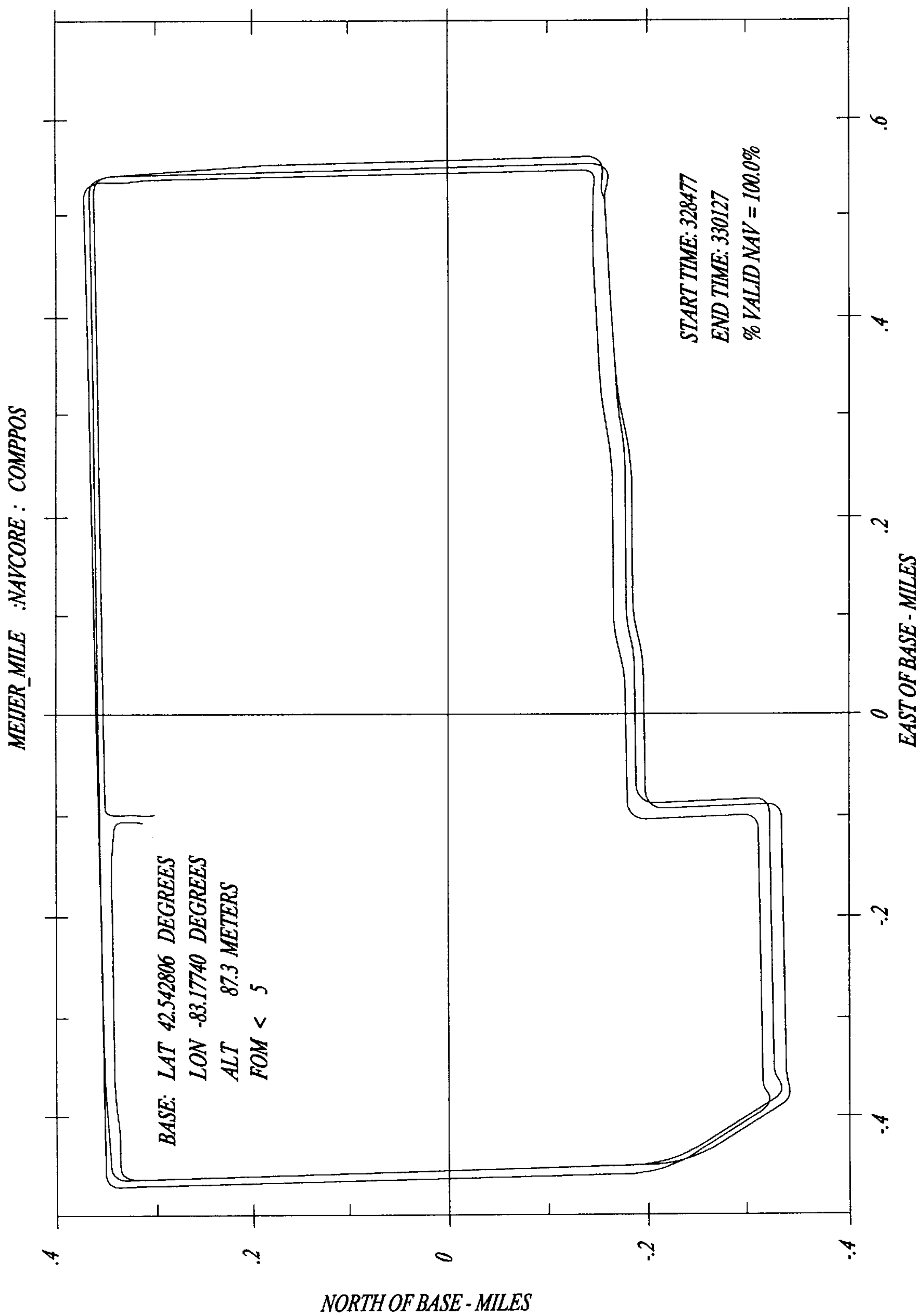
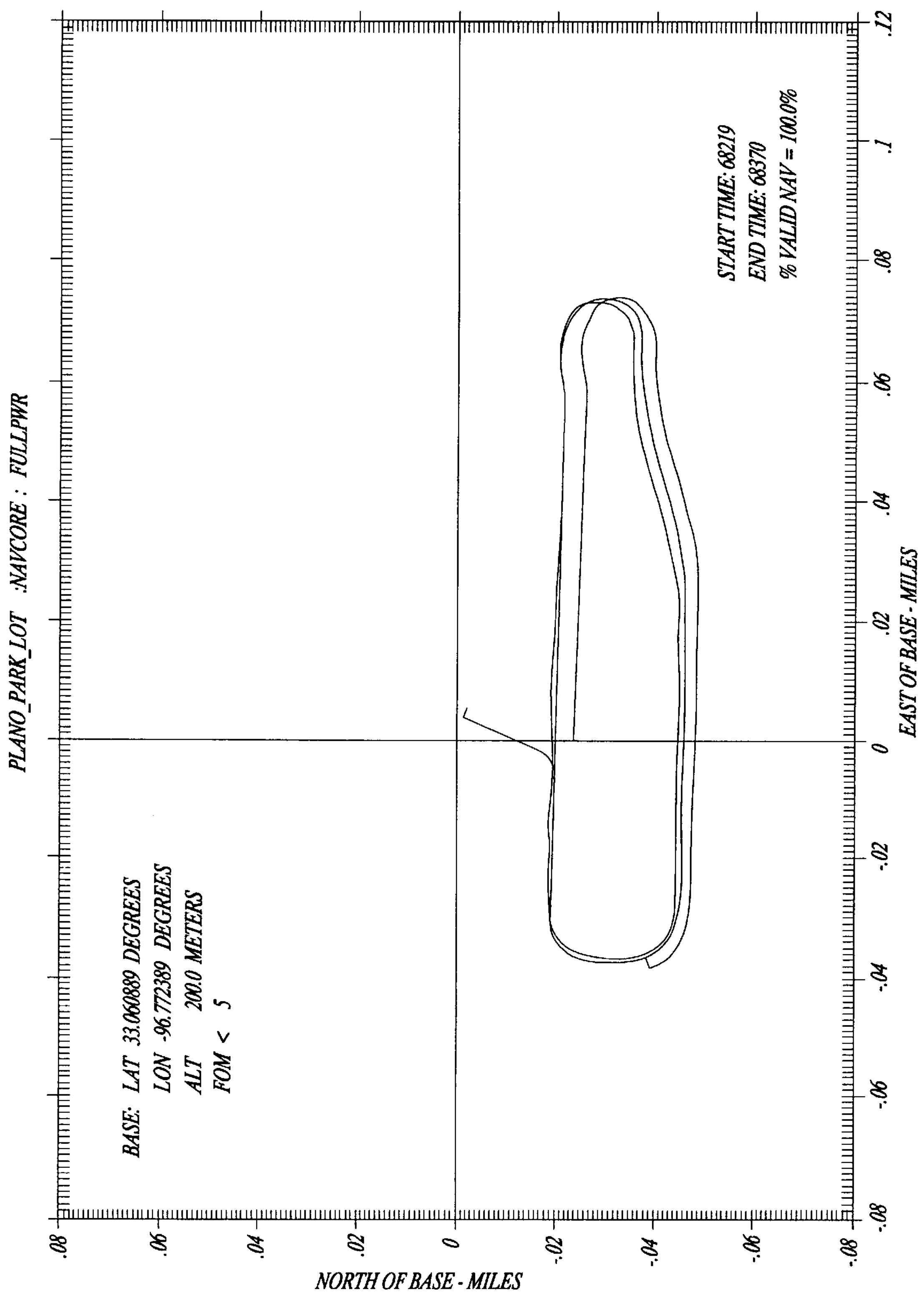

MEIJER_MILE :NAVCORE : COMPPOS
START TIME: 328477
END TIME: 330127
% VALID NAV = 100.0%
BASE: LAT 42.542806 DEGREES
LON -83.17740 DEGREES
ALT 87.3 METERS
FOM < 5
.6
.4
.2
0
-.2
-.4
EAST OF BASE - MILES
.4
.2
0
-.2
-.4
NORTH OF BASE - MILES

Fig-4C


PLANO_PARK_LOT :NAVCORE : FULLPWR
BASE: LAT 33.060889 DEGREES
LON -96.772389 DEGREES
ALT 200.0 METERS
FOM < 5
START TIME: 68219
END TIME: 68370
% VALID NAV = 100.0%
EAST OF BASE - MILES
NORTH OF BASE - MILES
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
.12
.1

