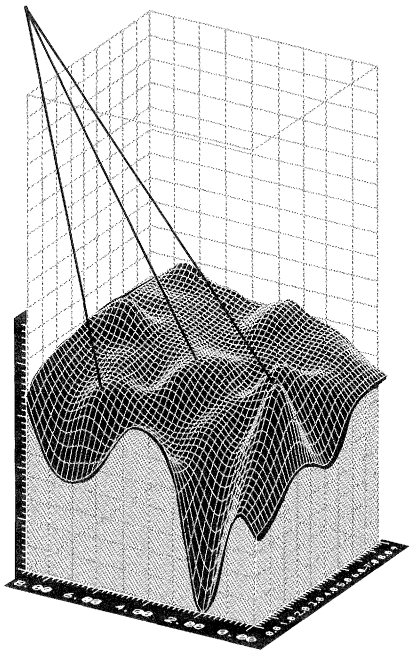

GPS and Vehicle Location and Navigation

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"Innovation" is a regular column in GPS World *featuring discussions on recent advances in GPS technology and its applications as well as on the fundamentals of GPS positioning. In our July/August 1990 column, we looked at the combination of GPS and the electronic chart for navigating at sea. This month Ed Krakiwsky, professor of geodesy and vehicle navigation systems at The University of Calgary, tells us about an equivalent system for cars and trucks.*

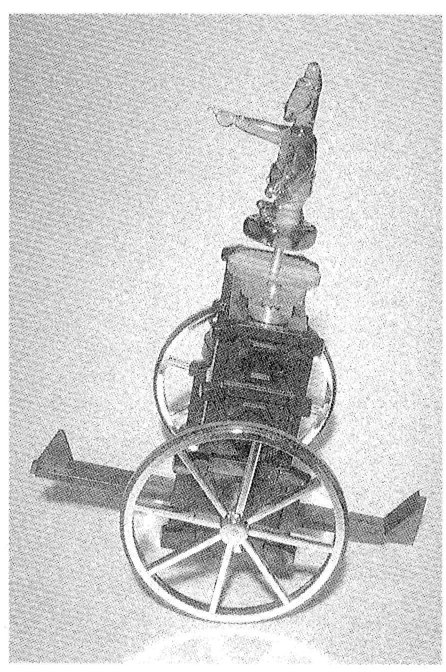
This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. As always, we welcome your comments and suggestions of topics for future columns.

The Global Positioning System (GPS) is having a profound impact on the development of automatic vehicle location and navigation (AVLN) systems. Such systems enable a user to

- position a vehicle using signals from satellites and information from onboard relative positioning (dead reckoning) devices,
- call up a digitized electronic road network map of the area in question,
- plot the position of the vehicle on the display and see the vehicle's location relative to a destination, and
- obtain instructions, visually or aurally, on how to proceed along a best route automatically chosen to fulfill a set of criteria. Figure 1 illustrates the concept behind such a system.

AVLN systems that incorporate GPS satellite technology are more robust and user-friendly and will prove to be cost-competitive with the purely land-based AVLN systems. The reason for the good news on this cost-related fact is that several manufacturers are about to produce "GPS engine" boards that can readily be integrated into AVLN systems as simply another sensor. The projected 1991 cost for these "GPS engines" is about $2,000, and the cost is predicted to drop to a few hundred dollars toward the end of the decade.

The user community (e.g., emergency and security vehicles, vehicles carrying hazardous goods, construction fleets, delivery fleets) is lined up waiting to purchase AVLN systems. They are, however, waiting for several developments: a drop in cost; more user-friendly and robust systems; further development and refinement of digital road network maps and route-related information databases; and development of customized software to suit the specific needs of each user group.



E.J. KRAKIWSKY PHOTO

Chinese South Pointing Carriage (model created by Sumimoto Electric Industries Ltd).

ANCIENT AVLN SYSTEMS

The earliest AVLN systems date back some 2,000 years to the ancient civilizations of Egypt, Greece, Rome, and China. The most famous of these is the Chinese South Pointing Carriage (see photo), which is credited to Chang Heng (circa 120 A.D.) and Ma Chün (circa 255 A.D.). This particular ancient AVLN system was chosen for historical perspective because the principle of *differential odometry* used then is still being used in the AVLN systems of today.

By keeping track of how much more (or less) one wheel moves than the other, the ancient Chinese could keep track of the change in heading and distance of a two-wheeled carriage as it moved across vast, featureless tracts of land. This motion was mechanically compensated for, thereby keeping the outstretched arm of a statue mounted on the carriage continuously pointed toward the south or some other chosen reference direction.

