MAP MATCHING AUGMENTED DEAD RECKONING

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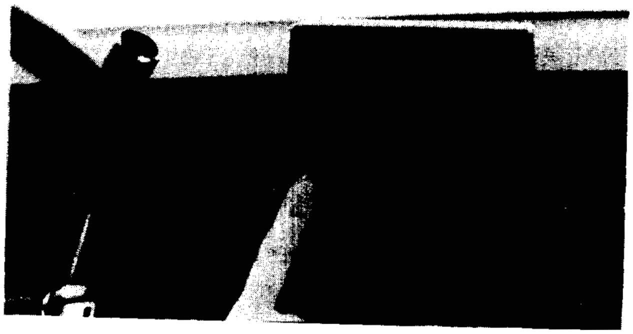

Figure 1

ABSTRACT

Where am I? Where is my destination? How do I get there? These are questions commonly asked by all drivers. The Etak Navigator is an accurate, low cost and informative vehicle navigation system designed to answer these questions.

The Navigator operates on a combination of dead reckoning and map-matching. map matching eliminates the accumulation of error attendant in all dead reckoning systems.

The Navigator utilizes an on-board digital map data base which serves as input for the map matching process for finding the location of selected street addresses and for display.

The combination of navigation and digital map technology opens new opportunities for useful products and services. Future special maps with Yellow Page information and routing will help individual drivers. An office-based map workstation can solve fleet routing problems or serve as the control center for real-time monitoring and dispatching of delivery or emergency service vehicles.

DESCRIPTION

The Etak Navigator provides an electronic road map as shown in Figure 1. The arrowhead car symbol is positioned on the screen to indicate the precise location of the vehicle. As the vehicle moves, the map shifts and rotates "under" the car symbol to maintain accurate position and orientation. With this heading-up moving-map display, the driver assimilates navigation information at a glance. The driver can select different map scales, ranging from a detailed view of the residential streets around him (Figure 2), to a region-wide overview of the freeway system (Figure 3). Roads are prioritized in categories from residential streets to interstates. To limit map complexity, the display shows only major highways in the region-wide scale and adds more detail at larger scales. In this way the display is not cluttered with extraneous data. Similarly, a dynamic labeling algorithm labels those streets most likely to be of interest to the driver. As the car changes direction and the map rotates, the labels are reoriented for easy reading and are always written in a readable font size.

Key to the Navigator's utility is its ability to conveniently locate destinations. A desired destination may be specified by the intersection of two streets, a street and house address, or a point on a single street. A street name index is used by the driver to select the desired street. Multiple choices having different street suffixes (e.g. street, avenue) and city abbreviations are presented when needed to resolve ambiguities. The Navigator uses the map data base to locate the destination and display it as a flashing star along with the current vehicle position on a suitably scaled map. Distance and direction-to-go information are also constantly maintained on the screen as the vehicle moves. In this way, if the driver subsequently selects a map scale which does not contain the destination, range and bearing information is still available.

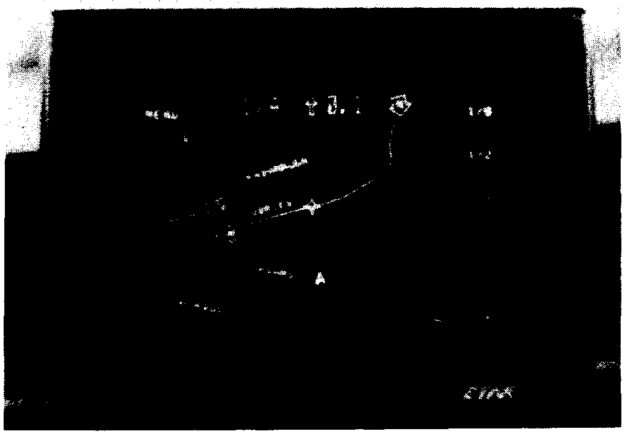

Figure 2

Figure 3

Multiple locations may be entered, permanently stored and sorted by city or distance. With this feature a driver may initially enter all appointments for the day and proceed to them in an orderly fashion.

The Navigator shows the driver the relevant road network between current position and destination. The prioritized road structure enables the operator to select an efficient route and unexpected detours or traffic situations can be easily accommodated.

