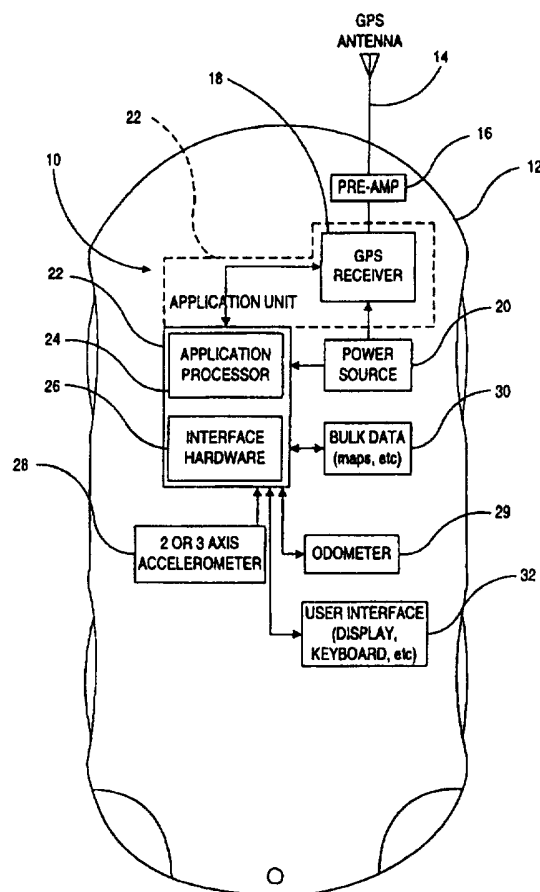




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<b>(21) International Application Number:</b> PCT/US96/20849  <b>(22) International Filing Date:</b> 27 December 1996 (27.12.96)  <b>(30) Priority Data:</b> 08/580,150      28 December 1995 (28.12.95)      US  <b>(71) Applicant (for all designated States except US):</b> ROCKWELL INTERNATIONAL CORPORATION [US/US]; 2135 West Maple Road, Troy, MI 48084 (US).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> CROYLE, Steven, R. [US/US]; 27201 Gardenway Road, Franklin, MI 48025 (US). SPENCER, Larry, E., II [US/US]; 525 Joslyn Road, Lake Orion, MI 48362 (US). SITTARO, Ernie, R. [US/US]; 420 Wonder Lane, Romeo, MI 48065 (US).  <b>(74) Agent:</b> SLENZAK, Laura, M.; Rockwell International Corporation, 2135 West Maple Road, Troy, MI 48084 (US).		<b>(81) Designated States:</b> JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>
<b>(54) Title:</b> IMPROVED VEHICLE NAVIGATION SYSTEM AND METHOD  <b>(57) Abstract</b>  <p>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 "dead reckoning" the vehicle position from a previous position. If information from the GPS is not available, then the improved vehicle navigation system uses information from an orthogonal axes accelerometer, such as two or three orthogonally positioned accelerometers, to propagate vehicle position. Because the GPS information should almost always be available, the improved vehicle navigation system relies less on its accelerometers, thereby allowing the use of less expensive accelerometers. The improved vehicle navigation system retains the accuracy of the accelerometers by repeatedly calibrating them with the velocity data obtained from the GPS 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.</p>		



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## IMPROVED VEHICLE NAVIGATION SYSTEM AND METHOD

### FIELD OF THE INVENTION

The present invention relates generally to vehicle navigation systems. More particularly, the present invention relates to an improved vehicle navigation system and method using information from a Global Positioning System (GPS) to obtain velocity vectors for vehicle position propagation, and if information from the GPS is not available, then using information from a multiple axis accelerometer to propagate vehicle position.

### 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 Figure 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

- 2 -

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.

5 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  
10 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.

The systems that use odometers, gyros and reverse gear hookups also lack portability due to the required connections to odometers and the frailty of gyros. Moreover, these systems are  
15 hard to install in different cars due to differing odometer configurations which can have different connections and pulse counts in the transmission. Odometer data also varies with temp, load weight, tire pressure, speed. Alternative connections to cruise control or ABS sensors bring up safety concerns.

Prior systems use a road network stored in a map database to calculate current vehicle  
20 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,  
25 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 potentially portable, vehicle navigation system which is flexible, accurate, efficient and cost-effective in determining a current position from a previous 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. If information from the GPS is not available, then the improved vehicle navigation system uses information from an orthogonal axes accelerometer, such as two or three orthogonally positioned accelerometers, to propagate vehicle position. Because the GPS information should almost always be available, the improved vehicle navigation system relies less on its accelerometers, thereby allowing the use of less expensive accelerometers. The improved vehicle navigation system retains the accuracy of the accelerometers by repeatedly calibrating them with the velocity data obtained from the GPS 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.

The use of accelerometers in the improved vehicle navigation system eliminates the need for connections to a heading sensor, speed sensors or a reverse gear, making the improved vehicle navigation system cheaper to install and potentially portable. The improved vehicle navigation system has sensors which are effectively calibrated because the scale factors for the accelerometers vary in a known manner dependent on temperature but fairly independent of other vehicle characteristics. In contrast, for example, an odometer loses accuracy if tire diameter changes due to falling tire pressure. If a third axis acceleration measurement sensor is added, the improved vehicle navigation system can operate completely independent of vehicle sensors, further increasing flexibility in mounting. The third accelerometer provides pitch to assist in calibrating the other accelerometers and in providing more accurate information by, for example, detecting a banked turn.

In accordance with another aspect of the present invention, the improved vehicle navigation system interrogates a map database to obtain heading information for the mapped path segment which the vehicle is moving on. The improved vehicle navigation system updates the

heading component for the velocity with the heading information from the map database. The updated velocity is used to propagate the vehicle position.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Other aspects and advantages of the present invention may become apparent upon reading  
5 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. 2a shows an improved vehicle navigation system using the improved position  
determination system according to the principles of the present invention, and FIGS. 2b show  
various hardware configurations for systems using aspects of the improved vehicle navigation  
10 system according to the principles of the present invention;

FIG. 3a shows a block/data flow diagram of the improved vehicle navigation system of  
FIG. 2a, and FIG. 3b shows a block data flow diagram of alternative improved vehicle navigation  
systems according to aspects of the present invention;

FIGS. 4a and 4b show flow charts for gathering acceleration information and orienting the  
15 multiple axis accelerometer;

FIG. 5a shows a block diagram of a zero motion detect system according to the principles  
of the present invention, and FIG. 5b shows a flow chart for the operation of the zero motion  
detect system of FIG. 5a;

FIGS. 6a and 6b show a general flow chart of the operation of the improved vehicle  
20 navigation system of FIG. 2a; and

FIGS. 7a-7e show general diagrams illustrating how the improved vehicle navigation  
system updates the heading information with the map heading for position propagations.

While the invention is susceptible to various modifications and alternative forms, specifics  
thereof have been shown by way of example in the drawings and will be described in detail. It  
25 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 vehicle navigation system according to the principles of the present invention and methodology is described below as it might be implemented 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 can be used in connection with a variety of system configurations in which GPS signals are used for position propagation. FIG. 2a illustrates, in block diagram form, an exemplary arrangement and use 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 -3dBiC 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 18, which is powered by a power source 20 for the vehicle navigation system 10.

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-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.

GPS accuracy has a statistical distribution which is dependent on two important factors. The accuracy which can be expected will vary with the error in the range measurements as well as the geometry or relative positions of the satellites and the user. The Geometric Dilution of Precision (GDOP) indicates how much the geometric relationship of the tracked satellites affects the estimate of the receiver's position, velocity, and time. There are four other DOP components which indicate how the geometry specifically affects errors in horizontal position (HDOP), vertical position (VDOP), position (PDOP), and time (TDOP).

DOPs are computed based on the spatial relationships of the lines of sight between the satellites and the user. The motion of the satellites relative to each other and the user causes the DOPs to vary constantly. For the same range measurement errors, lower DOPs relate to more accurate estimates. The errors in the range measurements which are used to solve for position may be magnified by poor geometry. The least amount of error results when the lines of sight have the greatest angular separation between them.

For example, if two lines of sight are necessary to establish a user position, the least amount of error is present when the lines cross at right angles. 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.

5 As shown in FIG. 2a, 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  
10 navigation system 10 with the application unit 22. In this embodiment, a 2 or 3 axis accelerometer 28 provides acceleration signals to the application unit 22. The accelerometer 28 can include recently available and low cost, micro-machined accelerometers. An odometer 29 provides information which can be used in place of the information derived from the accelerometers, but the odometer 29 is optional because it reduces the portability of the system. A map database 30 stores  
15 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.

20 FIGS. 2b shows alternative configurations which can incorporate aspects of the improved vehicle navigation as would be understood by one of skill in the art. FIG. 2b contains reference numerals which correspond to the reference numerals of FIG. 2a. FIG. 2b shows that a 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,  
25 the orthogonal axes accelerometer 28 and the map database 30 to propagate vehicle position. In additional embodiments, the improved vehicle navigation system 10 uses the orthogonal axes accelerometer 28, odometer 29 and the 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  
30 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. 3a shows a block and data flow diagram for the improved vehicle navigation system 10 of FIG. 2a. 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.