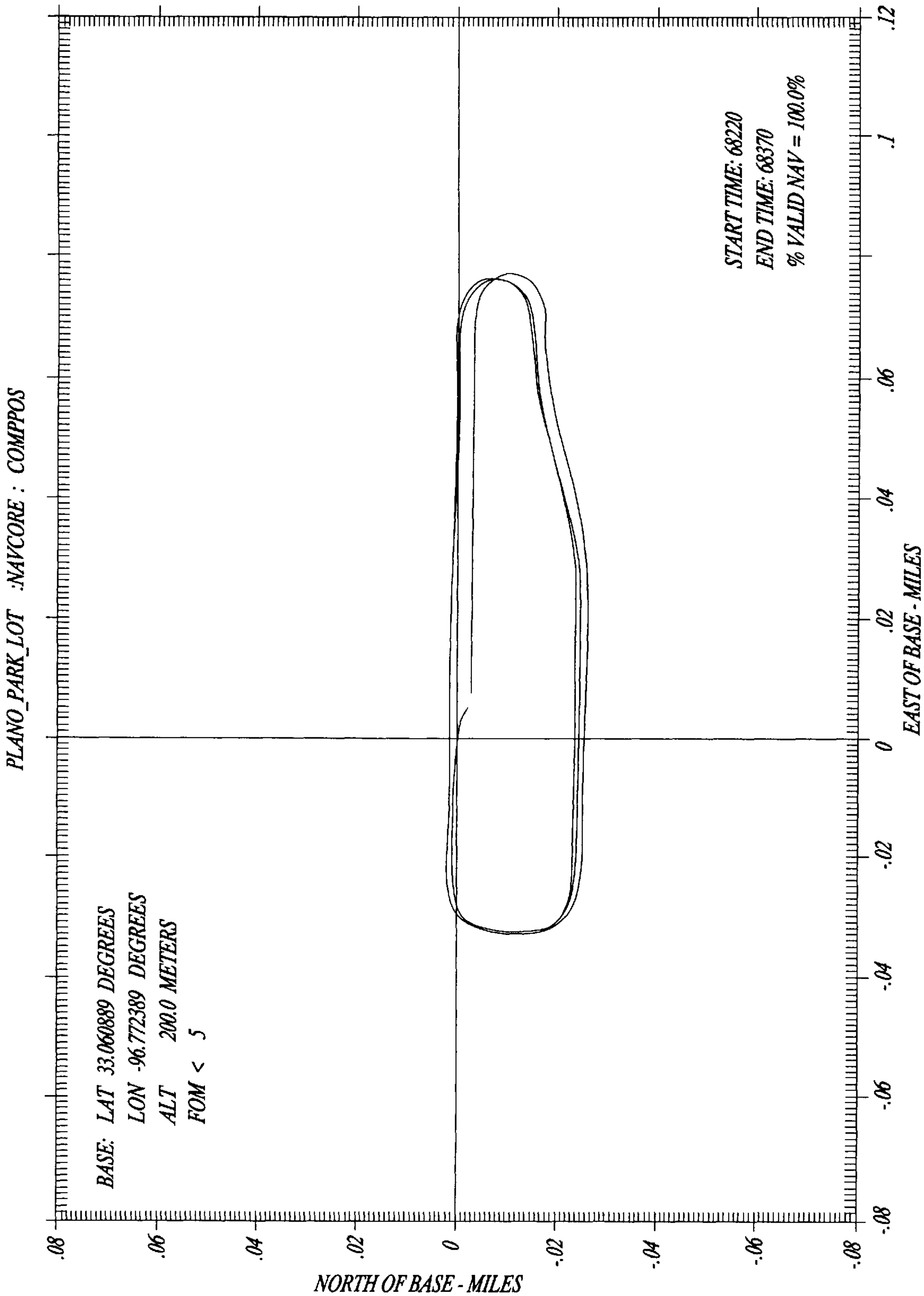

PLANO_PARK_LOT :NAVCORE : COMPPOS
BASE: LAT 33.060889 DEGREES
LON -96.772389 DEGREES
ALT 200.0 METERS
FOM < 5
START TIME: 68220
END TIME: 68370
% VALID NAV = 100.0%
NORTH OF BASE - MILES
EAST OF BASE - MILES
.08
.06
.04
.02
0
-.02
-.04
-.06
-.08
.12
.1
.06
.04
.02
0
-.02
-.04
-.06
-.08

Fig-4D

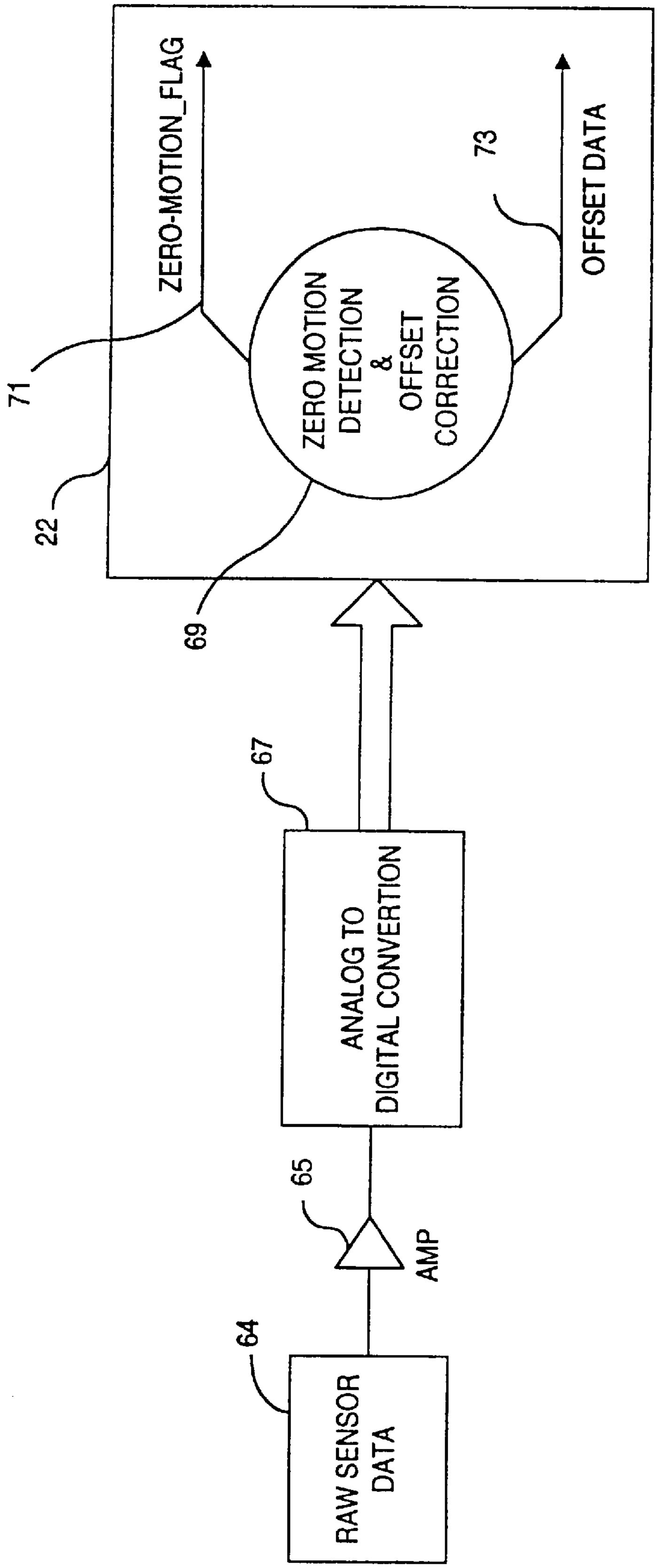

ZERO-MOTION_FLAG
71
22
ZERO MOTION
DETECTION
&
OFFSET
CORRECTION
69
73
OFFSET DATA
67
ANALOG TO
DIGITAL CONVERTION
65
AMP
64
RAW SENSOR
DATA