The Navigator was designed with the multi-task driving function in mind. The high contrast screen provides all pertinent information in one easy-to-view location. The heading-up presentation compliments the driver's intuitive sense of orientation. The prioritized map and dynamic labeling algorithm minimize display complexity enabling the driver to extract pertinent information at a glance. The information is available earlier and more continuously than when relying on passing road signs; giving the driver added flexibility in performing navigational tasks. These factors combined with the clear graphical presentation of the destination, enable the driver to proceed to an unfamiliar destination with efficiency and confidence.

HARDWARE

The hardware includes a compass, wheel sensors, a cassette transport, an electronic display and a processor. The compass is a two-axis flux-gate magnetometer which is digitally compensated during initial calibration. This solid state compass is small, about the size of a pill box, and slips between roof and headliner or is mounted on the rear window.

Wheel sensors comprise strips of rubberized magnetic tape adhered to the inside of two wheels, and small ferrous-cored coils clamped to the suspension. The non-driven wheels are used to avoid slip errors caused by poor traction or high speed driving.

The tape drive is placed within convenient reach of the driver. Program and map data base are stored on specially manufactured cassettes similar to audio cassettes. A cassette stores 3.5 MBytes and reads data at 200 kilobits per second. Each cassette covers an area comparable to that covered by two typical paper street maps. For example, three cassettes cover the greater San Francisco, Oakland, San Jose area. Highways over a larger area are included on each cassette.

A vector display of 770 by 1000 equivalent resolution is presented on either a 4.5 or 7 inch CRT. A vector display is used rather than raster scanning the entire display surface, because the vector display does not exhibit aliasing, offers greater brightness for similar phosphors and excitation voltages and eliminates the requirement for a large bit-mapped memory and a high-speed graphics processor. The CRT housing contains 12 buttons which are soft-labeled for ease of use.

The above components are connected to a trunk mounted processor unit, about the size of a small shoe box and made from a rugged aluminum extrusion. The processor unit houses three boards containing an 8088 CPU, 256K DRAM, 16K EPROM, 2K CMOS static RAM, power supply and supporting digital and analog circuitry. The

Navigator is connected to the vehicle's battery and draws 30 watts with ignition on and 0.12 watts under standby.

The Navigator hardware is capable of near instant-on operation. While the display and program take about one minute to be fully operational, navigation starts within five seconds of vehicle ignition. Current position and calibration constants are stored in non-volatile memory. The program stored in ROM is used to boot in the program from cassette and to navigate in the interim. By storing the program along with the map on cassette, future enhancements in navigation and added features can be easily made available.

NAVIGATION

The system navigates by a combination of dead reckoning and map matching.

Dead Reckoning

The compass measures heading and the wheel sensors are used to measure both distance and relative heading. This relative heading information is combined with the absolute heading information from the compass. Use of two independent heading sources allows the effects of magnetic anomalies and wheel skids to be minimized. A new dead reckoned (DR) position is thus computed each second from the previous position and the new distance and heading information. As with any dead reckoning system, errors in position accumulate in proportion to sensor inaccuracies and distance travelled.

Map Matching

By comparing the vehicle's track to the digital map, the Navigator eliminates the accumulated error that results from dead reckoning. For example, if the vehicle is driving in a straight path and the map contains a nearby straight road with a corresponding heading, the Navigator updates the DR position to a new estimated position along the road. The new position is more accurate than the DR position only in the direction perpendicular to the road. When the vehicle subsequently turns a corner, or drives around a curve, and the Navigator makes a new update, errors are eliminated in the remaining direction.

The example above provides a simplified description of some aspects of the navigation algorithms used. The Navigator uses other parameters in making decisions to update to the road network stored on the map. These parameters include the connectivity of the road network, analysis of ambiguous update options, and accuracy estimates of the current DR position. The key to system performance is proper updating.

Erroneous updates destroy the positional accuracy and may cause the system to become lost (i.e., consistently showing the vehicle on the wrong street). By executing map matching every few seconds, significant DR errors are not allowed to accumulate. In addition, the algorithm is designed only to perform map updates when reasonably certain the update will be correct. This enables the system to work well even when the vehicle is driven off the mapped roads, for example in parking lots, driveways or on new streets.