In accordance with another aspect of the present invention, FIG. 3b shows the flexibility and accuracy of certain embodiments of the improved vehicle navigation system. The vehicle positioning block 22 receives longitudinal acceleration information,  $a_{\text{long}}$ , a lateral acceleration information,  $a_{\text{lat}}$ , a gyro heading,  $\theta_g$ , an odometer distance,  $S$ , map heading,  $\theta_{\text{mm}}$ , and GPS information, including a velocity vector  $\bar{v}_G$ , a position vector  $\bar{x}_G$  and delta range measurements  $dR_i$ . When GPS velocity information is available and reliable, the vehicle positioning 22 propagates the position vector  $\bar{x}(t)$  with the GPS velocity vector  $\bar{v}_G$  as follows:

$\bar{x}(t) = \bar{x}(t-1) + \bar{v}_G \Delta t$ . If the difference between the GPS heading and the map heading is within a threshold, the map heading is used as the heading. If the GPS velocity information is not available or unreliable (at low velocities below 1.5 m/s), the vehicle positioning will propagate the position vector  $\bar{x}(t)$  using the available velocity vector with the most merit as follows:

$$\bar{x}(t) = \bar{x}(t-1) + \bar{v} \Delta t.$$

In this particular embodiment, the improved vehicle navigation system can obtain the information used to propagate the vehicle position from several sources such as the available GPS delta range measurement(s), the orthogonal axes accelerometer using lateral and longitudinal acceleration information, 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. 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  $\bar{v}_a$  from  $\bar{v}_G$  when possible. The GPS position information is used as an overall check on the current position. For example, if  $|\bar{x}(t) - \bar{x}_G(t)| < (18.5 * PDOP)$ , then

5  $\bar{x}(t) = \bar{x}(t)$ . Otherwise,  $\bar{x}(t) = \bar{x}_G(t)$ . In certain embodiments, all raw inputs could go into a Kalmann filter arrangement which outputs the velocity vector.

The sensor 28 for the embodiments of FIGs. 3a and 3b, which is a multiple axis accelerometer, provides acceleration information for at least two orthogonal axes (lateral, longitudinal and/or vertical). The accelerometers 28 produce a voltage measure. As shown in

10 FIG. 4a for the longitudinal accelerometer, the accelerometer data is read at step 48, and the zero offset (set at the factory and constantly re-checked and reset by the Zero Motion Detector mentioned below) is subtracted from this measure at step 49 to produce a number of volts displacement from zero. This number of volts displaced from zero is then multiplied by a scale

15 factor (set at the factory and continuously re-calibrated by the GPS) to produce a number of G's of acceleration at step 50. This number of G's of acceleration is then multiplied by the number of meters per second squared per G to produce meters per second squared of acceleration at step 51. The meters per second squared of acceleration is then multiplied by the delta time (integrated once) to produce a velocity at step 52. This velocity is saved for the next second. This acceleration information can be used to determine change in distance information,  $\Delta \text{DIST}$ , and change in turn

20 rate information,  $\Delta \theta$ .

Initially, the improved vehicle navigation system requires initial conditions for various items, such as accelerometer orientation, accelerometer zero offset, accelerometer scale factor, odometer pulses per mile, and initial vehicle orientation. Factory defaults will be used for each of these items so that no initialization will be necessary. Those items will also need to be maintained,

25 but not necessarily in the absence of all power (i.e. battery loss, or removal from vehicle). An option will be available to manually initialize these items. This would allow immediate use of the system, without having to wait for GPS to be acquired for calibrating these items.

Once GPS has been acquired and is determined to be useable based on its Figure of Merit, GDOP, and Number of Satellite Measurements Used, GPS can be used to calibrate all of the

30 configurable items. It will first determine the accelerometer orientation as described in FIG. 4b. At power on, the assignment of accelerometers to each of the lateral, longitudinal and down axes

(if three axis accelerometer is used) are in the same orientation as the last power down, which will be saved in some non-volatile storage. If three accelerometers are used, one will be measuring the Earth's gravity. The accelerometer measuring one G (Earth's Gravity) will be assigned to the Down Axis. For the other two axes, as shown in FIG. 4b, the following procedure will take place.

5 At step 53, the acceleration data is obtained as described in FIG. 4b. The acceleration measurements from each of the two accelerometers will be compared until their difference reaches a pre-defined threshold at step 54. The reason for this is to ensure that the accelerations are uneven enough that a valid compare against current vehicle conditions can be made without ambiguity.

10 As shown in steps 55-61 for this particular embodiment, once this situation occurs and there is acceleration data computed from the GPS data, the acceleration from each of the accelerometers will be compared to the lateral and longitudinal accelerations computed from the GPS and the accelerometers with the closest acceleration values for each of those axes will be assigned to those axes.

15 Additionally, the initial vehicle orientation is determined because the vehicle heading relative to True North can be computed from the GPS velocities.

With reference to FIG. 3a, the sensor integrator 40 can use the longitudinal and lateral acceleration information as described below to determine a current position for the vehicle if GPS velocity information is not available. In any event, if GPS is available or not, the sensor integrator  
20 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  
25 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  
30 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.

10       The sensor calibration block 44 contains the sensor calibration parameters, such as scale factors and zero factors for the sensors 28, 29 and provides the calibration parameters to the sensor integrator 40 to calibrate the sensors 28, 29. 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).

15       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.

20       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.

25       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 the system, and with GPS available, the following are the equations that will be used for computing the vehicle position and the calibration of the accelerometers and odometer.

**Definitions:**

- 10         $\bar{x}$         =        position vector [latitude longitude altitude]  
            $\dot{\bar{x}}$         =        velocity vector [north east down]  
            $\ddot{\bar{x}}$         =        acceleration vector [north east down]  
            $C_N^B$        =       Transformation matrix which rotates a vector from the Body coordinate frame to the North East Down coordinate frame.

- 15        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:

- 20        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.

- 25        The following subscripts will denote coordinate reference frames:

- N        =        North East Down  
           B        =        Body (Nose Right Door Down)  
           G        =        Geodetic (latitude longitude height)

- 30        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:

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

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.

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

The following information is collected at time t:

- 5      $\dot{\bar{x}}_{t-1}^G$      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);
- $\ddot{\bar{x}}_{t-1}^G$      The acceleration computed from GPS velocities that was valid from time t-2 to time t-1;
- 10      $\bar{x}$      The raw GPS position;
- $\dot{\bar{x}}_t^O$      The speed computed from the number of odometer counts that occurred from time t-1 to time t;
- and
- $\ddot{\bar{x}}_t^A$      The acceleration computed from the accelerometers 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

- 15     previous time:
- $\dot{\bar{x}}_{t-2}^G$      The velocity from GPS which was valid two time units ago;
- $\bar{x}_{t-1}$      The position computed at the previous time;
- $\ddot{\bar{x}}_{t-1}^A$      The acceleration, computed from the accelerometers, from time t-2 to time t-1; and
- $\dot{\bar{x}}_{t-1}^O$      The velocity computed from the odometer counts from time t-2 to time t-1.
- 20     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:

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

or

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$$\bar{x}_t = \bar{x}_{t-1} + (\dot{\bar{x}}_{t-1}^G * \Delta t) + \left( \frac{1}{2} \ddot{\bar{x}}_t^A * (\Delta t)^2 \right) + \left( \left( \frac{1}{2} \ddot{\bar{x}}_{t-1}^G * (\Delta t)^2 \right) - \left( \frac{1}{2} \ddot{\bar{x}}_{t-1}^A * (\Delta t)^2 \right) \right)$$

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  $\theta$  computed as the inverse tangent of the East and North velocities:

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

(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:

$$s = \sqrt{(\dot{x}_{t-1}^e * \Delta t)^2 + (\dot{x}_{t-1}^n * \Delta t)^2} + \frac{1}{2} \ddot{x}_t^A * (\Delta t)^2;$$

(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:

$$s = \sqrt{(\dot{x}_{t-2}^e * \Delta t)^2 + (\dot{x}_{t-2}^n * \Delta t)^2} + \frac{1}{2} \ddot{x}_{t-1}^G * (\Delta t)^2;$$

(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.

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

The use of GPS velocity information for vehicle position propagation in a vehicle navigation system is described in more detail in copending U.S. patent application no.

08/579,902, entitled "Improved Vehicle Navigation System And Method Using GPS

Velocities" and filed concurrently with this application.

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 specific time interval. Sensor calibration using the GPS velocities will typically involve the following sensors.

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 zero motion detect system discussed in FIGs. 5a and 5b will be used to compute the accelerometer zero offset value. 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 FIGs. 5a and 5b will be used to compute the accelerometer zero offset value.

FIG. 5a 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 zero motion detection and offset calculation block 69 which is in the application unit 22 (FIG. 2a). The vehicle navigation 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 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 following high level language program shows the operation of this particular embodiment of the zero motion detect system.

```

NUMSAMPLES = 16 (in filter array)
WORD DATA[NUMSAMPLES-1]
WORD NOISE
FOR (I=0; I < NUMSAMPLES; I++)
    NOISE = NOISE + |DATA[I] - DATA[I+1]|
    If (NOISE > THRESHOLD)
        ZERO_MOTION_FLAG = 0
    ELSE

```

ZERO\_MOTION FLAG = 1.

FIG. 5b shows a flowchart of a variation of the zero motion detect system. At step 75, the system initializes the variables I and NOISE to zero, and at step 77, the first value of the array is read. The counter I is incremented at step 79, and the system reads the next sample at step 81. At  
5 step 83, the system begins to accumulate the differences between consecutive samples of the motion signals. The system loops through steps 81-87 until all the samples have been read and the difference between consecutive samples accumulated in the variable NOISE. Once all the samples have been read, the system compares the variable NOISE with the threshold value at step 89. If  
10 the NOISE variable is greater than the threshold, then the system determines that motion has been detected in step 91. If the NOISE variable is less than the threshold, the system sets the zero motion flag and determines that the velocity is zero at step 93. The setting of the zero motion flag can set distance changes to zero, lock the heading and current position. Additionally, at step 95, the system calculates the zero offset for the sensor being sampled.

With regard to FIG. 5b and the high level program above, the system is described as  
15 sampling the motion signals from one sensor 64, such as one axis of the orthogonal axes accelerometer. In this particular embodiment, the motion signals for each of the orthogonal axes of the accelerometer is sampled and zero offsets for each is determined. Furthermore, zero offsets, sensor calibration or resolving of ambiguities can be accomplished for other sensors using the zero motion detection system according to the principles of the present invention. The use of a zero  
20 motion detection system in a vehicle navigation system is described in more detail in copending U.S. patent application no. 08/579,903, entitled "Zero Motion Detection System For Improved Vehicle Navigation System" and filed concurrently with this application.

FIGS. 6a and 6b show a general flowchart illustrating how the improved vehicle navigation system 10 propagates a previous position to a current position. At step 150, the  
25 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  
30 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.

