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The Author founded Etak Inc. in May 1983, and invented the navigational algorithm on which vehicle the navigation product is based.

The previous five years were spent as a Research Engineer at SRI International. There he was the principal investigator and manager of various programs resulting in innovations in ultra-precise radio navigation, underwater optical instrumentation, radar design, spectrum surveillance systems, RF circuit design, and digital signal processing.

The Author's interests and skills in navigation stem from his pastime activities as well, being well known as a world class offshore yacht racing navigator.

The Author has Navigated and won two Transpac Yacht Races, the Southern Ocean Racing Conference, the Bermuda Race, and navigated the highest scoring American boat in the 1981 Admiral's Cup. He built navigational computers that were instrumental in several of these victories.

A NOVEL APPROACH TO AUTOMOTIVE NAVIGATION AND MAP DISPLAY

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A novel approach to automotive navigation and map display is described. In order for a navigation and display system to be both cost-effective and useful in automobiles, solutions are needed to problems in navigation, map data base, data storage, and display.

A self-contained navigation technique is used, utilizing a compass and wheel sensors, a digital map data base, and an adaptive self-calibrating navigation algorithm. A prioritized map data base structure and a rugged digital tape deck solve problems of map data storage and distribution. Finally, a vector graphics CRT enables a flexible, high-resolution yet low-cost display to be implemented.

A functional description of the Etak Navigator is presented along with a description of its basic hardware and software components. Alternate approaches and future applications are summarized.

FUNCTIONAL DESCRIPTION

The Etak Navigator provides an electronic map display for use in vehicles. .It is useful for anyone dependent upon instructions or paper maps for finding a destination.

The Navigator has a graphic display which continuously shows a vehicle's position on a map of the surrounding area (see Figure I). An arrowhead symbol in the center of the display represents the position of the vehicle and points up towards the top of the map, indicating the direction the vehicle is heading. As the vehicle is driven, the map rotates and shifts about the arrowhead accordingly. Different size streets are represented by lines of varying brightness with streets and key landmarks labeled.

The operator can change the map's scale. At the most detailed scale, even the smallest streets are displayed and labeled. As the display scale is increased or decreased, features and labels appear and disappear in an orderly fashion according to their priority.

The driver selects destinations by entering a street address and scrolling through an index to choose the street name. Alternately a destination can be entered by selecting two intersecting streets. The Navigator then displays a map on which both the car and the destination are shown. The direction and distance to the destination are continuously indicated, which helps orient the driver if the scale of the map display is changed so that the destination is no longer shown on the screen.

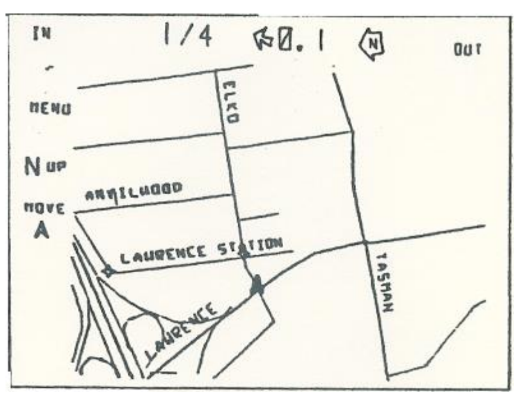

Figure I. MAP DISPLAY

HARDWARE

The Etak navigation system is packaged in three major parts: a processor, a cassette tape drive, and a display. The electronics unit can be mounted in the trunk or other accessible location. The tape drive is small enough to mount under the dashboard
or in the glove compartment. Access to the tape drive is required only to change cassettes.

In addition, a solid state compass and two wheel sensors are required. The compass is approximately half the size of an audio cassette and mounts either inside the vehicle's roof or on the rear window. Sensors are installed on two non-driven wheels. The wheel sensors are used not only to measure distance travelled, but also differentially to measure relative turning.