Fig-5

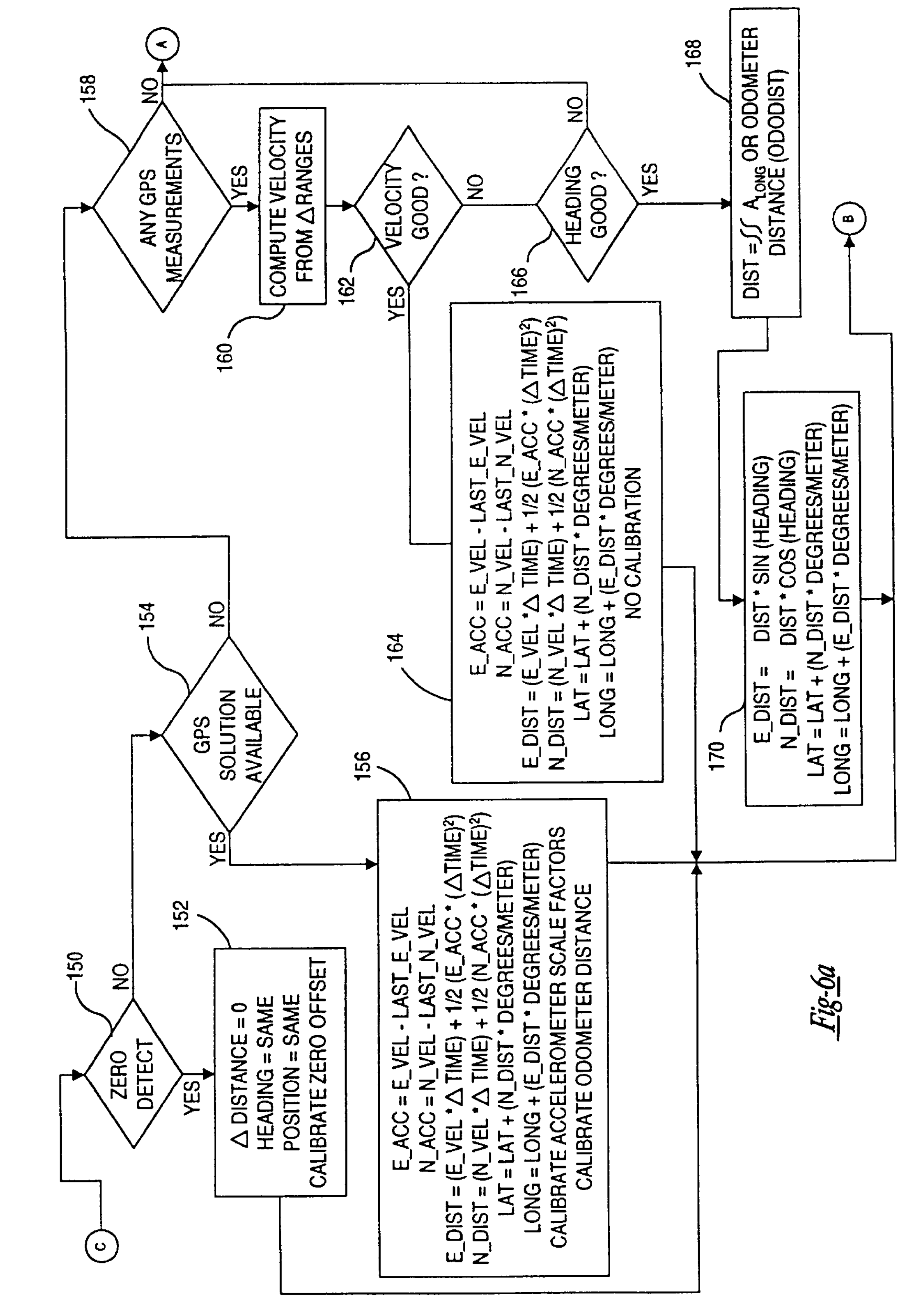

ZERO DETECT
150
YES
NO
Δ DISTANCE = 0
HEADING = SAME
POSITION = SAME
CALIBRATE ZERO OFFSET
152
GPS SOLUTION AVAILABLE
154
YES
NO
E_ACC = E_VEL - LAST_E_VEL
N_ACC = N_VEL - LAST_N_VEL
E_DIST = (E_VEL * Δ TIME) + 1/2 (E_ACC * (ΔTIME)²)
N_DIST = (N_VEL * Δ TIME) + 1/2 (N_ACC * (ΔTIME)²)
LAT = LAT + (N_DIST * DEGREES/METER)
LONG = LONG + (E_DIST * DEGREES/METER)
CALIBRATE ACCELEROMETER SCALE FACTORS
CALIBRATE ODOMETER DISTANCE
156
ANY GPS MEASUREMENTS
158
YES
NO
COMPUTE VELOCITY FROM Δ RANGES
160
VELOCITY GOOD ?
162
YES
NO
E_ACC = E_VEL - LAST_E_VEL
N_ACC = N_VEL - LAST_N_VEL
E_DIST = (E_VEL * Δ TIME) + 1/2 (E_ACC * (ΔTIME)²)
N_DIST = (N_VEL * Δ TIME) + 1/2 (N_ACC * (ΔTIME)²)
LAT = LAT + (N_DIST * DEGREES/METER)
LONG = LONG + (E_DIST * DEGREES/METER)
NO CALIBRATION
164
HEADING GOOD ?
166
YES
NO
DIST = ∬ A_LONG OR ODOMETER DISTANCE (ODODIST)
168
E_DIST = DIST * SIN (HEADING)
N_DIST = DIST * COS (HEADING)
LAT = LAT + (N_DIST * DEGREES/METER)
LONG = LONG + (E_DIST * DEGREES/METER)
170
A
B
C

Fig-6a

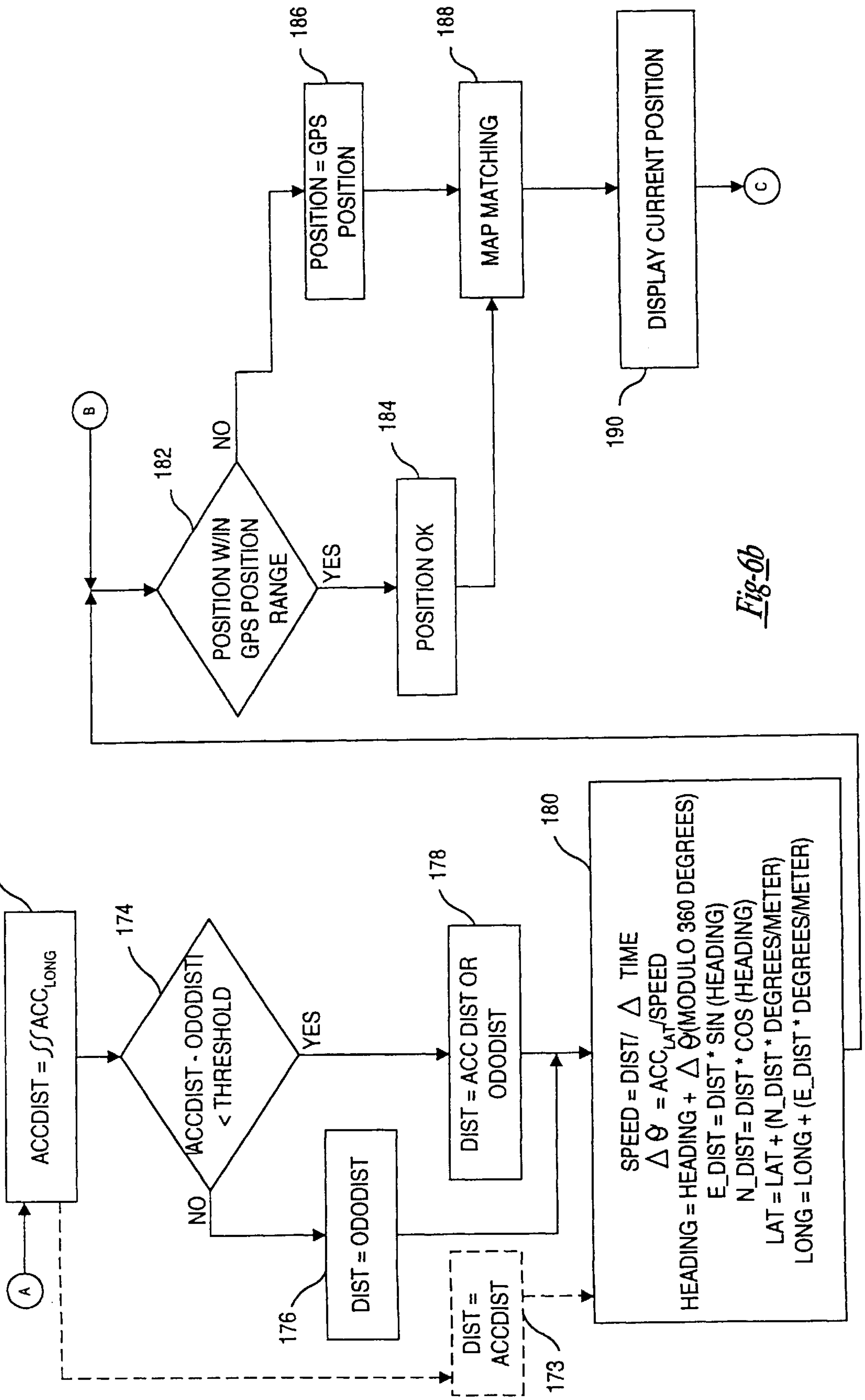

A
ACCDIST = ∬ACC$_{LONG}$
172
173
DIST = ACCDIST
174
ACCDIST - ODODIST < THRESHOLD
YES
NO
176
DIST = ODODIST
178
DIST = ACC DIST OR ODODIST
180
SPEED = DIST/ Δ TIME
Δ Θ = ACC$_{LAT}$/SPEED
HEADING = HEADING + Δ Θ (MODULO 360 DEGREES)
E_DIST = DIST * SIN (HEADING)
N_DIST= DIST * COS (HEADING)
LAT = LAT + (N_DIST * DEGREES/METER)
LONG = LONG + (E_DIST * DEGREES/METER)
B
182
POSITION W/IN GPS POSITION RANGE
YES
NO
184
POSITION OK
186
POSITION = GPS POSITION
188
MAP MATCHING
190
DISPLAY CURRENT POSITION
C