- 5 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:

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

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

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

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

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

The current position is calculated as follows:

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

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

where degrees/meter represents a conversion factor of meters 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

- 20 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

- 25 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
- 30 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:

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

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

- 5 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  
10 velocity information is subject to errors at speeds of less than 1.5m/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  
15 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. 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  
20 173, if an odometer is not used, the distance is derived from the longitudinal acceleration information. Once the change in distance is determined, the system calculates the position at step 180 using the following equations to determine heading as follows:

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

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

$$25 \quad \text{heading} = \text{heading} + \Delta\theta(\text{modulo } 360^\circ) \quad (11).$$

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.

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  
30 U.S. patent application no. 08/580,177, entitled "Improved Vehicle Navigation System And Method Using A Multiple Axes Accelerometer" and filed 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 (within 100m for example) from the GPS position, the system determines that the current position is valid at step 184. If not, the system  
5 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.

10 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. 2a) 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, which was based on GPS and/or sensor calculations, to obtain  
15 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, the heading based on the GPS position information of step 186, the heading from the sensors, or the heading based on a current position determined through a combination of GPS and sensor information, such as an embodiment with all raw inputs going into a Kalman filter.

20 As shown in FIG. 7a, the vehicle navigation system 10 (FIG. 2a) 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). In FIG. 7b, if GPS information is not available, the vehicle navigation system uses sensor information to propagate the previous position 191 to current position 192 using heading  
25 and distance 198. If the difference between the GPS heading (or current heading from the sensors if GPS is not used) 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. 7c 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  
30 map headings are within the threshold and integrates the rotated GPS velocity vector 204 to obtain

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the displacements 208 and 210. 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.

As shown in FIG. 7d, if the vehicle navigation system uses sensor information to propagate the previous position 191 to current position 192 using heading and distance 198, the map heading 202 can be used as the heading for position propagation to the updated current position 206. FIG. 7e 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. The use of map heading to update the information obtained from the non-GPS sensors or a combination of GPS and other sensors can be accomplished in a similar manner as would be understood by one of skill in the art. 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 will rely heavily 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. Moreover, the improved vehicle navigation system can obtain dead reckoning information from GPS signals when a full set of GPS measurements is available, and use its sensors when anything less than a full set of GPS signals is available. 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.

CLAIMS

1. An improved vehicle navigation system composing:  
a map database with map information, said vehicle navigation system derives a map heading from said map information; and  
a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position and interrogates said map database to obtain said map heading information; said vehicle navigation system updates said velocity information with said map heading for propagating said previous position to said current position if the difference between the heading of said velocity information and said map heading are within a threshold.
2. The system of claim 1 wherein said system uses said velocity to propagate a previous position to a current position.
3. The system of claim 2 wherein said system rotates said velocity to align with said map heading and integrates the rotated velocity to obtain displacements; said system obtains said current position by applying said displacements to said previous position.
4. The method of claim 2 wherein said system projects said velocity onto said map heading and integrating said projected velocity to obtain a displacement and obtaining said current position by applying said displacement to said previous position.
5. A method of estimating the velocity of a vehicle known to be on a mapped path comprising:  
interrogating a map database to obtain a map heading of said mapped path; and  
updating said velocity with said map heading if the difference between the heading of said velocity and said map heading are within a threshold.
6. The method of claim 5 further including the step of using said velocity to propagate a previous position to a current position.
7. The method of claim 6 wherein said step of using includes rotating velocity to align with said map heading and integrating rotated velocity to obtain a displacement and obtaining said current position by applying said displacement to said previous position.
8. The method of claim 6 wherein said step of using includes projecting said velocity to align with said map heading and integrating said projected velocity to obtain a displacement and obtaining said current position by applying said displacement to said previous position.

9. An improved vehicle navigation system, comprising an orthogonal axes accelerometer which provides longitudinal and lateral acceleration information, said vehicle navigation system uses said lateral acceleration information to derive heading change; said vehicle navigation system uses said heading change to propagate a previous position to a current position.

10. The system of claim 9 wherein said system uses heading change and said longitudinal acceleration information to propagate a previous position to a current position.

11. The system of claim 9 including a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position if GPS velocity information is used.

12. The system of claim 11 wherein said vehicle navigation system determines lateral and longitudinal calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer.

13. An improved vehicle navigation system, comprising:  
a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position;  
an orthogonal axes accelerometer provides longitudinal and lateral acceleration information, said vehicle navigation system determines lateral and longitudinal calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used.

14. The system of claim 13 wherein said system uses said longitudinal acceleration information and said heading change to propagate a previous position to a current position if said GPS velocity information is not used.

15. A method of propagating a previous position to a current position in a position determination system, said method including the steps of:

providing longitudinal acceleration information from a multiple axes accelerometer;  
providing lateral acceleration information from said multiple axes accelerometer;  
deriving heading change using said lateral acceleration information; and  
using said heading change to propagate a previous position to a current position.

16. The method of claim 15 wherein said step of using includes using said longitudinal acceleration and said heading change to propagate a previous position to a current position.

17. A method of propagating a previous position to a current position in a position determination system, said method including the steps of:

- providing longitudinal acceleration information from a orthogonal axes accelerometer;
- providing lateral acceleration information from said orthogonal axes accelerometer;
- determining longitudinal speed from said longitudinal acceleration information;
- deriving heading change from said lateral acceleration information and said longitudinal speed; and

- using said heading change and said longitudinal acceleration to propagate a previous position to a current position.

18. The method of claim 17 further including the steps of:

- providing GPS velocities;
- determining lateral and longitudinal calibration information from GPS velocities; and
- calibrating said orthogonal axes accelerometer with said lateral and longitudinal calibration information.

19. The method of claim 18 further including the steps of:

- updating scale factors for said orthogonal axes accelerometer using said lateral and longitudinal calibration information.

20. A vehicle navigation system having a GPS receiver which provides GPS velocity information, said vehicle navigation system uses GPS velocity information to propagate a previous position to a current position.

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

- providing GPS velocity information; and
- using said GPS velocity information to propagate a previous position to said current position.

22. The method of claim 21 wherein said step of using further includes the steps of:

- determining east and north displacements from said GPS velocity information; and

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

23. An improved vehicle navigation system having a GPS receiver which provides GPS delta range information and GPS velocity information calculated from a set of said GPS delta range information, said vehicle navigation system calculates GPS velocity information from a subset of said GPS delta range information when said set of GPS delta range information is not available and uses said GPS velocity information to propagate a previous position to a current position.

24. A method of determining a current position including the steps of:  
providing a subset of GPS delta range information;  
calculating GPS velocity information from said subset of GPS delta range information;  
and  
using said GPS velocity information to propagate a previous position to said current position.

25. An improved vehicle navigation system has a motion detection sensor which provides motion signals having zero offsets, said vehicle navigation system comparing said motion signals with a threshold to determine a zero motion state, and if in said zero motion state, said vehicle navigation system determines said zero offsets.

26. The system of claim 25 wherein said system determines said zero offsets by averaging said motion signals.

27. The improved vehicle navigation system of claim 25 wherein said vehicle navigation system locks heading changes and calibrates velocity measurements if said vehicle navigation system is in said zero motion state.

28. An improved vehicle navigation system, comprising:  
a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position; and  
an orthogonal axes accelerometer provides motion signals having longitudinal and lateral acceleration information and zero offsets, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system compares said motion signals with a

threshold to determine a zero motion state, and if said vehicle navigation system is in said zero motion state, said vehicle navigation system determines said zero offsets.

29. An improved vehicle navigation system, comprising:

a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position; and

an orthogonal axes accelerometer provides motion signals having longitudinal and lateral acceleration information and zero offsets, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system comparing said motion signals with a threshold to determine a zero motion state, and said vehicle navigation system locks heading changes and calibrates said zero offsets if said vehicle navigation system is in said zero motion state.

30. A method of detecting a zero motion state, said method comprising the steps of:  
providing a motion sensor signal;

determining a zero motion state by comparing at least two samples of said motion sensor signal with a threshold; and

using at least one of said samples to determine said zero offsets if said zero motion state is detected.

31. The method of claim 30 further including the step of providing a zero motion signal upon detecting a zero motion state to resolve ambiguity of low velocity measurements.

32. An improved vehicle navigation system, comprising:

a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position;

an orthogonal axes accelerometer provides motion signals having longitudinal and lateral acceleration information and zero offsets, including longitudinal and lateral acceleration information, said vehicle navigation system determines heading change using said lateral acceleration information and longitudinal speed; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system comparing said motion signals with a threshold to determine a zero motion state, and said vehicle navigation system locks heading changes and

calibrates said zero offsets of said orthogonal axes accelerometer if said vehicle navigation system is in said zero motion state;

an odometer provides displacement information, said vehicle navigation system determines displacement using at least one of said longitudinal acceleration information and said displacement information. said vehicle navigation system determines heading change from said lateral acceleration information, said vehicle navigation system determines odometer calibration information from said GPS velocity information if said GPS velocity information is used, said vehicle navigation system uses said heading change and said displacement to propagate a previous position to a current position if said GPS velocity information is not used; and

a map database which stores map information, said vehicle navigation system determines a heading from said map information, said vehicle navigation system updates said GPS velocity information with said heading before propagating said previous position to a current position.

33. An improved vehicle navigation system, comprising:

a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position;

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

an odometer provides displacement information, said vehicle navigation system determines displacement using at least one of said longitudinal acceleration information and said displacement information; said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change and said displacement to propagate a previous position to a current position if said GPS velocity information is not used; and

a map database which stores map information, said vehicle navigation system determines a map heading from said map information, said vehicle navigation system updates said GPS velocity information with said map heading before propagating said previous position to a current position if the difference between said map heading and the heading of said GPS velocity information is within a threshold.

34. The system of claim 33 wherein said system determines heading change using said longitudinal acceleration information.