Cassettes store map data for use by the Navigator. Each cassette covers an area comparable to that covered by two typical paper street maps. For example, one cassette allows navigation on any street throughout one third of the San Francisco Bay Area. Highways over an extended area are also included on each cassette.

Processor

The Processor consists of three circuit boards mounted in an aluminum extrusion which serves as a rugged enclosure and as a heat sink. The processor contains a microprocessor system based on the 8088, including 256 kilobytes of dynamic RAM, 16 kilobytes of ROM, and 2 kilobytes of non-volatile RAM.

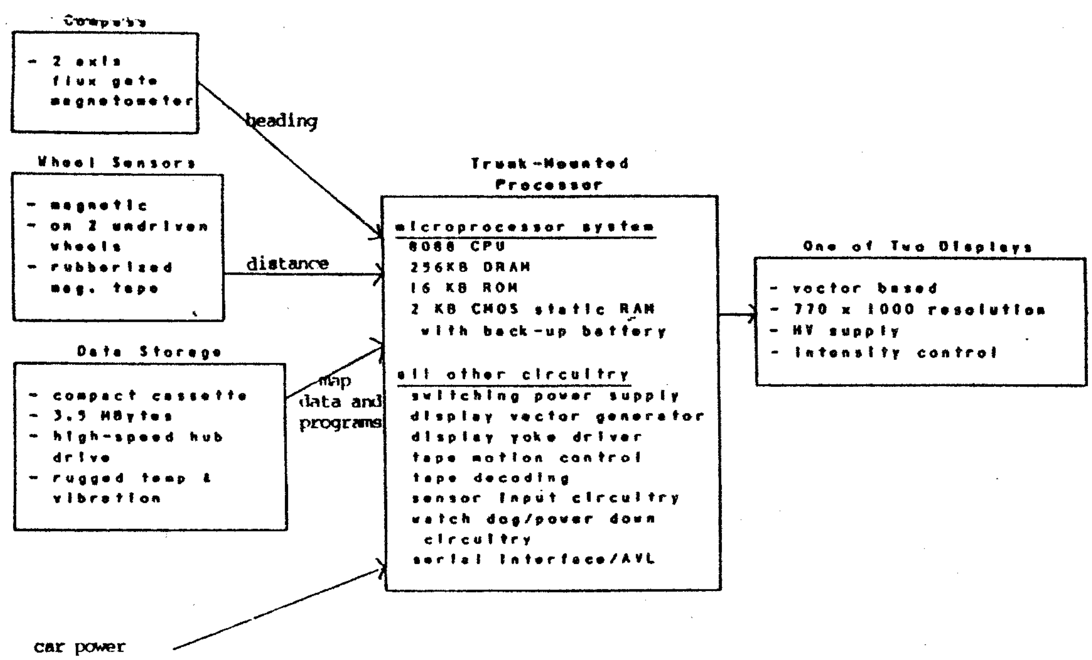

Figure II. HARDWARE BLOCK DIAGRAM

Data Storage

Specially manufactured cassettes, similar to audio cassettes, are used for map data and program storage. The primary advantages of this approach are: 3.5 Megabyte storage capacity, low media cost, low drive cost, tolerance to the automotive environment, tolerable access time, and present availability.

Display

A vector display approach is used in which the beam actually draws the map and writes the characters rather than raster scanning the entire display surface. The vector display does not exhibit aliasing ('jaggies' seen on diagonal lines of bit mapped displays) and offers greater brightness for similar phosphors and excitation voltages. More importantly, a vector display eliminates the requirement for a large bit-mapped graphics memory and a high-speed graphics processor to write and rotate map displays into the bit-mapped memory.

SOFTWARE

The programs run by the Navigator are loaded from the map cassette. The system ROM is used to boot the main program, for navigation while booting, and for diagnostics. This approach provides flexibility to offer future cassettes with enhanced navigation, special databases, and applications.