Fig-6b

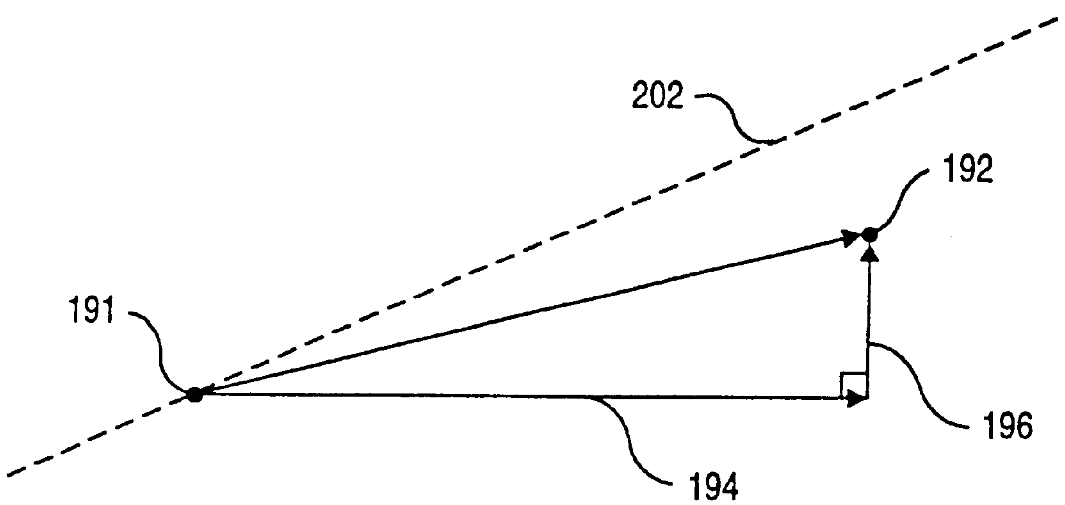


Fig-7a

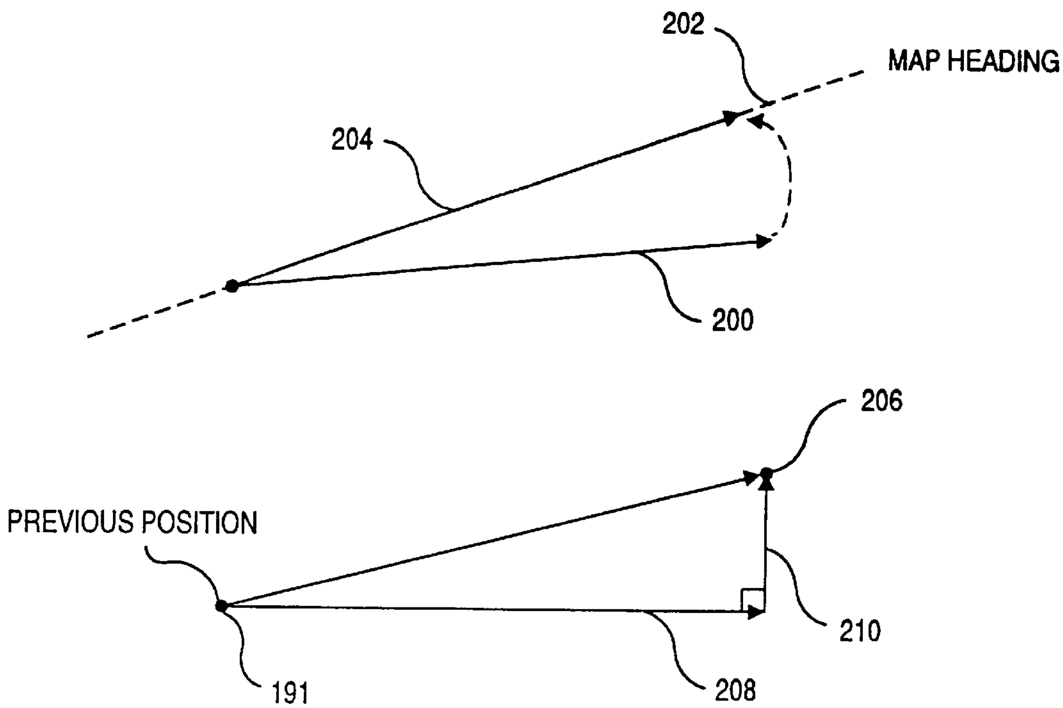

202
MAP HEADING
204
200
206
PREVIOUS POSITION
210
191
208

Fig-7b

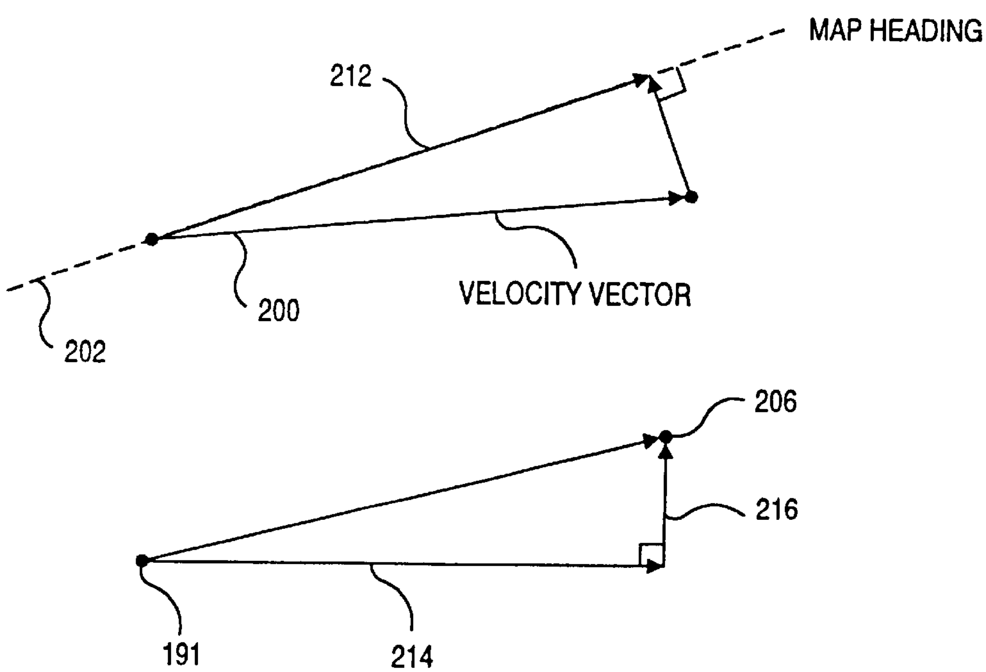

MAP HEADING
212
200
VELOCITY VECTOR
202
206
216
191
214

Fig-7c

VEHICLE NAVIGATION SYSTEM AND METHOD USING GPS VELOCITIES

FIELD OF THE INVENTION

The present invention relates generally to an improved vehicle navigation system, using an electromagnetic wave positioning system. More particularly, the present invention relates to an improved vehicle navigation system and method using GPS velocity data for position propagation.

BACKGROUND OF THE INVENTION

Current vehicle navigation systems use GPS, such as an electromagnetic wave positioning system, to determine a vehicle's position. Such a GPS system is the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System, which is a space-based satellite radio navigation system developed by the U.S. Department of Defense (DoD). GPS includes NAVSTAR GPS and its successors, Differential GPS (DGPS), or any other electromagnetic wave positioning systems. NAVSTAR GPS receivers provide users with continuous three-dimensional position, velocity, and time data.

NAVSTAR GPS consists of three major segments: Space, Control, and User as illustrated in FIG. **1**. The space segment **2** consists of a nominal constellation of 24 operational satellites which have been placed in 6 orbital planes above the Earth's surface. The satellites are in circular orbits in an orientation which normally provides a GPS user with a minimum of five satellites in view from any point on Earth at any one time. The satellites broadcast an RF signal which is modulated by a precise ranging signal and a coarse acquisition code ranging signal to provide navigation data.

This navigation data, which is computed and controlled by the GPS control segment **4**, includes the satellite's time, its clock correction and ephemeris parameters, almanacs, and health status for all GPS satellites. From this information, the user computes the satellite's precise position and clock offset.

The control segment consists of a Master Control Station and a number of monitor stations at various locations around the world. Each monitor station tracks all the GPS satellites in view and passes the signal measurement data back to the master control station. There, computations are performed to determine precise satellite ephemeris and satellite clock errors. The master control station generates the upload of user navigation data from each satellite. This data is subsequently rebroadcast by the satellite as part of its navigation data message.

The user segment **6** is the collection of all GPS receivers and their application support equipment such as antennas and processors. This equipment allows users to receive, decode, and process the information necessary to obtain accurate position, velocity and timing measurements. This data is used by the receiver's support equipment for specific application requirements. GPS supports a wide variety of applications including navigation, surveying, and time transfer.

GPS receivers may be used in a standalone mode or integrated with other systems. Currently, land-based navigation systems use vehicle speed sensor, rate gyro and a reverse gear hookup to "dead reckon" the vehicle position from a previously known position. This method of dead reckoning, however, is susceptible to sensor error, and therefore requires more expensive sensors for accuracy and dependability.

GPS has been used as a position back-up in use for land-based applications, in which position propagation is computed by "dead reckoning" using speed and heading. In determining the propagation of position, however, these systems are susceptible to the errors inherent in the reported GPS position and the errors in the dead reckoning calculation using speed and heading.

Additionally, prior systems use a road network stored in a map database to calculate current vehicle positions. These systems send distance and heading information to perform map matching, and map matching calculates the current position based on the road network and the inputted data. These systems also use map matching to calibrate sensors. Map matching, however, has inherent inaccuracies because map matching must look back in time and match data to a location. As such, map matching can only calibrate the sensors when an absolute position is identified on the map, but on a long, straight stretch of highway, sensor calibration using map matching may not occur for a significant period of time.

Accordingly, there is a need for a vehicle navigation system which is more accurate, efficient, flexible and cost-effective and potentially portable in propagating a previous vehicle position to a current vehicle position.

SUMMARY OF THE INVENTION

The improved vehicle navigation system and method uses information from a Global Positioning System (GPS) to obtain velocity vectors, which include speed and heading components, for propagating or "dead reckoning" the vehicle position from a previous position to a current position. The improved vehicle navigation system has a GPS receiver which provides the GPS velocity information which is calculated from a full set of GPS delta range measurements. GPS position data alone is not accurate enough for certain applications, such as turn-by-turn route guidance in automobile applications, because its error may be 100 m and there is considerable position drift, even when stationary. GPS velocities are much more accurate than the position data, 1 m/s or thereabouts, and can be used to propagate a known position forward and be more accurate over time than the GPS position solution. These velocities are instantaneous and not those computed from differencing two positions. The current position is calculated by adding displacements obtained from the GPS velocities to the previous position.

This calculation process will improve position data once a known point can be used as a reference to start the propagation. An application where map matching will produce a reference point with high degree of accuracy, most likely after a significant maneuver such as a change in direction, will provide a good starting point for position propagation based on GPS velocities. This will help to eliminate velocity drift in long duration tests and scenarios. Thus, these velocities can be used to propagate vehicle position forward with as much, if not greater, accuracy than the current solution of vehicle speed and rate gyro. Because the GPS information should almost always be available, the improved vehicle navigation system relies less on its sensors, thereby allowing for the use of inexpensive sensors. The improved vehicle navigation system retains the accuracy of the sensors by repeatedly calibrating them with the GPS data obtained from the GPS velocity information. The improved vehicle navigation system calibrates the sensors whenever GPS data is available (for example, once a second at relatively high speeds). Furthermore, the improved vehicle navigation system does not need to rely on map matching to calibrate sensors. System flexibility is improved because map matching is oblivious to the hardware, and the system hardware can be updated without affecting map matching or a change in the map database. When GPS velocity information is not available, a dead reckoning approach using sensors is necessary.

