Automobile Navigation System Using Beacon Information

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ABSTRACT

A navigation and communication system utilizing roadside beacons is currently under development. This paper outlines the functions and infrastructure of the system (named RACS), describes the in-vehicle equipment developed by TOYOTA and reports the results of field tests conducted in the Tokyo/ Yokohama area. The system is considered to have considerable potential for reducing and improving road safety as well as being of great benefit to drivers.

INTRODUCTION

Driving an automobile today is becoming increasingly complex: The extension of the road and highway network makes navigation more difficult, while the tremendous increase in vehicles has in many areas led to chronic traffic congestion. In order to promote road safety and ease congestion, an on-board navigational / informational system based on roadside beacons will soon become indispensable. In this paper, the authors present a prototype vehicle system developed to operate in conjunction with the communication network currently being established in Japan as a co-operative undertaking by the Public Works Reseach Institute of the Ministry of Construction and 25 private companies. The system provides the driver with such essential information as present location and traffic conditions, plots optimum and alternative route to the destination and enables limited two-way communication to be made. Field testing of the system is still being conducted. Here the results of the first two tests are discussed.

OUTLINE OF RACS

Road/Automobile Communication System (RACS) is a network providing various services by means of roadside devices and a vehicle mounted computer. Fig.1 shows the concept of RACS, which is based on intermittent narrow band digital data communication with limited range. Two-way individual communication (i.e. private communication) for personal needs is currently under development and has not yet been subjected to field testing.

Main Functions

The main functions of RACS are as follows.

Detection of vehicle location The dead reckoning navigation device determines the present location in real time using the vehicle directional and distance sensors and corrects any error when a signal is received from a roadside beacon. The location is continuously indicated on the digital road map display.

Road and traffic information Various items of information, such as traffic conditions, road works, location of car parks and available spaces etc., are transmitted from roadside beacons and may be selected for display on the digital map.

Route planning and guidance The shortest route between any two points can be calculated from stored data and indicated on the digital map. If information regarding delays on or impassibility of the indicated route is received from beacons, an alternative route is also displayed.

Personal communication Two-way communication for personal messages and fleet management etc. is provided via the communication service system.

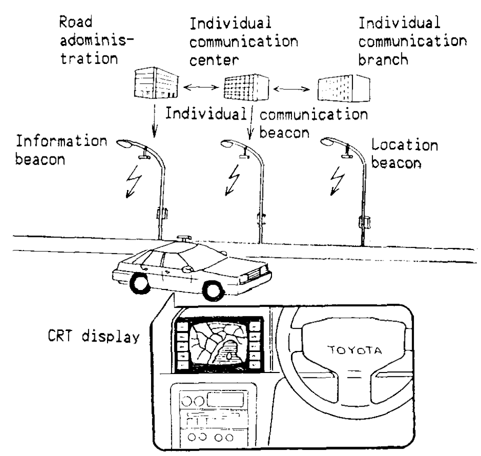

Fig.1 Road and automobile communication system

System Configuration

Beacons Beacons are of three types.
(i) The location beacon (LB) transmits signals identifying its location, i.e. secondary mesh code (the map reference number of the 1/25,000 scale maps issued by the Geographical Survey Institute), map coordinates (x,y), link number (the number designated to the road), link heading and beacon number. In addition other information of a constant nature may be transmitted.
(ii) The information beacon(IB) transmits both location signals and relays transient road and traffic information received via a cable. (See Table 1.)
(iii) The individual communication beacon (ICB) will establish two-way radio communication with the vehicle. The ICB itself will be connected to the communication service system center by cable. The

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functions of the ICB may be expanded to include those of the IB.

In the first two field tests, inductive radio was used for beacon transmissions. Currently microwave based communication is being tested. The specifications of the inductive radio are given in Table 2.

Traffic control and communication centers

The traffic control center, which is administered by the relevant local road authority, outputs road and traffic data based on the map and link numbers to the information beacons. The data is updated at 5-minute intervals.

The communication service system center and branches act as an interface for personal messages to and from particular vehicles.