MODERN AVLN SYSTEMS

A generic AVLN system that typifies most modern systems is shown in Figure 2. Like much of today's advanced positioning technology, an AVLN system consists of both hardware and software components. The hardware consists of a positioning module, a computer (microprocessor) with input and output devices, and a communication device such as a digital, cellular, UHF radio (not shown in the figure). The software consists of a control program that links the positioning component to various databases, such as the road network and en route–related information, and polls vehicles for position reporting.

When no transmission is made from the vehicle, we have what is normally called an *autonomous* AVLN system; in other words, only the question, "Where am I?" is answered. However, when the vehicle's position is transmitted to a central dispatch office, the question, "Where are you?" is answered. This kind of system is often referred to as a *dispatch* system. A third AVLN system is a *route information* or *guidance* system. Such systems answer the question, "How do I get there?"

Route information systems draw on special databases and overlay that information on the digital road network map. Such data include, for example, turn restrictions and one-way streets. Real-time traffic informa-

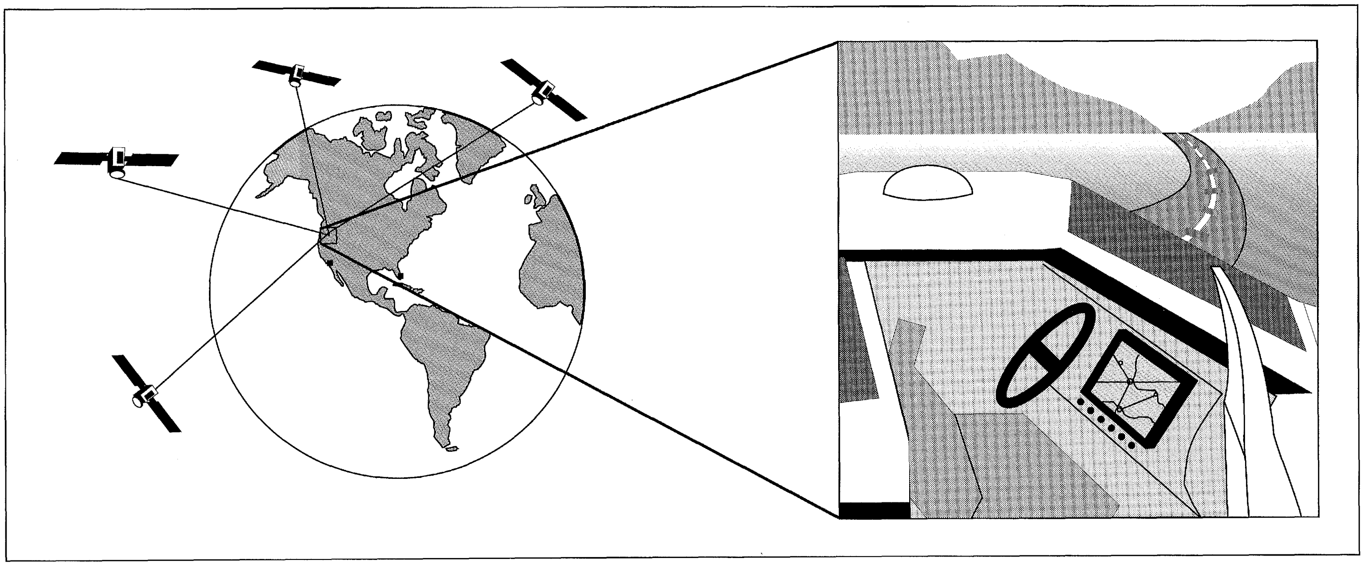


Figure 1. Concept of an automatic vehicle location and navigation (AVLN) system

tion is also needed to minimize route travel time. This feature is currently being implemented in Europe through the Radio Data System, in which traffic information in digital form is "piggy-backed" on normal broadcasts from FM radio stations using inaudible subcarrier modulation. The information is decoded by the radio and displayed. A significant percentage of new car radios in Germany have this feature and thus are ready to be interfaced with AVLN systems.

A fourth type of AVLN system, the *inventory* system, operates as a mobile coordinate tagging system. It utilizes differential observations between the vehicle and a fixed reference station to improve position accuracy.

The convergence and focusing of several technologies in a systems sense, namely digitization of information, satellite technology, computer power and storage, and communications technology, has facilitated the development of these modern AVLN systems.

It was not until the early 1970s that AVLN system development underwent a resurgence. The resulting systems used terrestrial dead-reckoning sensors coupled with map-matching techniques in which the vehicle's dead-reckoned path is correlated to an onboard digital map of the road network. The map coordinates are then used to position the vehicle at certain identifiable places, such as turns at intersections. In this way the vehicle's location is constrained to the road network.