In one embodiment of the present invention, the improved position determination system eliminates the use of the Vehicle Speed Signal by using a longitudinally mounted accelerometer. This allows the improved position determination system to be portable.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects and advantages of the present invention may become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. **1** is a general illustration of the various segments in the NAVSTAR GPS system;

FIG. **2** shows variations of an improved vehicle navigation system according to the principles of the present invention;

FIG. **3** shows a block/data flow diagram of a version of the improved vehicle navigation system of FIG. **2**;

FIGS. **4***a* and **4***c* show graphic plots of vehicle position using raw GPS position data, and FIGS. **4***b* and **4***d* show graphic plots of vehicle position using GPS velocity information;

FIG. **5** shows a block diagram of a zero motion detect system according to the principles of the present invention;

FIGS. **6***a* and **6***b* show a general flow chart of the operation of an embodiment of the improved vehicle navigation system of FIG. **3**; and

FIGS. **7***a*–**7***c* show general diagrams illustrating how the improved vehicle navigation system updates the GPS heading information with the map heading for position propagations.

While the invention is susceptible to various modifications and alterative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiment described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE DRAWINGS

An illustrative embodiment of the improved position determination system according to the principles of the present invention and methodology is described below as it might be implemented using GPS velocities to determine a current position from a previous position. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual implementation (as in any development project), numerous implementation-specific decisions must be made to achieve the developers' specific goals and subgoals, such as compliance with system- and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of device engineering for those of ordinary skill having the benefit of this disclosure.

Aspects of the improved vehicle navigation system has application in connection with a variety of system configurations in which GPS signals can be used for position determination. Such a vehicle navigation system is disclosed in copending patent application Ser. No. 08/580,150, entitled "Improved Vehicle Navigation System And Method" and filed concurrently with this application. Other configurations are possible as would be understood by one of ordinary skill in the art.

FIG. **2** illustrates, in block diagram form, exemplary arrangements of an improved vehicle navigation system **10** for an automobile **12**. In this embodiment, the improved vehicle navigation system **10** uses a GPS antenna **14** to receive the GPS signals. The antenna **14** is preferably of right-hand circular polarization, has a gain minimum of −3 dBiC above 5 degree elevation, and has a gain maximum of +6 dBiC. Patch or Helix antennas matching these specifications can be used. The GPS antenna **14** can be connected to a preamplifier **16** to amplify the GPS signals received by the antenna **14**. The pre-amplifier **16** is optional, and the GPS antenna can be directly connected to a GPS receiver **16**.

The GPS receiver **18** continuously determines geographic position by measuring the ranges (the distance between a satellite with known coordinates in space and the receiver's antenna) of several satellites and computing the geometric intersection of these ranges. To determine a range, the receiver **18** measures the time required for the GPS signal to travel from the satellite to the receiver antenna. The timing code generated by each satellite is compared to an identical code generated by the receiver **18**. The receiver's code is shifted until it matches the satellite's code. The resulting time shift is multiplied by the speed of light to arrive at the apparent range measurement.

Since the resulting range measurement contains propagation delays due to atmospheric effects, and satellite and receiver clock errors, it is referred to as a "pseudorange." Changes in each of these pseudoranges over a short period of time are also measured and processed by the receiver **18**. These measurements, referred to as delta range measurements or "delta-pseudoranges," are used to compute velocity. Delta ranges are in meters per second which are calculated by the receiver from pseudoranges, and the GPS receiver **18** can track the carrier phase of the GPS signals to smooth out the pseudoranges. The velocity and time data is generally computed once a second. If one of the position components is known, such as altitude, only three satellite pseudorange measurements are needed for the receiver **16** to determine its velocity and time. In this case, only three satellites need to be tracked.

The error in the range measurement is dependent on one of two levels of GPS accuracy to which the user has access. PPS is the most accurate, but is reserved for use by the DoD and certain authorized users. SPS is less accurate and intended for general public use. The SPS signal is intentionally degraded to a certain extent by a process known as Selective Availability (SA). SA is used to limit access to the full accuracy of SPS in the interest of U.S. national security. Differential GPS (DGPS) may be used to correct certain bias-like errors in the GPS signals. A Reference Station receiver measures ranges from all visible satellites to its surveyed position. Differences between the measured and estimated ranges are computed and transmitted via radio or other signals to differential equipped receivers/hosts in a local area. Incorporation of these corrections into the range measurements can improve their position accuracy.

As shown in FIG. **2**, the GPS receiver **18** provides GPS measurements to an application unit **22**. The application unit

22 consists of application processing circuitry 24, such as a processor, memory, busses, the application software and related circuitry, and interface hardware 26. In one embodiment of the present invention, the application unit 22 can be incorporated into the GPS receiver 18. The interface hardware 26 integrates the various components of the vehicle navigation system 10 with the application unit 22.

The system 10 can include a combination of the features, such as those shown in dashed lines. For example, the improved vehicle navigation system could rely upon information provided by the GPS receiver 18, an accelerometer 28 (which in certain embodiments is an orthogonal axes accelerometer of recently available low cost, micromachined accelerometers) and the map database 30 to propagate vehicle position. In additional embodiments, the improved vehicle navigation system 10 uses the accelerometer 28, an odometer 29 and a map database 30 according to other aspects of the present invention. Other embodiments can include a speed sensor 34, a heading sensor 36, such as a gyro, compass or differential odometer, and a one or two way communication link 38. Other configurations and combinations are possible which incorporate aspects of the present invention as would be understood by one of ordinary skill in the art. Moreover, the improved vehicle navigation system can be incorporated in an advanced driver information system which controls and provides information on a variety of automobile functions.

FIG. 3 shows a block and data flow diagram for the improved vehicle navigation system 10 which reveals the flexibility and accuracy of certain embodiments of the improved vehicle navigation system. The GPS receiver 18 provides position information, velocity information, pseudoranges and delta pseudoranges to the sensor integrator 40. The sensor integrator 40 uses the velocity information to determine a current position for the vehicle. In this embodiment, if GPS velocity information is not available, the sensor integrator 40 can calculate GPS velocity using the available delta range measurements to determine a current position. GPS velocity information is derived from a set of delta range measurements, and if only a subset of delta range measurements is available, the vehicle navigation system can derive GPS velocity information from the subset of delta range measurements. The vehicle navigation system uses the GPS position information at start-up as a current position and as a check against the current position. If the current position fails the check, then the GPS position can replace the current position.

If GPS velocity information is not available, certain embodiments can obtain the information used to propagate the vehicle position from the sensors. The sensor 28, which is a multiple axis accelerometer, provides acceleration information for at least two orthogonal axes (lateral, longitudinal and/or vertical) to the application unit 22. The odometer 29 provides information which can be used in place of the information derived from the accelerometers. Other available information can include the odometer distance and GPS heading, a distance calculation and map heading, the GPS speed information and map heading, gyro heading and longitudinal speed and other variations.

A map database 30 stores map information, such as a road network, and provides map information to the application unit 22. The map database should have some level of known accuracy, confidence, or defined error. In this embodiment, every change in street segment heading is designated as a shape point which has a heading with a fixed measurement error. A user interface 32, which includes a display and keyboard, allows interaction between the user and the improved vehicle navigation system 10. In this embodiment, if the difference between the current heading and map heading is less than a threshold value, then the map heading is used as the heading. Vehicle positioning 22 calibrates $\vec{v}_a$ from $\vec{v}_G$ when possible. The GPS position information is used as an overall check on the current position. For example, if $|\vec{x}(t)-\vec{x}_G(t)|<(18.5>*PDOP)$, then $\vec{x}(t)=\vec{x}(t)$. Otherwise, $\vec{x}(t)=\vec{x}_G(t)$. In certain embodiments, all raw inputs could go into a Kalmann filter arrangement which outputs the velocity vector.

In any event, if GPS is available or not, the sensor integrator 40 provides the current position and a velocity (speed and heading) to a map matching block 42. The map matching block 42 provides road segment information for the road segment that the vehicle is determined to be travelling on, such as heading, and a suggested position. The sensor integrator 40 can update the heading component of the velocity information with the heading provided by the map matching block 42 to update the current position. If the map matching block 42 indicates a good match, then the map matched position can replace the current position. If not, the sensor integrator propagates the previous position to the current position using the velocity information. As such, the sensor integrator 40 determines the current position and provides the current position to a user interface and/or route guidance block 46.

The map matching block 42 also provides correction data, such as a distance scale factor and/or offset and a turn rate scale factor and/or offset, to a sensor calibration block 44. The sensor integrator 40 also provides correction data to the sensor calibration block 44. The correction data from the sensor integrator 40, however, is based on the GPS information. Thus, accurate correction data based on the GPS information is continuously available to calibrate the sensors 28 (2 or 3 axis accelerometer) as well as for other sensors 29, 34 and 36 depending on the particular embodiment. The correction data from the map matching block may be ignored by the sensor calibration block 44 until a good match is found between the map information and the current position. If a highly accurate match is found by map matching 42, most likely after a significant maneuver such as a change in direction, the map matched position is used as a reference point or starting position for position propagation according to the principles of the present invention.