Table 1 Road and traffic information

Congestion	Link No., Direction, Congested lane, Cause, Level of congestion, etc.
Traffic accident	Link No., Direction, Cause, etc.
Roadwork	Link No., Direction, etc.
Road/lane regulation	Link No., Direction, Regulated lane, Nature of regulation, Cause, etc.
Time needed to travel link length	Link No., Direction, Time

Table 2 Inductive radio specifications

Transmission antenna	Ferrite core coil
Frequency	247.2KHz
Transmission power	Very weak
Modulation	MSK
Transmission speed	9600bps
Transmission data	LB: 136bits, IB: about 8000bits
Car antenna	Ferrite core coil

In-vehicle equipment In-vehicle equipment consists of a dead reckoning device, a ROM unit in which map data are stored, CRT display, antenna and receiver. The map database was prepared by the Public Works Research Institute (PWRI) and comprises twelve files, e.g. link file, node (or intersection) file, railway file, facility location file etc. The data covers an area of approximately 350Km^2 including southwestern Tokyo, Kawasaki and northern Yokohama.

DEVELOPMENT OF IN-VEHICLE EQUIPMENTS

Fig.2 shows a block diagram of the prototype in-vehicle system developed by the authors. The system is composed of a dead reckoning device with geomagnetic sensor, gyroscope and wheel revolution sensor; a 6 inch CRT with touch-sensitive switches; a receiver; a map data storage unit and a processing unit which controls the system. A 16 bit personal computer (NEC PC9801VM21) was used as the processor.

The prototype system was installed in an '88 model TOYOTA CROWN as a sub-system of the multi-purpose display unit called ELECTRO MULTIVISION.[1]

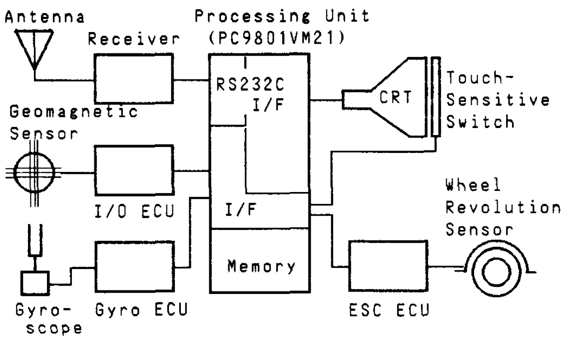

Fig.2 Block diagram of in-vehicle system

Map Display and Data

CRT and memory unit The core of the man-machine interface is the display unit. Ideally the CRT should be as large as possible to facilitate use, but a limit is imposed by the available space. As viewing angle is also an important consideration, the test car made use of a 6 inch CRT mounted in the center of the dash board (see Fig.3). In the prototype system, an IC memory (ROM) was used to store map data since the field test area is reasonably small. For commercial systems, a CD-ROM such as used in the ELECTRO MULTIVISION system would appear to be the most promising media for data storage. Specifications of the CRT and memory device are given in Table 3.

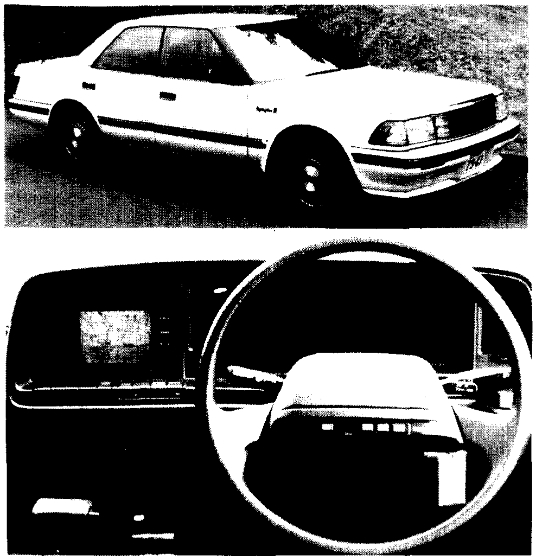

Fig.3 Test car

Digital map data Stored map data were compiled from the database prepared by PWRI. As shown in Table 4, four scales of map are available. The smaller scale maps are provided to enable selection of the larger scale maps (1:115000 and 1:28500), which are used for navigation. Fig.4 shows an example of the largest scale navigation maps. The display changes automatically when the vehicle moves from one navigation map to another. Each navigation map overlaps neighbouring maps by 10% so that the driver can easily follow the transition. In addition, a map of the Tokyo Metropolitan Expressway System and a map of car park locations are provided. All maps are displayed in the north-up mode, i.e. north is to the top of the screen.