35. An improved vehicle navigation system, comprising:

a GPS receiver which provides which provides GPS delta range information and GPS velocity information calculated from a set of said GPS delta range information, said vehicle navigation system uses said GPS velocity information when said set of GPS delta range information is available and calculates GPS velocity information from a subset of said GPS delta range information when said set of GPS delta range information is not available and uses said GPS velocity information to propagate a previous position to a current position;

an orthogonal axes accelerometer provides motion signals having longitudinal and lateral acceleration information and zero offsets, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system comparing said motion signals with a threshold to determine a zero motion state, and said vehicle navigation system locks heading changes and calibrates said zero offsets if said vehicle navigation system is in said zero motion state; and

a map database which stores map information, said vehicle navigation system determines a map heading from said map information, said vehicle navigation system updates said GPS velocity information with said map heading before propagating said previous position to a current position if the difference between the heading of said GPS velocity information and said map heading is within a threshold.

36. An improved vehicle navigation system, comprising:

a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position;

an orthogonal axes accelerometer provides longitudinal and lateral acceleration information, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system determines latitudinal and longitudinal calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer;

an odometer provides displacement information, said vehicle navigation system determines displacement using at least one of said longitudinal acceleration information and said displacement information; said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change and said displacement to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system determines odometer calibration information from said GPS velocity information if said GPS velocity information is used to calibrate said odometer; and

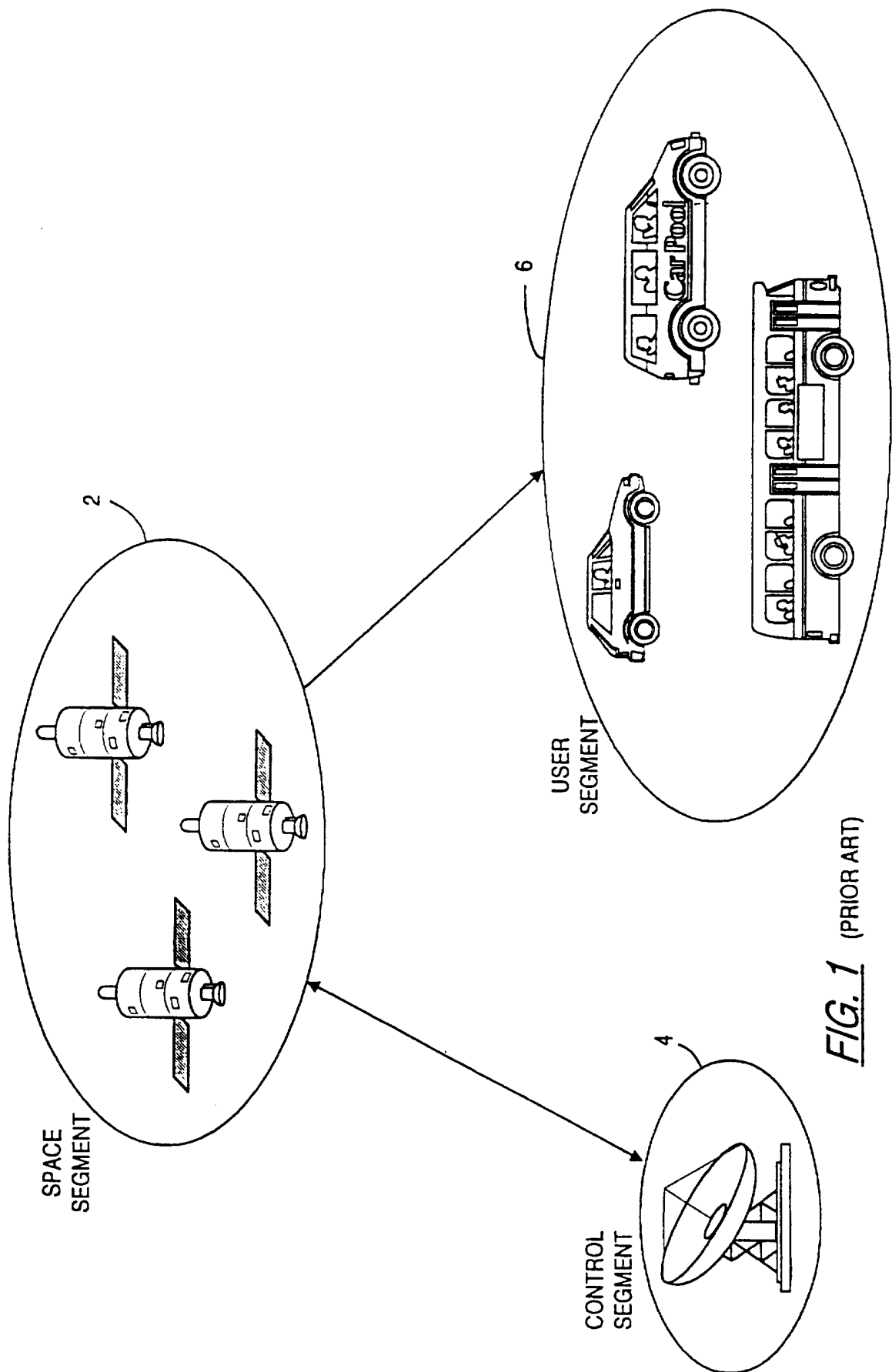
a map database which stores map information, said vehicle navigation system determines a map heading from said map information, said vehicle navigation system updates said GPS velocity information with said map heading if the difference between the GPS heading and said map heading are within a threshold before propagating said previous position to a current position.

37. An improved vehicle navigation system, comprising:

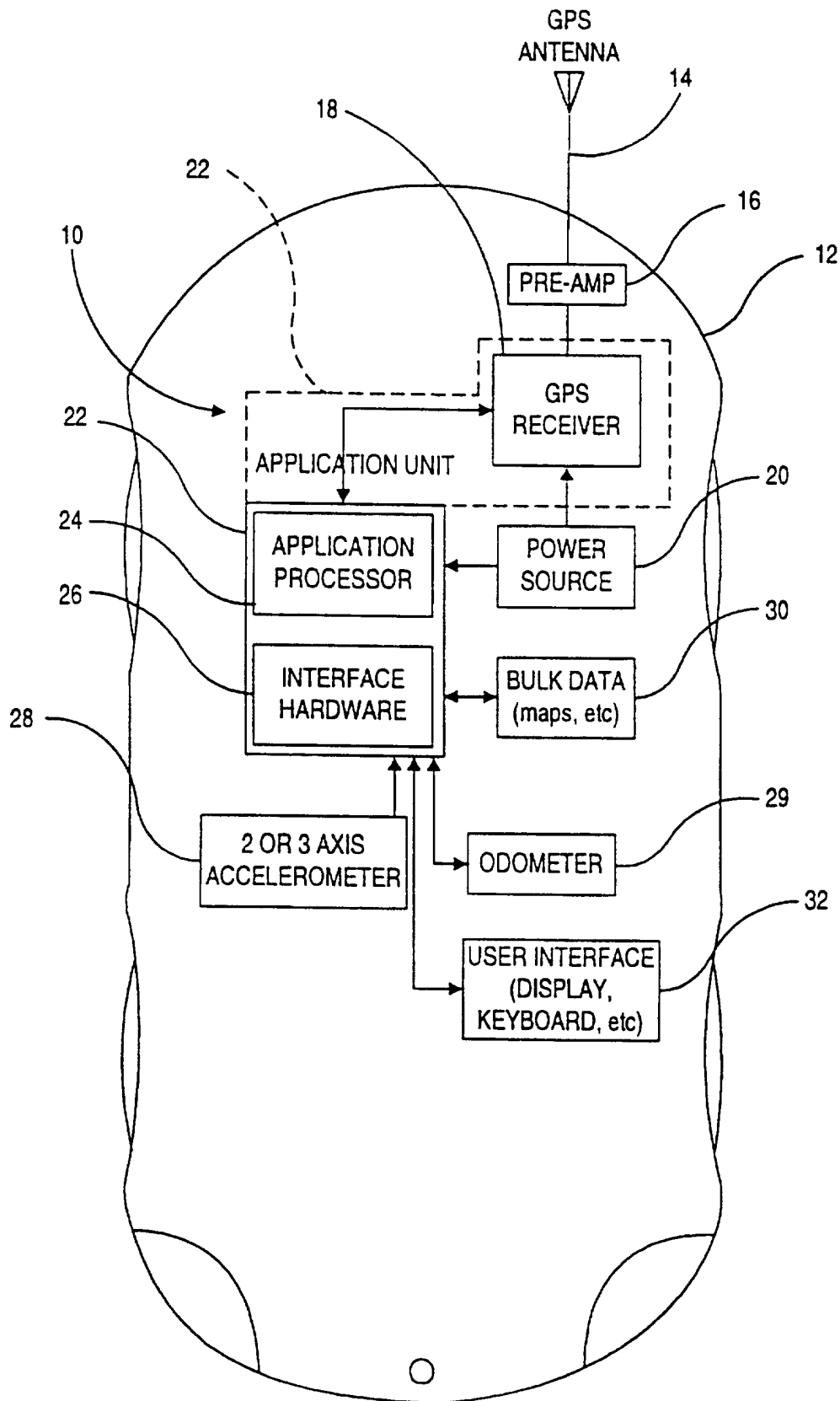
a GPS receiver which provides GPS velocity information, said vehicle navigation system uses said GPS velocity information to propagate a previous position to a current position;

an orthogonal axes accelerometer provides motion signals having longitudinal and lateral acceleration information and zero offsets, said vehicle navigation system determines heading change using said lateral acceleration information; said vehicle navigation system uses said heading change to propagate a previous position to a current position if said GPS velocity information is not used, said vehicle navigation system comparing said motion signals with a threshold to determine a zero motion state, and said vehicle navigation system locks heading changes and calibrates said zero offsets if said vehicle navigation system is in said zero motion state, said vehicle navigation system determines lateral and longitudinal calibration information from said GPS velocity information to calibrate said orthogonal axes accelerometer if said GPS velocity information is used if said vehicle navigation is not in said zero motion state; and

a map database which stores map information, said vehicle navigation system determines a map heading from said map information, said vehicle navigation system updates said GPS velocity information with said map heading if the difference between the heading of said GPS velocity information and said map heading is within a threshold before propagating said previous position to a current position.