The sensor calibration block 44 contains the sensor calibration parameters, such as scale factors and zero factors for the sensors 28 and 29 and provides the calibration parameters to the sensor integrator 40 to calibrate the sensors 28–36. In one embodiment, the system can combine the sensor integrator 40 and sensor calibration 44 into GPS engine 18 using its processor. In certain embodiments, the route guidance and user interface, the sensor integrator 40 and the sensor calibration 44 is performed on an application specific integrated circuit (ASIC).

If the accuracy of a current position is determined to be high (for example, a map matched position at a isolated turn), the improved vehicle navigation system 10 can update the current position with the known position. After the vehicle has moved a distance from the known position which is now a previous position, the improved vehicle navigation system must accurately propagate the vehicle position from the previous position to the current position.

The calculations that will be performed to compute the vehicle position will take place in three coordinate frames. The vehicle position will be reported in geodetic coordinates (latitude, longitude, altitude). The non-GPS data will be provided in body or platform coordinates. The GPS velocities and the equations used for velocity propagation of position will take place in the North, East, Down frame.

The geodetic frame is a representation of the Earth Centered Earth Fixed (ECEF) coordinates that is based on spherical trigonometry. This is the coordinate frame that the mapping database uses. Its units are degrees and meters displacement in height above the geoid. These coordinates will be with respect to the WGS-84 Earth model, which is the Earth model used by the Global Positioning System (GPS). This is mathematically equivalent to the North American Datum 1983 (NAD 83) system which the mapping database is referenced to. The North East Down frame is a right-handed orthonormal coordinate system fixed to the vehicle with its axes pointing to the True North, True East, and True Down (perpendicular to the Earth) directions. The body coordinates form a right-handed orthonormal coordinate system with their origin at the navigation unit, the x axis pointing toward the nose of the vehicle, the right axis pointing out the right door of the vehicle and the z axis pointing down perpendicular to the Earth.

During normal operation of a particular embodiment of the system (with an odometer and orthogonal axes accelerometer), and with GPS information available, the following are the equations that will be used for computing the vehicle position and the calibration of the accelerometers and odometer.

Definitions:

$$\vec{x} = \text{position vector [latitude longitude altitude]}$$

$$\dot{\vec{x}} = \text{velocity vector [north east down]}$$

$$\ddot{\vec{x}} = \text{acceleration vector [north east down]}$$

$$C_N^B = \text{Transformation matrix which rotates a vector from the Body coordinate frame to the North East Down coordinate frame.}$$

The following superscripts will be used to denote the origin of the data:

G=GPS

A=Accelerometer

O=Odometer

The following subscripts will denote time—either time of validity or time period of integration:

t=current time

t-**1**=time of last data set before the current data set

t-**2**=time of data set before t-**1**

Note that t-**1** and t-**2** do not necessarily imply a one second difference, but only data collection and/or data validity times.

The following subscripts will denote coordinate reference frames:

N=North East Down

B=Body (Nose Right Door Down)

G=Geodetic (latitude longitude height)

To use the information from the non-GPS sensors, their data needs to be rotated from the body frame to the North East Down frame. This is a rotation about the yaw axis measured in degrees from True North to the Nose Axis of the vehicle. The equations for this is:

$$\vec{x}^N = C_N^B(\vec{x}^B)$$

The steady state position propagation equation is based on the physical definition of velocity and acceleration. The current position is equal to the previous position plus the integral of velocity plus the double integral of acceleration.

$$\vec{x}_t = \vec{x}_{t-1} + \int_{t-1}^{t} \dot{\vec{x}}\,dt + \int_{t-1}^{t}\left(\int_{t-1}^{t} \ddot{\vec{x}}\,dt\right)dt$$

The following information is collected at time t:

$\dot{\vec{x}}^G_{t-1}$ The velocity from GPS which was valid at the previous second. This consists of:

$\dot{x}^e$=Velocity in the True East direction (meters/second);

$\dot{x}^n$=Velocity in the True North direction (meters/second);

$\dot{x}^u$=Velocity in the Up direction (meters/second);

$\ddot{\vec{x}}^G_{t-1}$ The acceleration computed from GPS velocities that was valid from time t-**2** to time t-**1**;

$\vec{x}$ The raw GPS position;

$\dot{\vec{x}}^O_t$ The speed computed from the number of odometer counts that occurred from time t-**1** to time t; and

$\ddot{\vec{x}}^A_t$ The acceleration computed from the accelerators which occurred from time t-**1** to time t.

The following other information is available for use at time t, but was collected at a previous time:

$\dot{\vec{x}}^G_{t-2}$ The velocity from GPS which was valid two time units ago;

$\vec{x}_{t-1}$ The position computed at the previous time;

$\ddot{\vec{x}}^A_{t-1}$ The acceleration, computed from the accelerometers, from time t-**2** to time t-**1**; and

$\dot{\vec{x}}^O_{t-1}$ The velocity computed from the odometer counts from time t-**2** to time t-**1**.

When GPS is available and has produced a valid position and velocity solution, the following equation will be used for the propagation of the vehicle position:

$$\vec{x}_t = \vec{x}_{t-1} + \int_{t-1}^{t} \dot{\vec{x}}\,dt + \int_{t-1}^{t}\left(\int_{t-1}^{t} \ddot{\vec{x}}\,dt\right)dt$$

or

$$\vec{x}_t = \vec{x}_{t-1} + \left(\dot{\vec{x}}_G^{t-1} * \Delta t\right) + \left(\frac{1}{2}\ddot{\vec{x}}_A^{t} * (\Delta t)^2\right) + \left(\left(\frac{1}{2}\ddot{\vec{x}}_G^{t-1} * (t)^2\right) - \left(\frac{1}{2}\ddot{\vec{x}}_A^{t-1} * (\Delta t)^2\right)\right)$$

This equation is: the current position is equal to the previous position plus the GPS velocity (vector) times the delta time plus the GPS acceleration from two time periods ago minus the Accelerometer acceleration from two time periods ago (a correction factor) plus the Accelerometer acceleration from the current second. In certain embodiments, other sensor information, such as the odometer information, can be used in the above equations if it is determined to be more appropriate than the accelerometer information.

Also computed at this second are:

(1) the GPS heading θ computed as the inverse tangent of the East and North velocities:

$$\theta = a\ \tan\left(\frac{\dot{x}^e}{\dot{x}^n}\right);$$

(2) the distance from time t-**1** to time t, computed from the GPS velocity valid at time t-**1** and the double integration of the longitudinal Accelerometer acceleration from time t-**1** to time t:

$$s = \sqrt{(\dot{x}^e_{t-1} * \Delta t)^2 + (\dot{x}^n_{t-1} * \Delta t)^2} + \frac{1}{2}\ddot{x}^A_t * (\Delta t)^2;$$

(3) the distance from time t-**2** to time t-**1**, computed from the GPS velocity and acceleration from time t-**2** to time t-**1**. This will be used as a calibration factor for both the Vehicle Speed Sensor and the Longitudinal accelerometer:

$$s = \sqrt{(\dot{x}^e_{t-2} * \Delta t)^2 + (\dot{x}^n_{t-2} * \Delta t)^2} + \frac{1}{2}\ddot{x}^G_{t-1} * (\Delta t)^2;$$

(4) the change in heading from time t-**2** to time t-**1** from the GPS heading computed at those times. This is used as a correction factor for the lateral accelerometer.

$\Delta\theta = \theta_{t-2}^G - \theta_{t-1}^G$

Position data from GPS velocity information propagated positions is smoother than GPS position data which is not accurate enough by itself for turn-by-turn vehicle position propagation. For example, FIGS. **4***a* and **4***c* show a position plot of the raw GPS position information for a vehicle, and FIGS. **4***b* and **4***d* show a propagation of the vehicle position over the same path using GPS velocity information. As shown, the GPS velocity information provides a much smoother plot of vehicle position.

To maintain the system accuracy when GPS velocity information is not available, each sensor needs to have calibrations performed on it. The calibrations will be performed using known good data from the GPS receiver **18**. The GPS receiver **18** has velocity accuracy to within one meter per second. The GPS velocity information becomes less accurate in low velocity states of less than 1.5 m/s. The GPS velocity information is time tagged so that it matches a particular set of odometer and accelerometer data on a per second basis. Map matching provides correction factors, but they are based on long term trends and not directly associated with any specify time interval. Sensor calibration using the GPS velocities will involve the following sensors in this particular embodiment.

Odometer (Vehicle Speed Sensor) Calibration. The odometer output is the number of ticks of a counter, with a specified number of ticks to be equal to one unit of linear distance traversed. An example is that the GM Vehicle Speed Sensor has 4000 pulses per mile. This will have a default value from the factory and a calibrated value stored in FLASH thereafter. The odometer will be calibrated once per second from the GPS velocity and acceleration that occurred over that same time period, when valid GPS data is available.

Lateral Accelerometer. The lateral accelerometer measures centripetal acceleration. It is used to compute turn angle from the equation: Turn angle in radians is equal to the quotient of centripetal acceleration and tangential velocity. The lateral accelerometer has two values which need to be calibrated: The zero offset and the scale factor. The zero offset is the measurement that the accelerometer outputs when a no acceleration state exists. The scale factor is the number that is multiplied by the difference between the accelerometer read value and the accelerometer zero offset to compute the number of G's of acceleration. The first derivative of the GPS velocities will be used to compute the scale factor calibration.

Longitudinal Accelerometer. The longitudinal accelerometer measures the acceleration along the nose/tail axis of the vehicle, with a positive acceleration being out the nose (forward) and a negative acceleration being out the rear of the vehicle. The longitudinal accelerometer has two values which need to be calibrated: The zero offset and the scale factor. The zero offset is the measurement that the accelerometer outputs when an no acceleration state exists. The scale factor is the number that is multiplied by the difference between the accelerometer read value and the accelerometer zero offset to compute the number of G's of acceleration. The first derivative of the GPS velocities will be used to compute the scale factor calibration.