In the United States, early efforts included the Automatic Route Control System (ARCS), developed by Robert L. French in 1974 for the delivery of newspapers, and the Fleet Location and Information Reporting System (FLAIR) completed by Boeing in 1977 for the tracking of police vehicles in St. Louis. In the United Kingdom, the LANDFALL (Links and Nodes Data Base for Automatic Land Vehicle Location) system was developed by GEC-Marconi in 1978 for the tracking of police vehicles in London.

Two waves of AVLN system development followed this period of resurgence. Both waves happened almost simultaneously but each had its own philosophy. One wave of development was terrestrially based in that it relied heavily on dead reckoning (the use of terrestrial sensors) and map matching, while the second wave employed GPS satellite technology. The absolute positions (coordinates) of the vehicle come from the map database in the former group, whereas in the second grouping the absolute positions come from GPS and, to a lesser extent, from the map database via map matching.

About 40 systems being built worldwide, including the Etak Navigator in the United States and CARIN (Car Information and Navi-

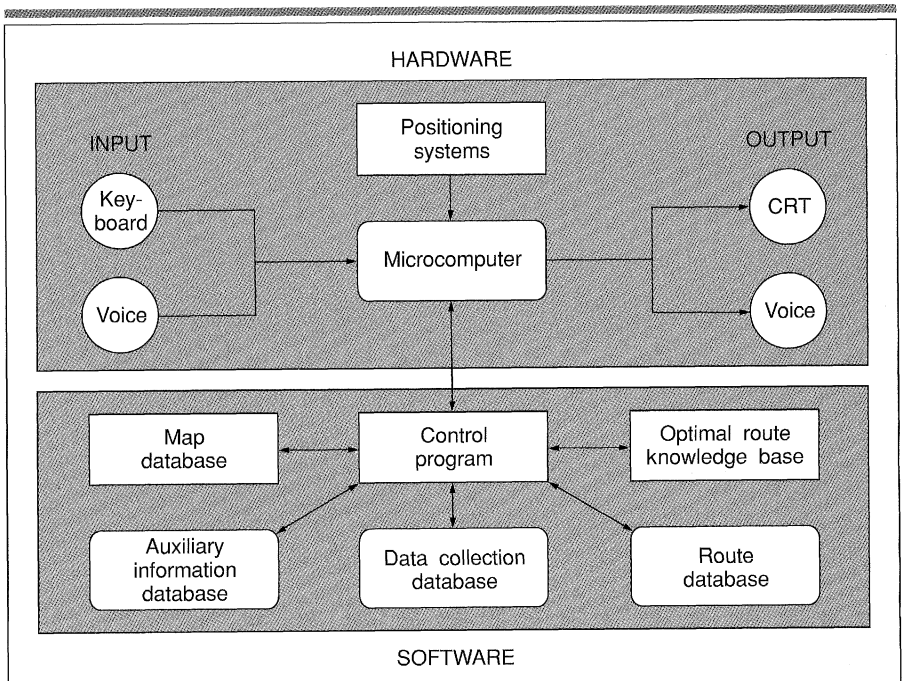


Figure 2. Components of a generic AVLN system

Table 1. Some GPS-based AVLN systems

Country	Date of publication (entry)	Name of system	Originator/ company	SYSTEM TYPE Auton- omous	Dispatch	Route information (guidance)	Inventory (DGPS)*
Japan	1983	DRIVE GUIDE	Nissan Co.	x			
	1983	MAZDA SATNAV	Mazda Co.	x			
	1985	MMC SATNAV	MMC Co.	x			
	1985	SUZUKI NAV	Suzuki Co.	x			
	1985	TOYOTA FX-V	Toyota Corp.	x			
	1986	TELECOM VAN	Mazda Co.		x		
	1987	MADIX-III	Nippondenso Co.	x			
	1989	MAZDA SCNS	Mazda Co.	x		x	
	Unknown	NISSAN GPS NAV	Nissan Co.	x	x		
USA	1983	CLASS	Chrysler Corp.	x		x	
	1984	NAV TEST CAR	General Motors	x		x	
	1988	Ashtech VTS	Ashtech	x	x	x	x
	1990	NAV-COM AVLS	Nav-Com Inc.		x		
	1990	Trimble AVLS	Trimble Navigation Ltd.	x	x		x
Canada	1988	AVLN 2000	Univ. of Calgary	x			
	1989	ALTA INV System	Alberta Transportation/ Univ. of Calgary				x
	1990	NavTel 2000	Pulsearch Navigation Systems Ltd., SaskTel Mobile Communications	x	x		x
Germany	1989	Location Systems	Nukem GmbH		x		
	1989	VELOC	DMT Marinetechnik				
UK	1990	NAVSTAR IVN	Navstar		x		

*DGPS = Differential GPS to improve accuracy.

gation System) by Philips in The Netherlands, fall into the first group. Some of these systems are based on terrestrial radio signals such as those from the Decca, Omega, and Loran-C navigation systems.