Table 3 Display and memory unit specifications

Type of display	CRT
Size	6 inches
Resolutions	320*240
Location	Center of dashboard
Type of memory	IC memory
Memory capacity	8MBytes

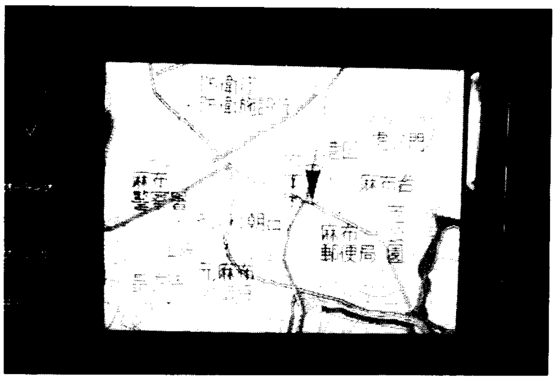

Fig.4 Navigation map (1:28500)

Detection of Vehicle Location

The dead reckoning device calculates the present position of the vehicle from directional and distance data. The calculated position is displayed on the navigation map. Accumulated errors in the dead reckoning are corrected when the vehicle passes an LB or IB. Consequently the navigational system operates with a high degree of accuracy.

Dual directional sensors In order to minimize any error in directional data, both a flux gate type geomagnetic sensor and vibration type gyroscope are used to calculate heading. A geomagnetic sensor is an efficient means of detecting heading but its accuracy is affected by regional differences in magnetic declination and by interference caused by buildings, tunnels, bridges, railways and large vehicles which are travelling alongside. On the other hand, a gyroscope, although unaffected by magnetic declination and interference, accumulates directional errors because it is subjected to drift as time passes. Hence, the TOYOTA dead reckoning system utilizes data from both sources and weights them appropriately.

Distance sensor Wheel sensors producing 48 pulses per revolution were adopted as the distance sensor and mounted on the non-driving (i.e. front) wheels.

Calculation and display of location Directional and distance data are continuously input to the control unit, which computes the movement vector of the vehicle at quarter-second intervals and outputs the present location in terms of navigation map co-ordinates every four intervals. Thus the position of vehicle location mark on the CRT is updated every second. The flowchart and calculation principle are shown in Figs 5 and 6 respectively.

Table 4 Stored map contents

Contents		Scale 1:380,00 Area dis played 45*37Km No. of maps 1	Scale 1:190,00 Area dis played 22*18Km No. of maps 4	Scale 1:115,00 Area dis played 14*11Km No. of maps 12	Scale 1:28,500 Area dis played 3.5*2.5K No. of maps 182
Land		○	○	○	○
Sea		○	○	○	○
Lakes and marshes		–	○	○	○
Rivers		–	–	○	○
Expressways		○	○	○	○
Toll roads		–	○	○	○
National roads		–	○	○	○
Prefectual roads		–	–	○	○
Municipal roads		–	–	–	○
Railways		–	–	○	○
Land-marks	buildings	–	–	–	○
	beacons	–	–	○	○
Names	Road names	–	–	○	○
	Place names	–	–	○	○

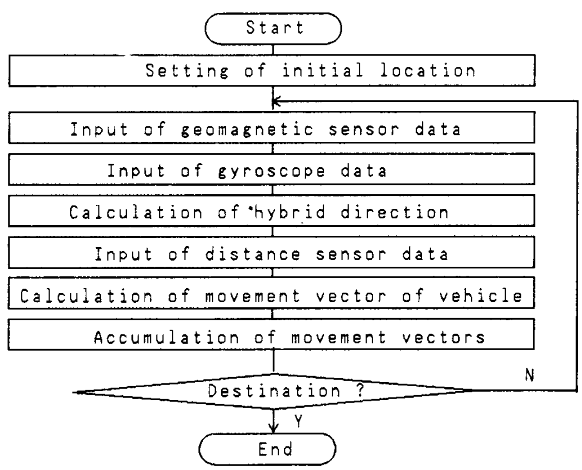

Fig.5 Flowchart of dead reckoning

Error correction The control unit compares location data received from a beacon with the calculated location and corrects any errors. Because of the intermittent communication and processing time,

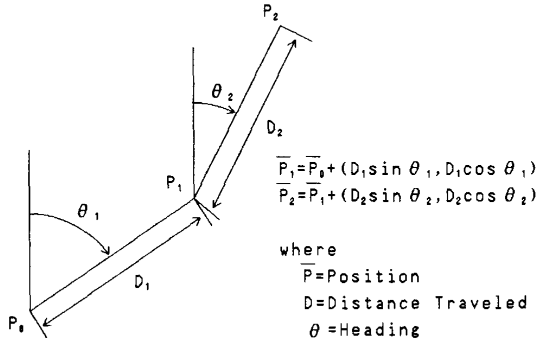

Fig. 6 Dead reckoning navigation computation

beacon location data is accurate to within ±5m, but this error is too small to effect the accuracy of the navigation system.