Performance

Navigator performance was evaluated quantitatively on over 40,000 miles of test driving in 15 vehicles and qualitatively in over 400,000 miles in 50 vehicles. Samples collected at random intersections showed an average 50 foot accuracy while the Navigator was matched to the road network. A more significant measure is a demonstrated average in excess of 120 miles between map matching mistakes requiring manual reset. Once lost, the Navigator can be reset in under 20 seconds. Keeping the Navigator on-track is thus less time consuming than operating a car radio.

Calibration

The Navigator is initially calibrated during installation. The installer is instructed to perform simple driving maneuvers during which sensor measurements are processed to compute compass compensations for the vehicle's magnetic effects and distance coefficients for each wheel.

The Navigator uses comparisons between the map and the DR track to continually improve the calibrations during routine driving. For example if the DR track generally is "long" compared to the map, the wheel calibration is corrected. This compensates for tire diameter changes due to tread wear. The compass is likewise continually corrected through comparisons with known headings from the map data base.

DIGITAL MAP DATA BASE

The Navigator requires map information to update its dead reckoning display, to compute destination positions and for display. In order to meet the many map requirements, a topologically structured digital map data base is used. Such a system defines significant points, lines and areas, along with their incidence relations. Unlike a digital map image, this map structure can be compactly stored and easily searched, modified, and manipulated. Cultural and geographic features can be associated to any data item. Examples include elevations linked to points, street names linked to lines, and terrain features or city names linked to areas.

To support the Navigator, Etak is developing a digital map data base covering the USA. The Census Bureau's digital map file is used as the primary source of street name and address information. Coordinates are obtained from either United States Geological Survey topographical maps, or from aerial photographs. Approximately one half of the roads in US metropolitan areas have been digitized using a mapping process which provides approximately a three fold improvement in productivity over conventional techniques.

An accurate and up-to-date nationwide digital map data base has many applications beyond in-vehicle navigation. Applications include routing, paper map publishing, matching address fields to coordinates, enhanced Yellow Pages and aids to marketing, billing, field asset management and travel itinerary functions.

AUTOMATIC VEHICLE LOCATION

Perhaps the most direct application of the data base is in linking a fleet of Navigator equipped vehicles to a central control or dispatch center. By connecting the Navigator's optional RS232C interface to a digital radio, position and status messages can be automatically radioed to headquarters. There with a map workstation, the dispatcher can monitor in real time the whereabouts of the fleet, take new calls and quickly and reliably dispatch the closest vehicle. The dispatch instructions can be conveyed by radio back to the vehicle to appear unambiguously on its screen - again aiding response time.

In non-real time applications a map workstation can be used to input a fleet's daily deliveries. Clustering and routing algorithms can aid the dispatcher in efficient utilization of the fleet. Once a vehicle's route is established it may be down-loaded to a memory cartridge, given to the driver and plugged into the vehicle's Navigator for efficient, hastle free deliveries.

SUMMARY

The Etak Navigator has been described with emphasis placed on its accurate navigation, low cost design achieved through innovative use of digital maps, and its informative display approach. The Navigator is indicative of taking the technology and information explosion onto the nation's roads. Future applications are many and varied; each in part will answer the questions; Where am I? Where is my destination? How do I get there?

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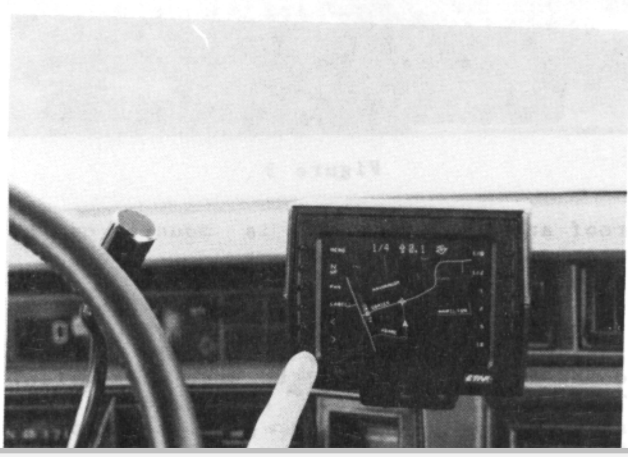

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