**FIG. 1** (PRIOR ART)

*FIG. 2a*

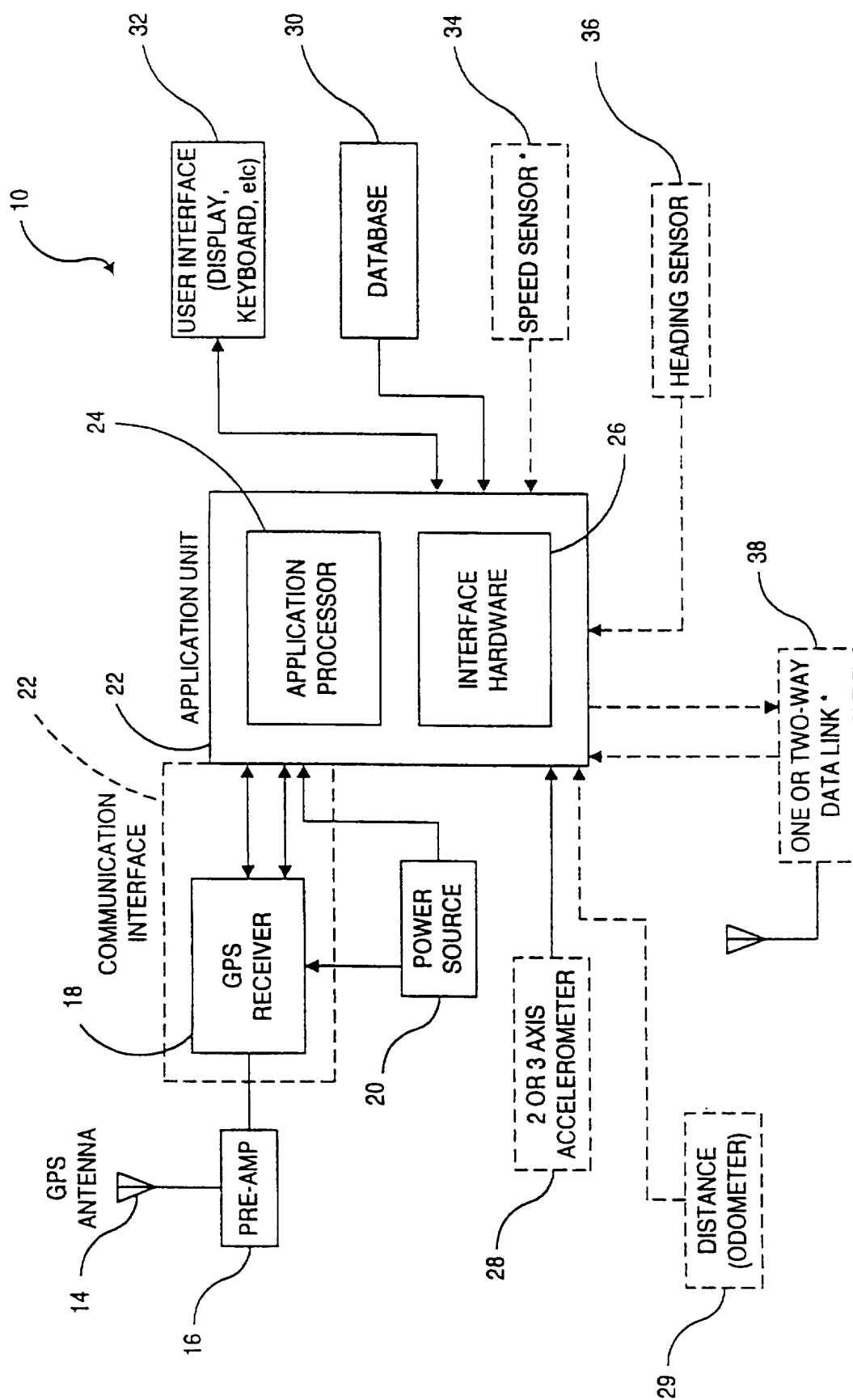
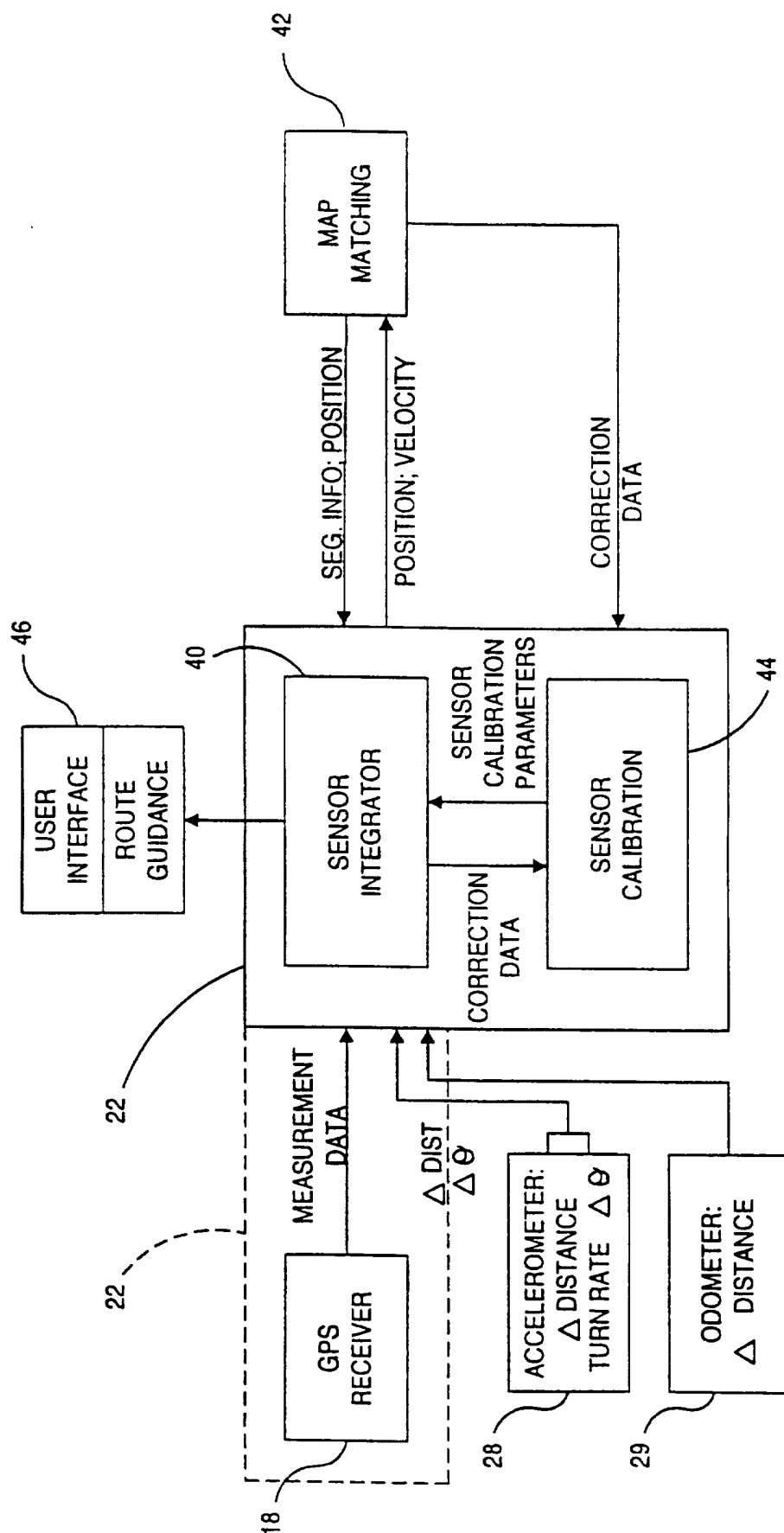
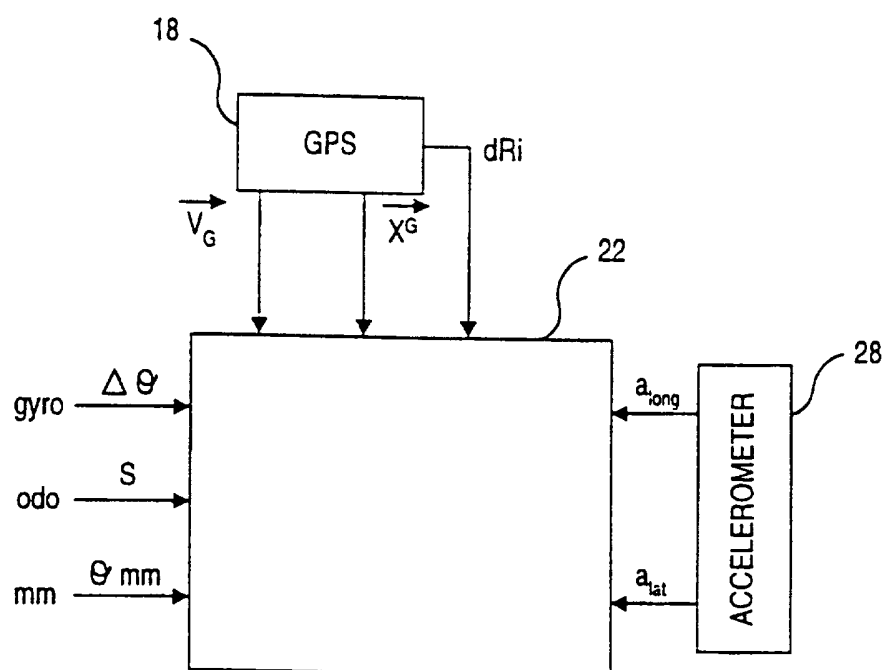