Reception and Display of Transient Information

Receiver and antenna The receiver utilizes a digital circuit for modulation and demodulation of the signal and a control unit including an 8-bit micro-computer. The antenna is a ferrite core coil mounted on the trunk lid (see Fig.7).

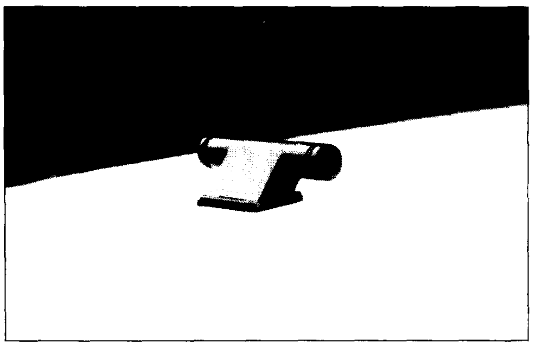

Fig.7 Inductive radio antenna

CRT display As stated above, information received from an IB, such as congestion, road works and local traffic regulations, are displayed on the CRT. Careful consideration was given to the content and manner of display.

The principal features are as follows:
(i) When traffic information is received, words to this effect are superimposed on the navigation map.
(ii) The driver may opt to view this information either on the navigation map in use or on the Tokyo Metropolitan Expressway. (See Figs 4 and 8.)
(iii) The information itself is expressed by a flashing color along the affected part of the road: violet for congestion, black for road or lane closure, red for an accident and yellow for road works.
(iv) If the navigation map is showing the shortest route (see below) and information regarding road or lane closure or congestion of the route is received, the driver may select a textual display giving details.

Fig.8 Display of congestion on Metropolitan Expressway

Shortest Route

The shortest route between any two given points is calculated using data regarding link length and flow direction at intersection (e.g. no right-hand turn etc.). This route is displayed on the navigation maps in a flashing green color. A feature of the system is that an alternative route is calculated and displayed if signals from an IB advise of congestion or closure of the planned route. When data are available, the program will be extended to enable the quickest route to be calculated as well.

Input The driver inputs the departure point and destination on the appropriate navigation maps, using the touch-sensitive switches on the screen to move the cursor. He must also input whether or not toll roads are to be used. The route is displayed from the node of origin (i.e. the intersection closest to the actual position of the vehicle, determined from the departure point coordinates and vehicle heading) to the node of destination.

Algorithm of route search To minimize computation time, a practical algorithm adequate for navigation was developed.[2] Based on Nicolson's bidirectional path finding algorithm, the method deals with an O-D (origin-destination) pair problem and calculates an approximate optimum. The main features are:
(i) The network for search is restricted to the elliptical area between O and D, the size of which changes in proportion to the distance.
(ii) A node amount equality method, whereby the number of nodes on the possible paths from O is equal to the number on the possible paths from D, is used to establish the shortest route.
(iii) The principle of network degeneration is applied. The initial search from O and D expands along all classes of roads. However the network is degenerated by eliminating any lower grade road if a higher grade road may be followed.
(iv) The revised origin method enables fast calculation of a rerouting should the driver stray from the planned route. If the vehicle passes an LB or IB that is not on the designated route, the shortest route from that point to D is calculated, making use of the previously computed possible paths from D. Figs 9 and 10 respectively show the concept and efficacy of the developed algorithm, which achieves a reduction in computation time of up to 90% compared to the single source algorithm.

Database for route search The in-vehicle database for route search was compiled from the previously