Navigation

Dead Reckoning:

Dead reckoning is the ancient technique of advancing a known position from measured courses and distances. The Navigator uses dead reckoning, with wheel sensors to measure distance, and differential wheel sensors and compass to measure heading. Each wheel sensor consists of magnetic tape which is applied to the inside of the wheel rim and a sensor assembly which is clamped to the suspension. The non-driven wheels are used rather than the driven wheels, which are more subject to errors during high-speed driving or driving in conditions of poor traction.

An adaptive filter combines relative turn information from the differential wheel sensors with absolute heading information from the compass. This signal processing allows effects of magnetic anomalies and wheel skids to be ignored. As with any dead reckoning system, errors in position accumulate proportionally to the distance travelled and proportionally to the inaccuracy of the sensors.

Augmented Dead Reckoning:

The Navigator takes advantage of the fact that automobile drivers tend to drive on roads if there are roads nearby. 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 drives in an S curve, and the map has a nearby road with a corresponding S curve, cross-correlation between the vehicle's dead reckoned (DR) track and the S curved road on the map can yield an accurate positional update.

In another 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 on the road. The new position is more accurate than the old DR position only in the direction perpendicular to the road. No information is available to improve the positional accuracy in the direction along the road. If the vehicle subsequently turns a corner, or drives around a curve, the Navigator makes a new update in the direction perpendicular to the new road.

The above examples provide a simplified description of some aspects of the navigation algorithms used in the Navigator. The Navigator also uses other parameters to make 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 estimates of the accuracy of the current DR position. The key to system performance is proper updating. The algorithm is designed to use all information available in the map to make certain of update correctness.

Erroneous updates destroy the positional accuracy and may cause the system to become lost (i.e. consistently showing the vehicle on erroneous streets). Proper updates cancel the error accumulated in dead reckoning. Dead reckoning with map augmentation thus shows error statistics which are similar to radio navigation: independent of distance travelled. The Navigator exhibits positional error of under 50 feet regardless of distance travelled as long as updates are performed properly.

Extensive testing throughout the San Francisco Bay Area has shown the system will average more than 120 miles between loss situations. Once lost, the system can be easily corrected, taking the driver less than 20 seconds. The net result is that keeping the Navigator 'aligned' is less time consuming than operating a car radio.

<u>Self Calibration:</u>

The Navigator uses comparisons between the map and the DR track to continually improve the calibration of both the wheel and compass sensors. For example if the DR track generally is 'long' compared to the map, the wheel calibration will be corrected. This avoids the effects of tire diameter changing due to tread wear.

The compass is likewise continually corrected through comparisons with known headings from the map data base. The compass is corrected for both the permanent magnetism of the vehicle (hard iron) and induced magnetism in the vehicle (soft iron).

<u>Display:</u>

The display is adaptively configured by an algorithm designed to select only the information that the driver is likely to need, and to present it in a form which is readable at a glance.

<u>Limited Complexity:</u>

The driver is able to change the scale of the map display thereby adjusting the area shown. As the scale of the map is changed, road priority information encoded in the map data base is used to select the roads to be displayed, and still keep the display complexity limited.

<u>Selective Labels:</u>

Only the streets most likely to be of interest to the driver are labeled. These include cross-streets ahead, high priority streets ahead, the street being driven, and streets near a selected destination. Labels are always written upright and at a constant size, regardless of map scale.

<u>Heading Up Presentation:</u>

The heading up orientation of the display causes the display to correspond to the driver's orientation and therefore align with what is seen out the window. This allows the driver to quickly 'grasp' information sought from the map display.

<u>Database:</u>

The map is stored as a vector database, and not as images. This is necessary to allow the navigation algorithm to use the database for map matching. Additionally, the display algorithm requires access to the map as a database to find destinations and to format displays as a function of display scale, orientation, and road density. If the map were stored as images, storage requirements would be higher and use of the map for functions beyond display would require significant additional processing.