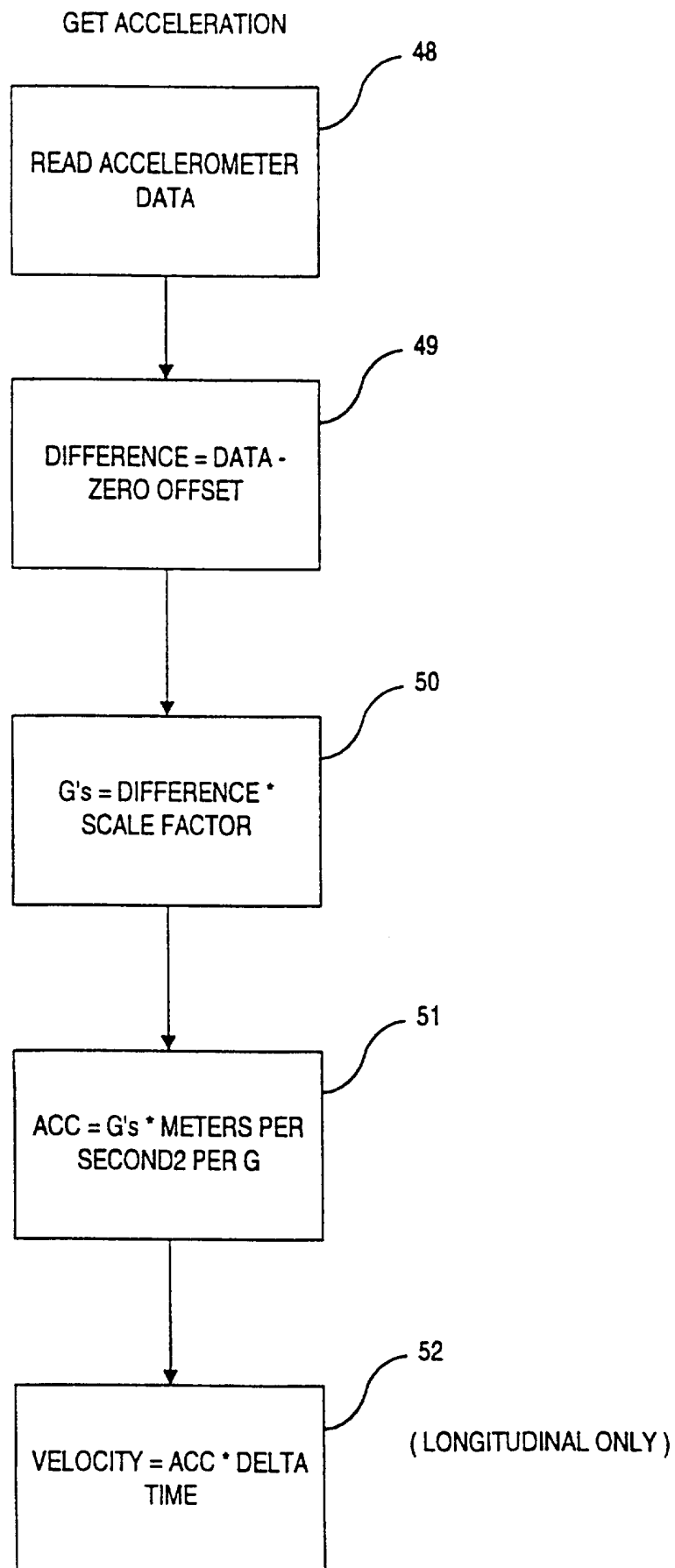
FIG. 2b

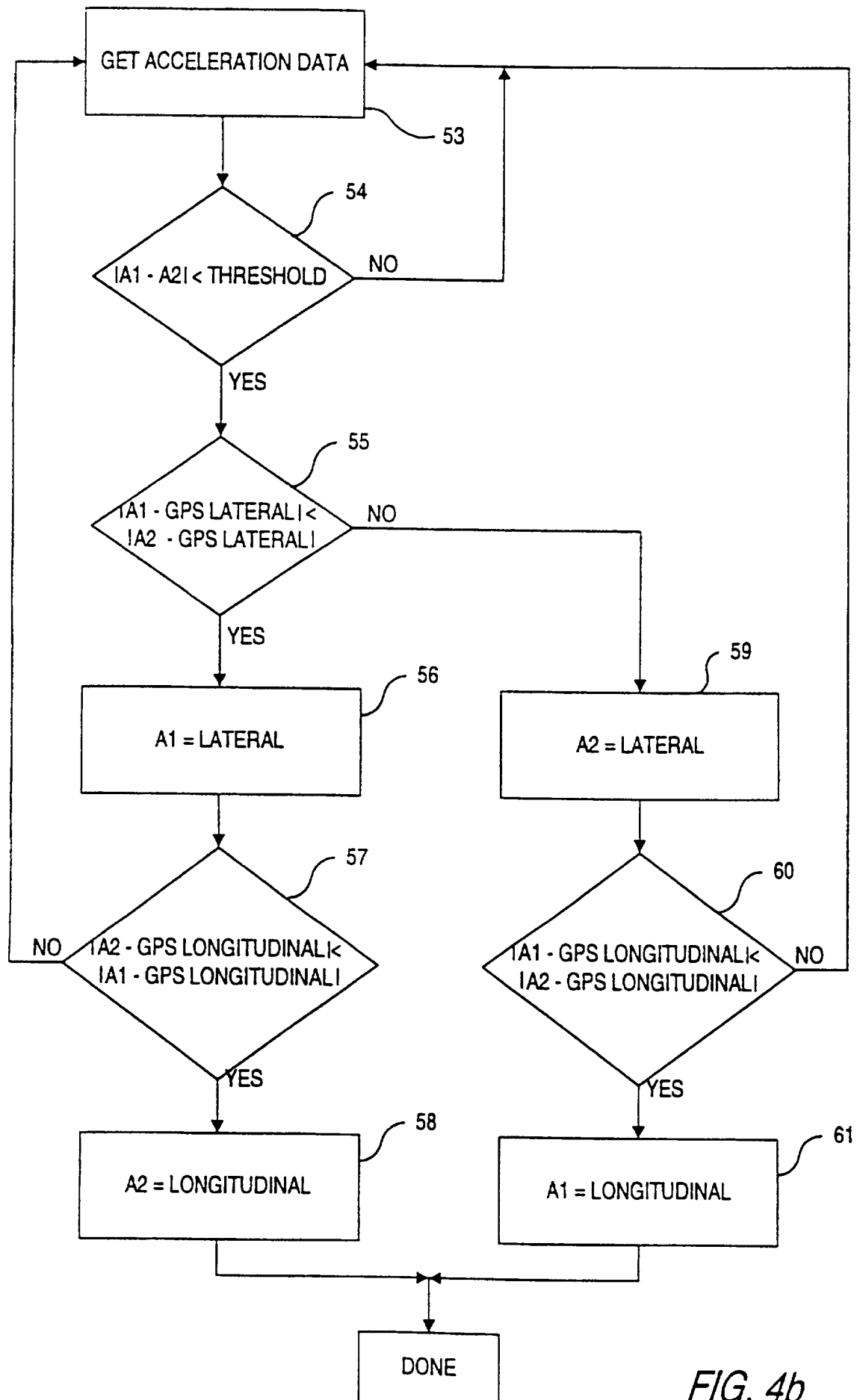
\* OPTIONAL

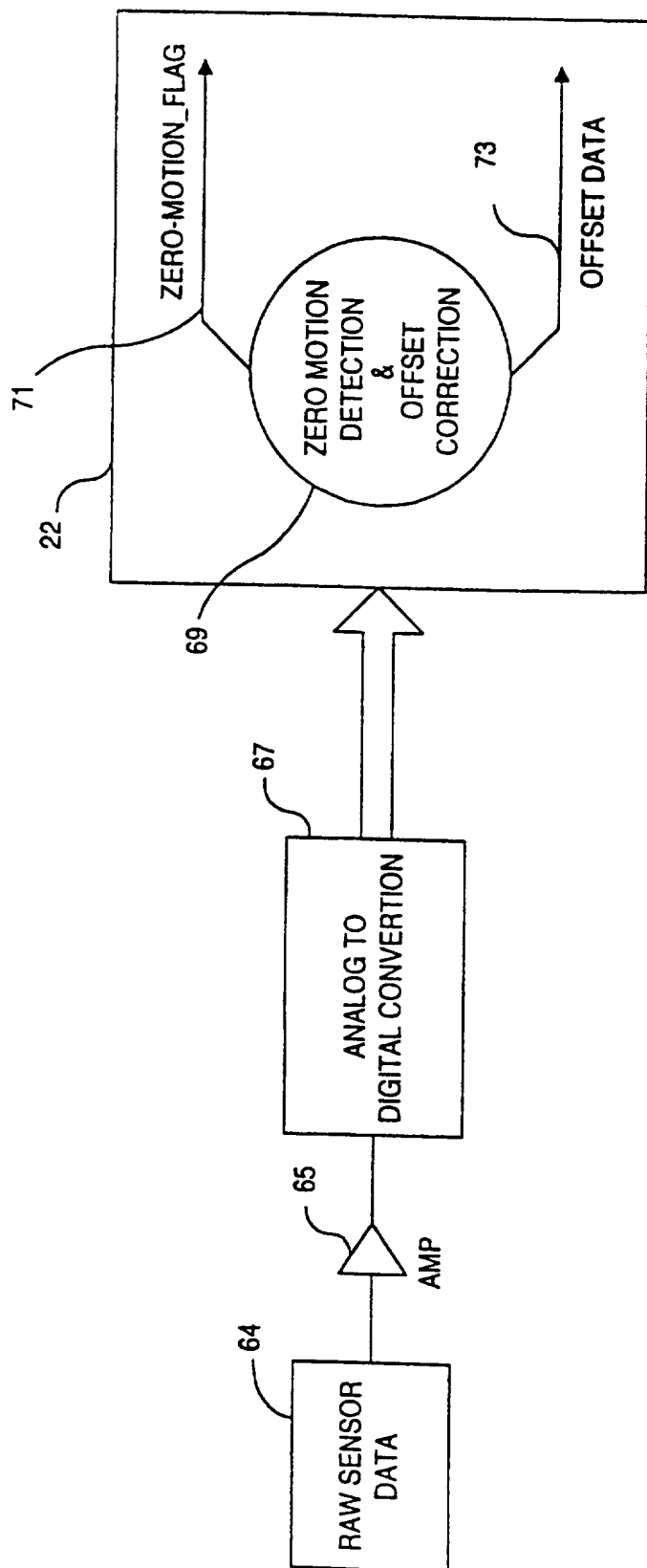


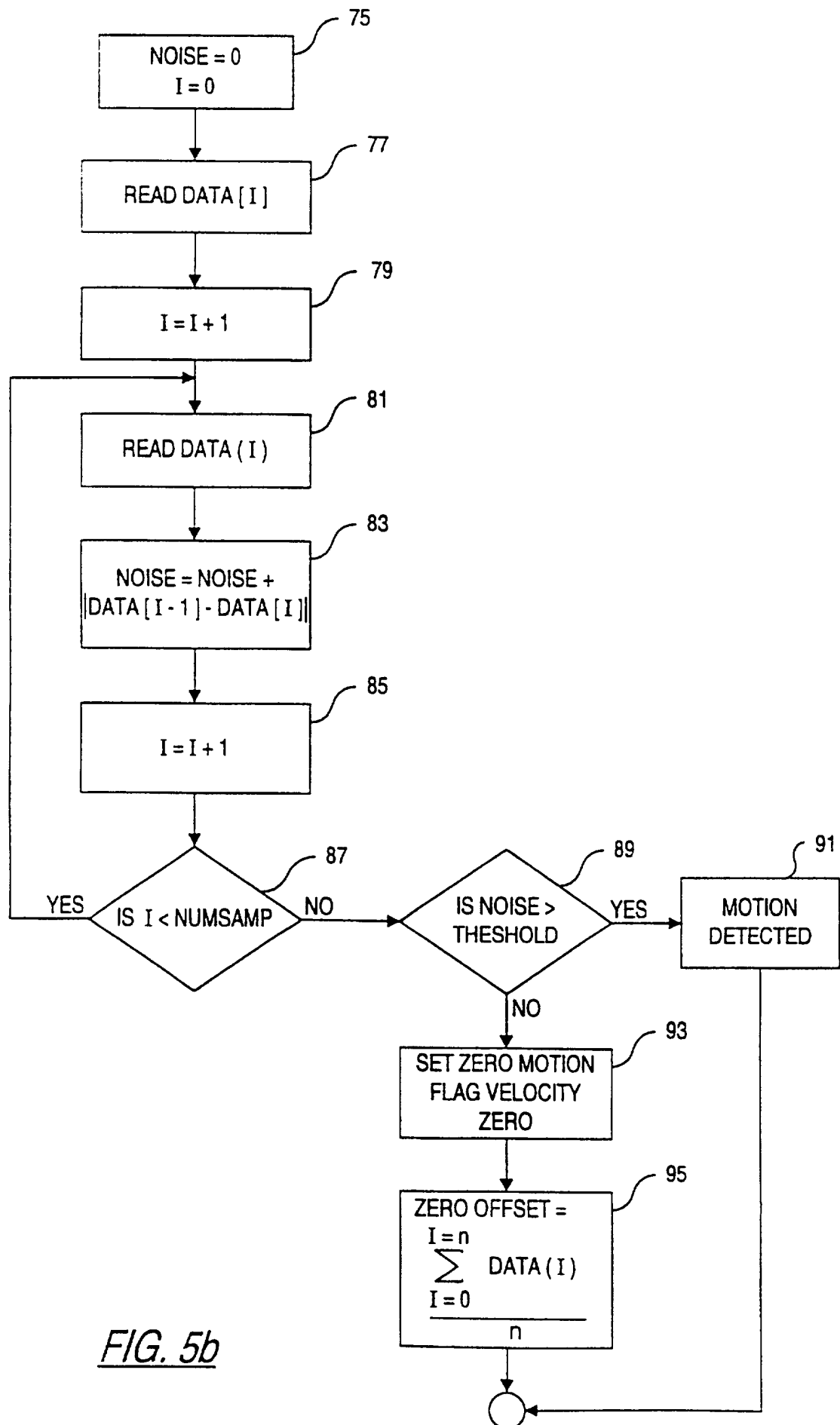