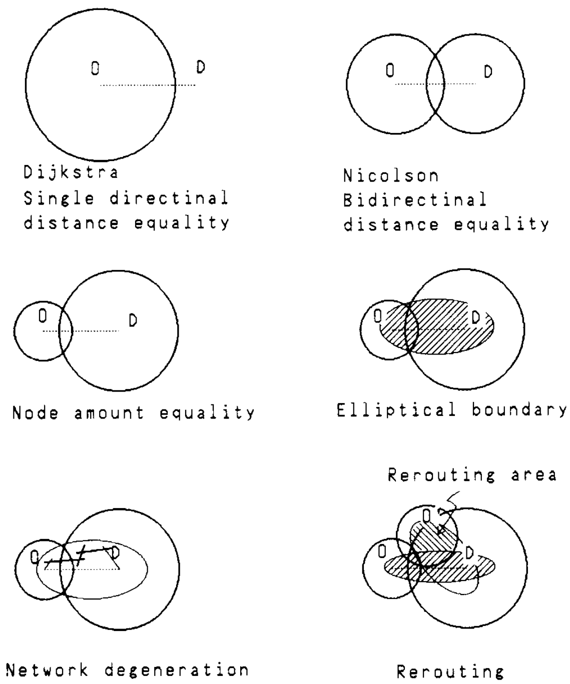

Fig.9 Concept of route search algorithm

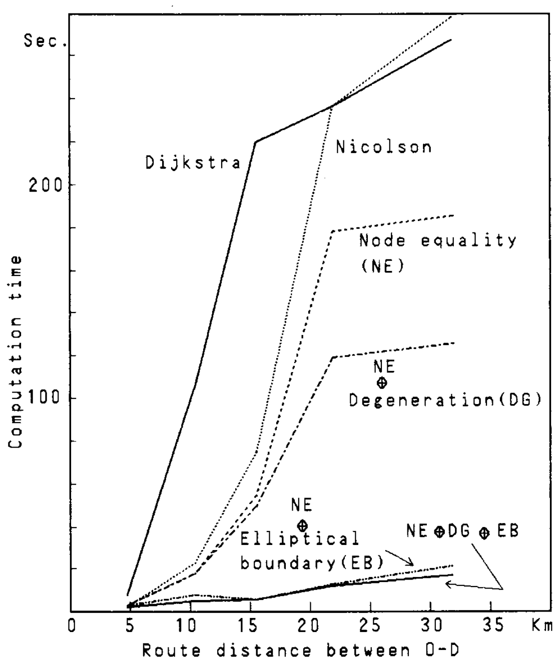

Fig.10 Comparison of computation times

mentioned digital map database and is characterised as follows:
(i) The file volume is as small as possible.
(ii) The database can meet options of and limitations on the search (e.g. whether or not toll roads are to be used, road restrictions on vehicle type, time-based traffic regulations etc.).
(iii) The database is well matched with the stored map data. The network for the field experiment area contains 2867 nodes and 4219 links.

Detour route search IB data concerning congestion is expressed as a congestion factor (corresponding to link flow rate). When such information is received, the shortest route from the preceding node to D is calculated (as above) in terms of total link cost (distance x congestion factor) and displayed on the CRT.

Display of Roadside Information

Roadside information obtained from an IB may be selected for displayed on the CRT. Fig.11 shows an example of car park information. Space availability, charge and opening hours are displayed.

ROAD TEST RESULTS AND EVALUATION

The road test area is shown in Fig.12. A total of 93 beacons including two IBs were installed along major roads in this area.

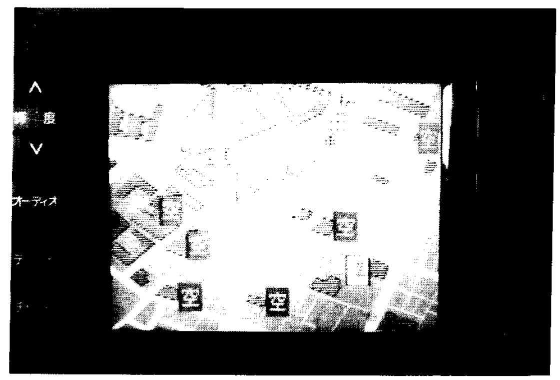

Fig.11 Display of car park information

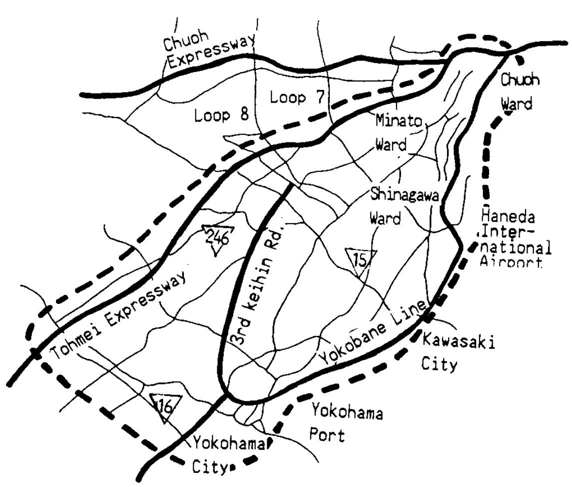

Fig.12 Field experiment area [3]

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