TERRESTRIALLY BASED AVLN

Even though a few of the terrestrially based AVLN systems are surprisingly robust in that one can travel many miles before the system gets lost, they have two serious shortcomings that may impede their mass acceptance. The first problem is the need to initialize the system at a starting location before commencing travel. This means that the user must input the location of the vehicle via known coordinates or an address. This will be troublesome for the typical user — many people don't know how to set the clock on their VCRs.

The second problem is the mismatching of the vehicle's dead-reckoned path to a nearby parallel street when the position error grows too large. This lost situation will also occur when venturing into an uncharted area or a parking lot or after a ferry ride. Clearly, these terrestrially based systems require not only complete, highly reliable, and accurate maps, but also overlaid address information that has a high degree of integrity and reliability because it is used to initially position the vehicle. If this initial position is wrong, the vehicle eventually gets lost because the map-matching algorithm gets confused when it is unable to correlate a traced-out path with any of those in the map database.

Furthermore, compasses used for dead reckoning in these systems are also problematic because the magnetic field surrounding the vehicle is constantly changing due to metal in overpasses, interference from passing vehicles, and simple actions such as closing the door of the vehicle. In short, purely terrestrially based systems have not proven to be as robust as necessary for the mass consumer market.

GPS-BASED AVLN

Let's now examine how GPS can make AVLN systems more accurate and user-friendly. First of all, GPS yields absolute positions (coordinates), say, every second. The location of the vehicle is obtained by superimposing the coordinates on a digital map on board the vehicle, or by digitally communicating the location to a dispatch center using the same map. Thus, errors in the map will not cause the vehicle to get lost. Moreover, with GPS, initialization is performed automatically when signals are available. When signals are not available, the previously determined position is used to initialize the system.

GPS satellite radio signals may be temporarily blocked while a vehicle is in "urban canyons," tree-covered areas, and tunnels. Although a GPS-only AVLN system may be able to coast through such periods if they are short, to operate with a higher degree of reliability the GPS component must be integrated with terrestrial sensors such as odometers (for change in azimuth and distance), compasses (for azimuth), rate gyros (for change in azimuth), altimeters (for height), and map matching. The selection of the sensors to be integrated is part of the system design process and is dependent, in part, on the environment within which the system is to function.

Table 1 lists most of the GPS-based AVLN systems that have been developed. It includes both those that employ only GPS and those that combine GPS with other sensors and map matching.

Combination systems work in one of two ways: A switch from one sensor to the other is made after ascertaining which sensor is yielding the best solution, or a filtering approach is employed in which the information from each sensor is taken along with its estimated uncertainty and combined with all the other sensor information to yield a best, unbiased solution with minimum uncertainty. In the former method, a knowledge-based artificial intelligence approach is used to make decisions automatically in real time. The systems employing the second approach are distinguished from each other by the array of sensors used, the type of filter selected, and the manner in which the filter is implemented.

The Mazda Satellite Car Navigation System is an example of the first method, while the AVLN 2000 system is an example of the second. These integrated, multisensor AVLN systems incorporating GPS typically yield the vehicle's coordinates to an accuracy better than 15 to 20 meters (standard error), which is deemed satisfactory for navigating to a particular address.

OUTLOOK

Looking back, we can see that the 1970s and 1980s marked the dawn of modern AVLN systems. Looking ahead, we can already see that the 1990s will be the decade in which AVLN systems will blossom at the high end of the market. In Japan, Pioneer has already brought one onto the market for about $4,000, and Mazda's system is priced around $5,000.

The year 2000 — when "GPS engines" are mass produced, along with "mobile digital communication devices," and every road intersection in the developed world is geometrically and topologically mapped — will mark the beginning of the age of widespread acceptance and usage of AVLN systems at the low end of the market. The cost of these AVLN systems will be no more than that of top-of-the-line car radios. Too, AVLN will be totally integrated into car and home information systems.

The 1990s will be the decade in which AVLN systems will blossom at the high end of the market.

Automatic vehicle location and navigation systems are but one component of a broader movement known as intelligent vehicle highway systems (IVHS) in North America and road transport informatics (RTI) in Europe. These systems will radically change the way we drive, making highways, cars, and, hopefully, their drivers a lot smarter. The Global Positioning System will play an important role in bringing these systems to fruition.

ACKNOWLEDGMENTS

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