*FIG. 3a*

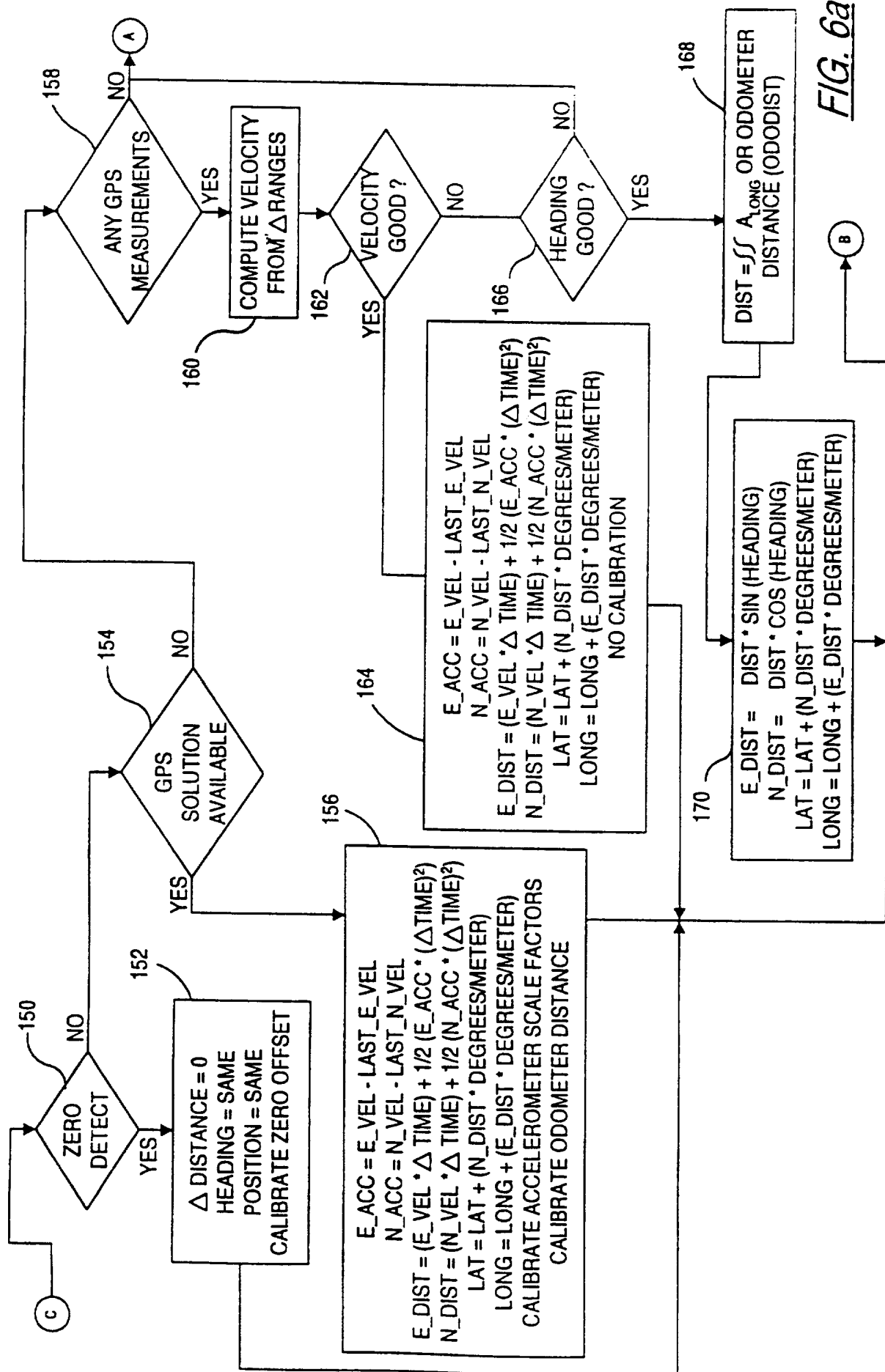
FIG. 3b

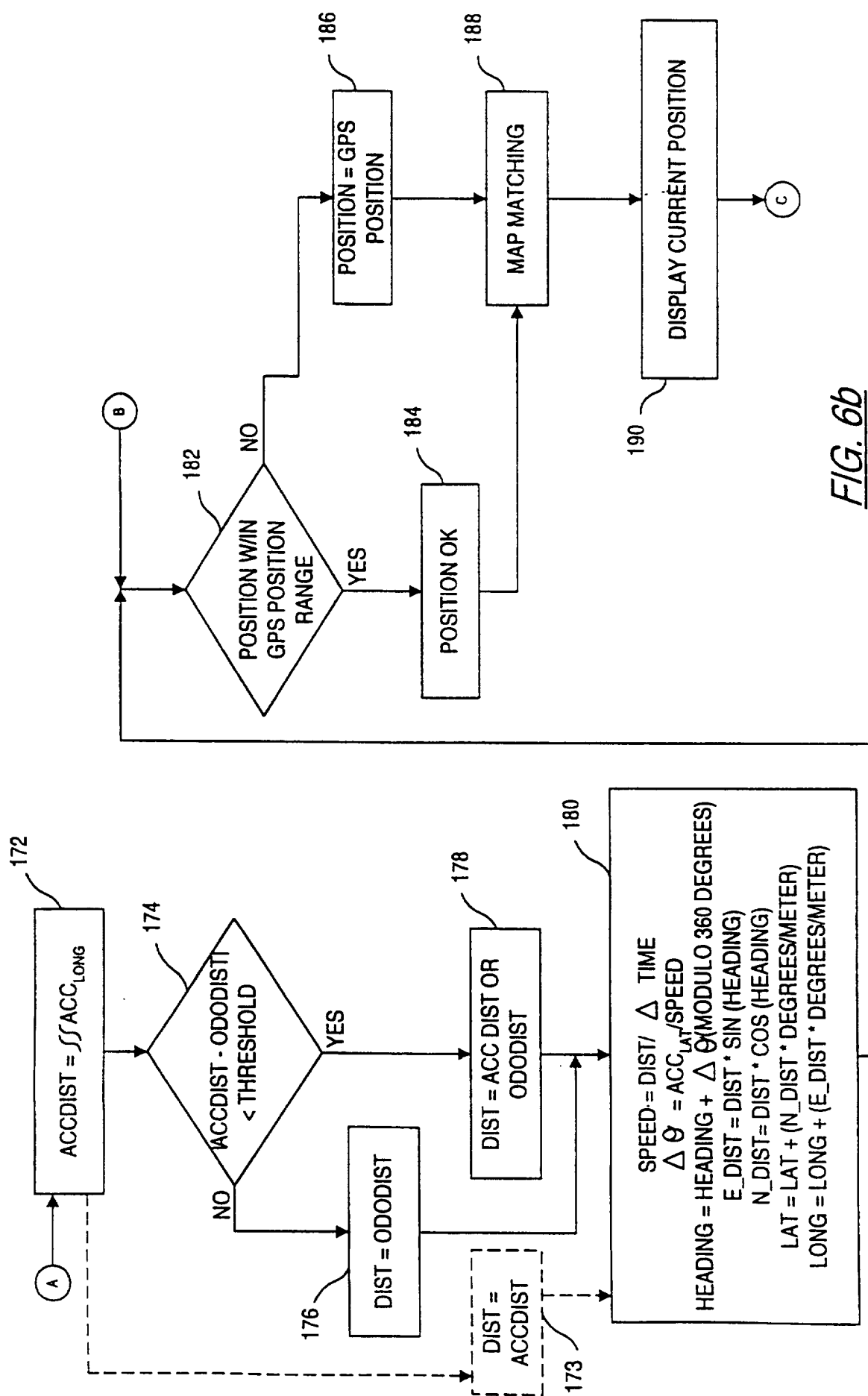
*FIG. 4a*

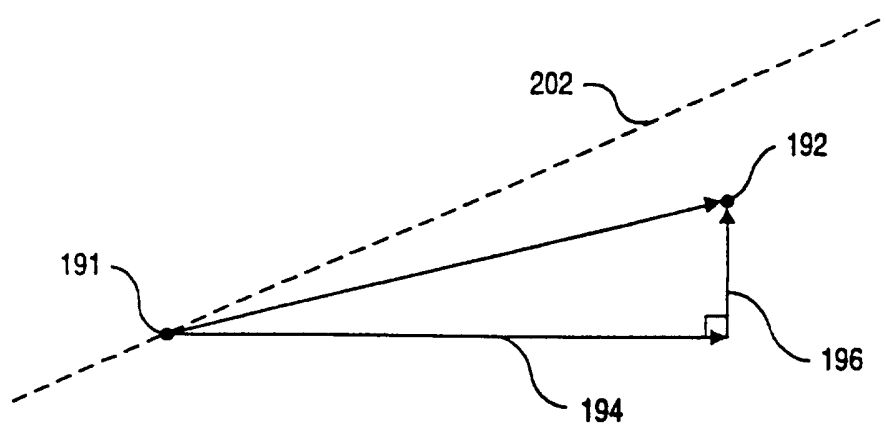
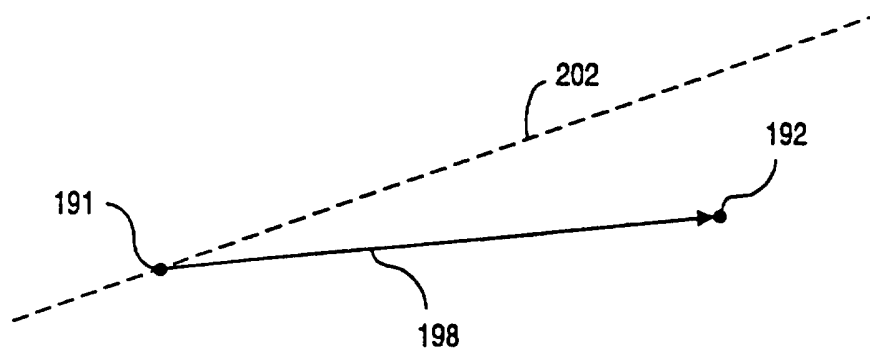