MAPPING

Driven by the requirements of vehicle navigation, Etak is developing a digital map data base covering the USA. Approximately one fourth of the roads in the metropolitan areas have been mapped. The Census Bureau DIME file is a digital file containing rough coordinates, street names, addresses, and other data useful for taking a census. Etak uses the Dime file as the primary source of street name and address information.

Coordinates are principally obtained from either United States Geological Survey topographical maps, or from aerial photographs. Etak has developed a mapping process which provides approximately a three fold improvement in productivity per mapping person hour over conventional techniques.

A nationwide digital map database may have other applications beyond real time in-vehicle navigation. Applications have been suggested in fields of routing, paper map publishing, matching address fields to coordinates, and to enhance the utility of Yellow Pages databases.

ADDITIONAL APPLICATIONS

The navigation system described in this Paper has the characteristic that the in-vehicle system knows the vehicle's position. To use this navigation approach for an automatic vehicle location (AVL) system requires only the addition of telemetry between the vehicle and its dispatch center. To provide for this, the Navigator can optionally be equipped with a general purpose asynchronous (RS232C) interface. Using a sensible reporting period, and compressed messages, this adds little loading to a data telemetry system.

A vehicle equipped with a navigation system may have other applications for the computer system and high-resolution display. These resources can be used as a mobile data terminal. The driver can send and receive text messages as well as receive destinations from the dispatch center. The map database can be extended to include information on roadside services and even Yellow Pages information. The transmission of traffic information has also been suggested to enable areas of slow traffic or hazardous conditions to be indicated on the system display.

OTHER APPROACHES

A number of other approaches to vehicle navigation have been suggested and in some cases implemented. Simple dead reckoning systems without map updating have been used to display the range and bearing to a destination after the driver enters both the present location and the coordinates of the desired destination. These systems accumulate error and occasionally present the driver with a dilemma in which the driver finds obstacles in the indicated direction. Rivers are an obvious example.

Signpost navigation is an approach that is in use for AVL systems. Transmitters, or in some cases receivers, are mounted at intersections throughout the area of interest. As an instrumented vehicle travels by a signpost, this fact is telemetered to the dispatch center. Some signpost systems use dead reckoning between signposts. In general, the high installation cost of signpost 'systems limits their use to small areas or fixed route applications.

Several radio navigation systems are in use in AVL systems. Loran and wideband pulse trilateration are two examples with GPS-C expected in the future. The accuracy of these sytems is measured in hundreds of feet, which makes them appropriate for use in AVL systems in which the dispatch center only needs to know the approximate location of the vehicle. Greater accuracy is required when vehicle position is displayed on large scale map displays.

If a navigation system is to be helpful in making driving decisions, the Navigator must show the vehicle at an intersection when the vehicle is actually at that intersection. This requires 50 foot accuracy.

FUTURE IN NAVIGATION

We are only now beginning to see the plurality of applications for the currently available Navigator. These include such simple but valuable aids to drivers as showing their destinations draw nearer as they proceed, making wrong turns immediately evident, and taking street names out of the night time dark. Navigator equipped drivers confidently enter labyrinthine neighborhoods, turn onto streets lacking signs, and drive to an address without straining to read house numbers for blocks on end.

The present Etak Navigator offers acceptable navigation performance at a remarkably low price. Improved navigation algorithms currently under development, coupled with increased computation and memory resources available at ever-dropping prices will allow future navigation systems to be designed that perform still better at even lower cost.

The use of the Compact Disk Read Only Memories (CD-ROMS) for data storage will allow vast amounts of map and other data to be available with relatively fast random access. AVL systems will take advantage of the ability to send destinations and routes to the drivers, making fleets less sensitive to rapidly changing demands, and to illness and turnover among drivers.

New sensors will become affordable which will still further improve navigational performance and open other applications. For example, integration of a GPS receiver would allow use for extensive off-road travel and for applications in mapping and surveying.