The zero motion detect system shown in FIG. **5** is used to resolve ambiguity in the GPS velocity information. FIG. **5** shows the zero motion detect system with a motion sensor **64** (an orthogonal axes accelerometer in this embodiment) providing motion signals. An amplifier **65** amplifies the motion signals, and in this particular embodiment, the motion signals are digitized in an analog to digital converter **67**. The motion signals are provided to a sensor filter block **69** which is in the application unit **22**. The vehicle navigation system determines a zero motion state by comparing samples of the motion signals from the motion sensor **64**, such as an accelerometer, a gyro, or piezoelectric sensors with a threshold (the threshold is determined by vehicle vibration characteristics for the type of vehicle that the unit is mounted in, or the threshold for motion sensor could be set using other sensors which suggest zero motion, such as odometer, GPS or DGPS). The vehicle navigation system uses at least one of the samples to determine the zero offsets if the zero motion state is detected. At least two samples are preferred to compare over a time interval and averaging those samples to obtain a zero offset for the motion sensor **64**. If a zero motion state exists, the vehicle navigation system sets a zero motion flag **71** and uses at least one of the samples to determine the zero offset for the sensor providing the processed motion signals.

The system also provides offset data signals **73** which reflect the zero offset for the sensor providing the motion signals or the raw data used to calculate the zero offset. Upon detecting a zero motion state, the vehicle navigation system can resolve ambiguity of low velocity GPS measurements because the velocity is zero. GPS velocities do not go to zero, so ambiguities exist when in a low velocity state of less than 1.5 m/s. If a zero motion flag is on, then the ambiguities in the GPS velocity information are resolved because the system is not moving. As such, the system freezes the heading and can also set the speed component of velocity to zero. The use of a zero motion detect system in a vehicle navigation system is described in more detail in copending U.S. patent application Ser. No. 08/579,903, entitled "Zero Motion Detection System For Improved Vehicle Navigation System" and filed concurrently with this application.

FIGS. **6***a* and **6***b* show a general flowchart illustrating how the improved vehicle navigation system **10** using the multiple orthogonal axes accelerometer **28** and the odometer **29** propagates a previous position to a current position. At step **150**, the improved vehicle navigation system determines if the vehicle is in a zero motion state as described above. If so, the system, at step **152**, sets the change in distance to zero, locks the heading and current position, and calibrates the zero offsets.

If the system determines that the vehicle is moving, the system proceeds to step **154** to determine if a GPS solution is available. If GPS is available, the system uses the GPS velocity information to determine the current position. The GPS velocity information is very accurate above velocities of 1.5 m/s because GPS delta ranges are used to calculate the velocities. Using the GPS velocities for position propagation has other advantages. For example, the GPS receiver does not require calibration because of no inherent drift, and the GPS measurements can be used to calibrate other sensors. Moreover, cheaper sensors can be used because there is no need to use the sensors very often, and the sensors can be calibrated very often using the GPS measurements. The GPS receiver supports portability because it is independent of the vehicle and does not require a link to the vehicle odometer and reverse gear.

As shown in step **156**, the system calculates east and north accelerations as follows:

$$\text{e-acc}=\text{e-vel}-\text{last.e-vel} \quad (1)$$

$$\text{n-acc}=\text{n-vel}-\text{last.n-vel} \quad (2).$$

The accelerations are used to calculate east and north displacements as follows:

$$\text{e-dist}=(\text{e-vel}*\Delta t)+1/2(\text{e-acc}*(\Delta t)^2) \quad (3)$$

$$\text{n-dist}=(\text{n-vel}*\Delta t)+1/2(\text{n-acc}*(\Delta t)^2) \quad (4).$$

The current position is calculated as follows:

$$\text{lat}=\text{lat}+(\text{n-dist}*\text{degrees/meter}) \quad (5)$$

$$\text{long}=\text{long}+(\text{e-dist}*\text{degrees/meter}) \quad (6),$$

where degrees/meter represents a conversion factor of meter to degrees, taking into consideration the shrinking number of meters in a degree of longitude as the distance from the Equator increases. Finally, at step **156**, the system calibrates the sensor items, such as the accelerometer scale factors and the odometer distance using information from the equations described above. The system can keep the sensors well calibrated because calibrating can occur once per second (scale factors) if the vehicle speed is above 1.5 m/s.

If a full GPS solution is not available at step **154**, the system checks at step **58** whether any GPS measurements are available. If so, the system computes the velocity information from the available subset of delta range measurements at step **160**. If, at step **162**, the velocity information is good, the system calculates current position using the equations 1–6 at step **164** but without calibrating the acceleration scale factors and the odometer distance in this embodiment. If the GPS velocity is determined not to be good at step **162**, the system checks the heading component of the GPS velocity at step **166**. If the GPS heading component is determined to be valid, then at step **168**, the change in distance is set with the odometer distance, and the heading is set with the GPS heading calculated from the GPS delta range measurements. Alternatively, an odometer is not used, and the distance is derived from the longitudinal acceleration information. With this heading and distance, the system calculates a position (lat, long) at step **170** using the equations as follows:

$$\text{e-dist}=\Delta\text{Dist}*\sin(\text{heading}) \quad (7)$$

$$\text{n-dist}=\Delta\text{Dist}*\cos(\text{heading}) \quad (8).$$

After calculating the east and north distances, the system determines the vehicle position using equations 5 and 6, but calibration is not performed at this point in this embodiment.

If the system determines at step **166** that the GPS heading is not valid (GPS blockage or low velocity) or at step **158** that the GPS measurements are insufficient, the system falls back on the orthogonal axes accelerometer(s) and the odometer in this particular embodiment. GPS velocity information is subject to errors at speeds of less than 1.5 m/s, unless using a more accurate GPS system. For example, in a vehicle navigation system using DGPS, the threshold velocity is lower because of the higher accuracy of the system. As such, the vehicle navigation system proceeds to step **172** to determine the change in distance using lateral and longitudinal acceleration information from the orthogonal axes accelerometer(s). At step **174**, the system compares the longitudinal distance from the accelerometer with the odometer distance, and if the difference between them exceeds a threshold value, the odometer distance is used at step **176**. If the difference is less than the threshold, then the accelerometer distance or the odometer distance can be used for the distance at step **178**. Once the change in distance is determined, the system calculates the position at step **180** using the following equations to determine heading as follows:

$$\text{speed}=\Delta\text{Dist}/\Delta t \quad (9)$$

$$\Delta\theta=a_{lat}\ (\text{lateral acceleration})/\text{longitudinal speed} \quad (10)$$

$$\text{heading}=\text{heading}+\Delta\theta(\text{modulo } 360^\circ) \quad (11).$$

After determining heading, the system uses equations 7 and 8 to determine the east and north distances and equations 5 and 6 to determine position.

According to some aspects of the present invention, the system could fall back on only the orthogonal axes accelerometer(s). As shown in dashed step **173**, if an odometer is not used, the distance is derived from the longitudinal acceleration information. The use of multiple, orthogonal axes acceleration information to propagate a vehicle position from a previous position to a current position is described in more detail in copending U.S. patent application Ser. No. 08/580,177, entitled "Improved Vehicle Navigation System And Method Using Multiple Axes Accelerometer" and filed on concurrently with this application.

After determining the initial current position at step **156**, **164**, **170** or **180**, the system proceeds to step **182** where the current position is compared with the GPS position. If the current position is within an acceptable distance from the GPS position, the system determines that the current position is valid at step **184**. If not, the system replaces the current position with the GPS position at step **186**. At this point, the system sends to a map matching step **188** a position and velocity, which has speed and heading components. Depending on the configuration of the map database **30**, other information can be sent to the map matching block **188**, such as heading and distance based on the current and previous positions, a current position and figures of merit (FOM) for each.

The map matching block **188** sends back a map matched current position, distance, heading, FOMs for each and calibration data. In this embodiment, the map matching block **188** interrogates the map database **30** (FIG. **2***a*) to obtain a heading of the mapped path segment which the vehicle is determined to be traversing. The map matching block **188** updates the heading associated with the current position to obtain an updated current position. As such, the map matching block **188** uses the map heading to update the heading based on the GPS velocity information.

As shown in FIG. **7***a*, the vehicle navigation system **10** uses GPS velocity information to propagate a previous position **191** to a current position **192** (by adding displacements **194** and **196** obtained from the velocity information (integrated) to the previous position). If the difference between the GPS heading and the map heading is within a threshold, then the map heading is used as the heading for position propagation. The vehicle navigation system **10** can accomplish this in alternative ways. For example, as shown in FIG. **7***b* using GPS velocities, the vehicle navigation system **10** rotates the GPS velocity vector **200** to align with the map heading **202** if the GPS and map headings are within the threshold and integrates the rotated GPS velocity vector **204** to obtain the displacements. As shown, the updated current position **206** is obtained by applying orthogonal displacements **208** and **210** to the previous position **191**.

Errors usually involve heading determinations due to drift errors in gyro or compass. Displacement is easy to test and one of the most accurate components in the GPS measurements and also in the sensors, so the system uses the entire displacements from the GPS velocity information or the dead reckoning sensors, such as the accelerometers. Thus, the improved vehicle navigation system can use low cost sensors which are less sensitive because heading can be corrected with map heading.