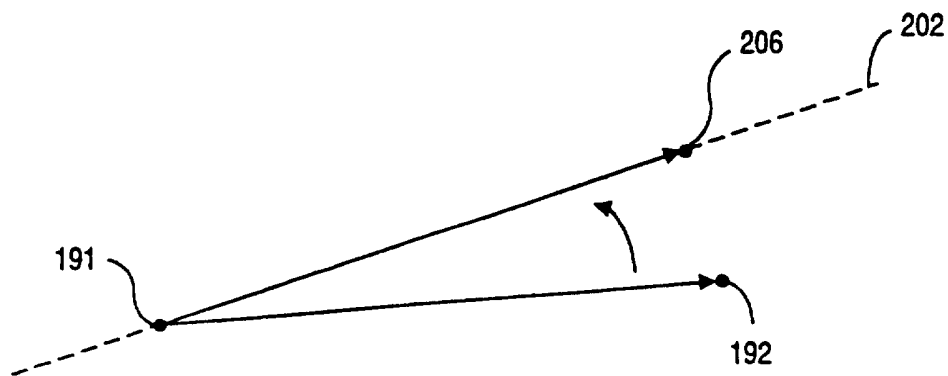
*FIG. 4b*

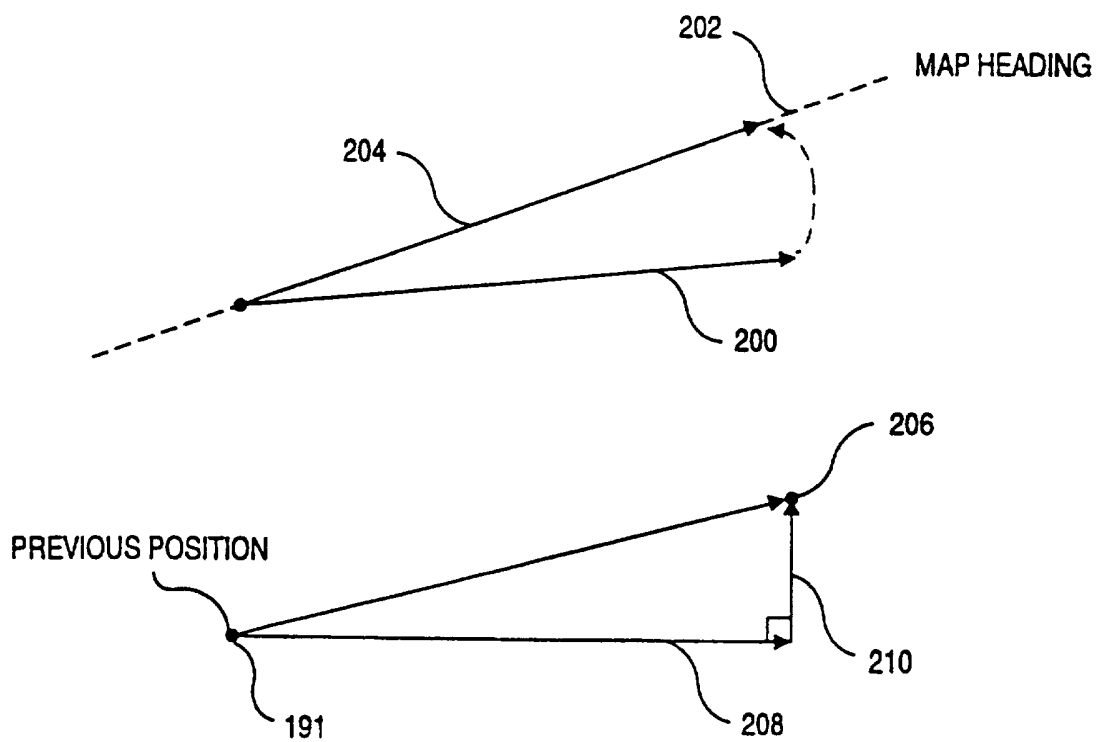
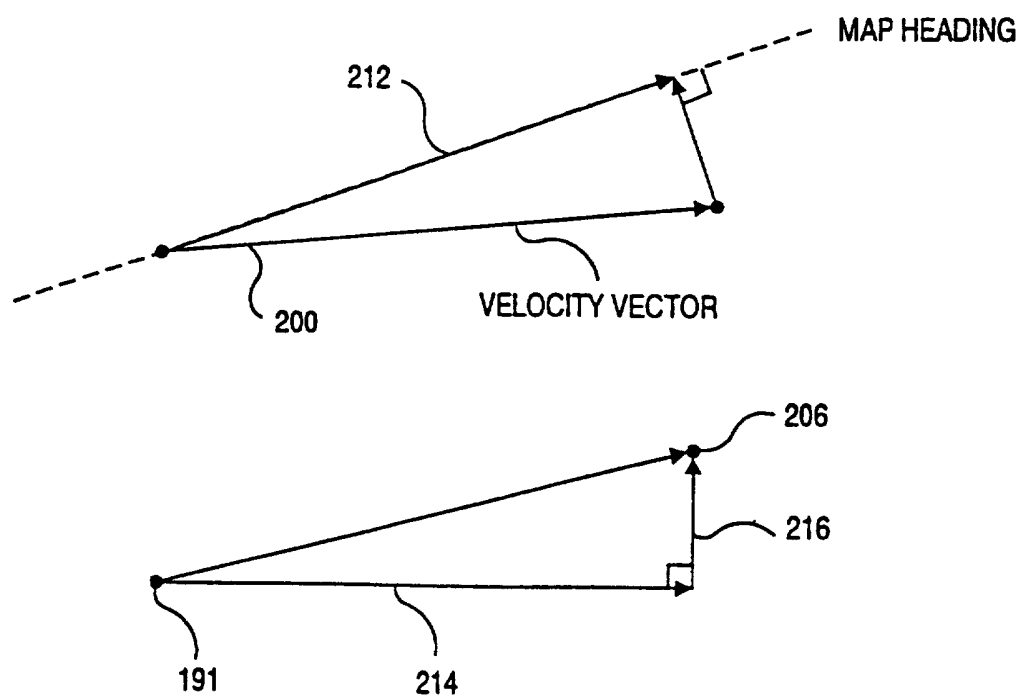
*FIG. 5a*

*FIG. 5b*





FIG. 7aFIG. 7bFIG. 7d

FIG. 7cFIG. 7e