FIG. **7***c* shows an alternative way of updating the GPS heading and thus the current position by projecting the velocity vector **200** to align with the map heading **202** and integrating the projected velocity **212** to obtain displacements **214** and **216**. The system **10** obtains the updated current position **192** by applying the displacements **214** and **216** to the previous position **191**. Depending on the information available and the particular embodiment, the improved vehicle navigation system can react differently to the information provided by the map matching block **188**.

The improved vehicle navigation system relies on the GPS information for positioning and a high frequency of sensor calibration because GPS information is available a great deal of the time. When GPS is available, the improved vehicle navigation system can use the map matching block **188** to provide an overall check on the current position and to provide position and heading correction data which is used if map matching **188** determines it is highly reliable. In this particular embodiment, the current position (w/o map matching) is determined once per second. If the vehicle has travelled more than 15 meters since the last call to map matching **188**, then the current position is passed to map matching **188**. If the vehicle is travelling at high speed, the system will go to map matching **88** at each current position determination at the maximum rate of once per second. When GPS is not available or unreliable, the improved vehicle navigation system has well calibrated sensors to rely on, and the improved vehicle navigation system can rely more on the information from the map matching block **188** for positioning and sensor calibration.

Thus, the improved vehicle navigation system provides several significant advantages, such as flexibility, modularity, and accuracy at a cheaper cost because GPS information can be used to calibrate sensors more often and updating can be performed at a complete stop. These advantages occur because the system relies heavily on GPS velocity information to propagate vehicle position. The GPS velocity information is more reliable (within about 1 m/s) than the GPS position data (within about 100 m). Position data from GPS velocity information propagated positions is smoother than GPS position data which is not accurate enough by itself for turn-by-turn vehicle position propagation.

The principles of the present invention, which have been disclosed by way of the above examples and discussion, can be implemented using various navigation system configurations and sensors. The improved vehicle navigation system, for instance, can be implemented without using an odometer connection and obtaining distance information from the accelerometer inputs when GPS is not available to improve portability and installation costs. Those skilled in the art will readily recognize that these and various other modifications and changes may be made to the present invention without strictly following the exemplary application illustrated and described herein and without departing from the true spirit and scope of the present invention, which is set forth in the following claims.

I claim:

1. An improved navigation system having a GPS receiver which provides GPS velocity information, said navigation system calculating a displacement based upon said GPS velocity information over a time interval, said vehicle navigation system adding said displacement to a previous position to obtain a current position.

2. The zero motion detection system of claim **1** including a zero motion signal, said detection system produces a zero motion signal to lock heading changes and calibrate velocity information.

3. The zero motion detection system of claim **2** wherein said detection system resolves ambiguity in GPS velocity information.

4. The zero motion detection system of claim **1** wherein said detection system determines said offset by averaging samples of said motion signals.

5. The zero motion detection system of claim **1** wherein said detection system compares at least two samples of said motion signals with a threshold to determine said zero motion state.

6. An improved navigation system according to claim **1** wherein said GPS velocity information is calculated from delta range measurements.

7. An improved navigation system according to claim **6** wherein said navigation system calculates each of said delta range measurements based upon a first pseudorange measurement and a subsequent second pseudorange measurement, said time interval between said first pseudorange measurement and said second pseudorange measurement.

8. An improved navigation system according to claim **7** wherein said navigation system calculates said displacement by integrating said GPS velocity over said time interval between said first and second pseudorange measurements.

9. An improved navigation system according to claim **8** wherein said navigation system utilizes said GPS velocity information to dead reckon said current position from said previous position.

10. An improved navigation system comprising:

a GPS receiver which provides GPS velocity information, said navigation system using GPS velocity information to propagate a previous position to a current position, said system determines east and north displacements by integrating said GPS velocity information and applies said east and north displacements to said previous position to obtain said current position; and

sensors providing information used to propagate vehicle position if said GPS velocity information is not available, said navigation system determines calibration information from said GPS velocity information to calibrate said sensors.

11. The system of claim **10** wherein said sensors is an orthogonal axes accelerometer.

12. The system of claim **10** further including a zero motion detection system which provides a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity GPS information.

13. An improved navigation system according to claim **10** wherein said navigation system calculates said GPS velocity based upon a plurality of delta range measurements, said navigation system calculating each said delta range measurement based upon a different pair of pseudorange measurements, each said pair of pseudorange measurements being received from a different GPS satellite, said navigation system calculates said displacement by integrating said GPS velocity over a time interval between said first and second pseudorange measurements.

14. An improved navigation system comprising:

a GPS receiver which provides GPS velocity information, said navigation system using GPS velocity information to propagate a previous position to a current position, said system determines east and north displacements from said GPS velocity information and applies said east and north displacements to said previous position to obtain said current position; and

an orthogonal axes accelerometer providing longitudinal and lateral acceleration information, said vehicle navigation system determines longitudinal and lateral calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer; and

a zero motion detection system which provides a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity GPS information.

15. An improved navigation system according to claim **14** wherein said system integrates said GPS velocity over a time interval to obtain said east and north displacements.

16. An improved navigation system according to claim **15** wherein said navigation system calculates each of a plurality of delta ranges from different pairs of pseudorange measurements, said navigation system calculates said GPS velocity based upon said delta ranges.

17. A method of determining a current position from a previous position including the steps of:

providing GPS velocity information;

calculating a displacement based upon said GPS velocity information over a time interval; and

using said displacement to propagate a previous position to a current position.

18. The method of claim **17** wherein said displacement comprises

east and north displacements said method further including the step of

applying said east and north displacements to said previous position to obtain said current position.

19. The method of claim **17** further including the step of providing a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity GPS information.

20. The method of claim **17** further including the steps of:

providing sensor information used to propagate position if said GPS velocity information is not available; and

determining calibration information from said GPS velocity information to calibrate said sensors.

21. The method of claim **17** further including the steps of:

providing longitudinal and lateral acceleration information by an orthogonal axes accelerometer;

determining longitudinal and lateral calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer.

22. A method of determining a current position from a previous vehicle position including the steps of:

providing GPS velocity information;

determining east and north displacements by integrating said GPS velocity information over a time interval;

applying said east and north displacements to said previous position to obtain said current position;

providing longitudinal and lateral acceleration information by an orthogonal axes accelerometer;

determining longitudinal and lateral calibration information from said GPS velocity information; and

calibrating said orthogonal axes accelerometer with said calibration information.

23. The method of claim **15** further including the step of providing a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity GPS information.

24. The method of claim **22** further including the steps of:

calculating said GPS velocity based upon a plurality of delta ranges.

25. The method of claim **24** further including the steps of:

receiving a plurality of pairs of pseudorange measurements, each said pair of pseudorange measurements received from a different satellite;

calculating each of said plurality of delta range measurements from a different pair of said pseudorange measurements.

26. A method for dead reckoning position utilizing GPS velocity including the steps of:

a) determining a first position;

b) determining a first pseudorange measurement with respect to each of a plurality of satellites;

c) determining a second pseudorange measurement with respect to each of said plurality of satellites after said step b);

d) calculating a delta range with respect to each of said plurality of satellites, each based upon one of said first pseudorange measurements and one of said second pseudorange measurements;

e) calculating GPS velocity based upon said plurality of delta ranges;

f) calculating a displacement based upon said GPS velocity over a time interval;

g) adding said displacement to said first position to obtain a second position.

27. The method of claim **26** further including the steps of:

receiving a plurality of pairs of pseudorange measurements, each said pair of pseudorange measurements received from a different satellite;

calculating each of said plurality of delta range measurements from a different pair of said pseudorange measurements.

28. The method of claim **27** further including the step of integrating said GPS velocity over time to obtain said displacement.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,029,111
APPLICATION NO. : 08/579902
DATED : February 22, 2000
INVENTOR(S) : Croyle

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

Title Page, Item (57) ABSTRACT:
The abstract has been replaced with the following:

--The improved vehicle navigation system and method uses information from a Global Positioning System (GPS) to obtain velocity vectors, which include speed and heading components, for propagating or “dead reckoning” the vehicle position from a previous position to a current position. The improved vehicle navigation system has a GPS receiver which provides the GPS velocity information which is calculated from a full set of GPS delta range measurements. GPS position data alone is not accurate enough for certain applications, such as turn-by-turn route guidance in automobile applications, because its error may be 100 m and there is Considerable position drift, even when stationary. GPS velocities are much more accurate than the position data, 1 m/s or thereabouts, and can be used to propagate a known position forward and be more accurate over time than the GPS position solution. These velocities are instantaneous and not those computed from differencing two positions. The current position is calculated by adding displacements obtained from the GPS velocities to the previous position.--

Claim 2, Column 14, Line 25, the claim has been replaced with --The system of claim 1 wherein said system determines east and north displacements from said GPS velocity information and applies said east and north displacements to said previous position to obtain said current position.--

Claim 3, Column 14, Line 29, the claim has been replaced with --The system of claim 1 further including sensors providing information used to propagate position if said GPS velocity information is not available, said navigation system determines calibration information from said GPS velocity information to calibrate said sensors.--

Claim 4, Column 14, Line 32, the claim has been replaced with --The system of claim 3 wherein said sensors include a orthogonal axes accelerometer providing longitudinal and lateral acceleration information, said navigation system determines longitudinal and lateral calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer.--

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,029,111
APPLICATION NO. : 08/579902
DATED : February 22, 2000
INVENTOR(S) : Croyle

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

Claim 5, Column 14, Line 35, the claim has been replaced with --The system of claim 1 further including a zero motion detection system which provides a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity GPS information.--

Signed and Sealed this

Sixth Day of November, 2007

JON W. DUDAS

Director of the United States Patent and Trademark Office