

Map Navigation Software of the Electro-Multivision of the '91 Toyota Soarer

Kunihiro Ishikawa and Michima Ogawa
Nippondenso Co., Ltd.

Shigetoshi Azuma and Tooru Ito
Toyota Motor Corp.

ABSTRACT

This paper describes the Electro-Multivision map navigation software mounted in the Toyota Soarer (1991). The following functions are required of on-board map navigation software:

1. Indication of the exact position of the vehicle to the driver
2. Determination of the optimum path to the destination and presentation of this route to the driver in the simplest way
3. Accommodation of a wide variety of destinations and settings for different users

The following gives some examples of how these functions are achieved and outlines the associated technologies.

1. Path finding and associated display technology
Path finding algorithm and technology for displaying the calculated on the map; construction of a data base on CD-ROM
2. Technology for determination of the current position utilizing map matching and the global positioning system(GPS)
A method with improved reliability based on two current position outputs obtained using map matching and the GPS and the mutual com-

pensation method

3. Software vendor participation technology
Utilization of CDCRAFT and methods of determining and setting the destination devised by software vendors

Finally, an outline is given of the course of future development of on-board navigation systems.

OVER VIEW

Electro-Multivision displays several kinds of information that helps communications among automobile, driver, and passengers.

The system uses a color LCD (liquid crystal display) monitor, placed in the center console, on which different displays can be called up, depending on the vehicle information needed.

The view and configurations of Electro-Multivision is shown in Figure 1, 2.

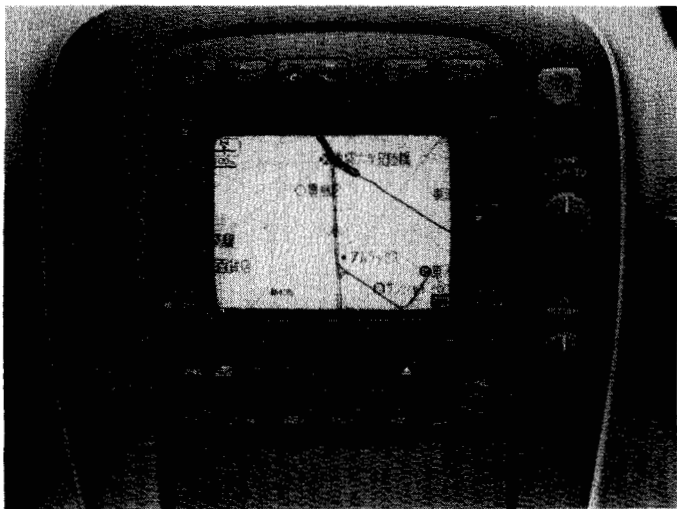


Figure 1

1.1 ROAD NETWORK MAP DATA BASE

1.1.1 DATA BASE HIERARCHY

The road network data base file for path finding consists of the following three layers:

(1) Regional network files

The whole of Japan is divided into nine regions, and the regional network files are used to store data on typical paths connecting these regions. Roads included in these files are expressways and the main national highways.

(2) Basic network files

The whole of Japan is divided into areas measuring approximately 18 kilometers square. These areas are called basic sections. One basic network file consists of 5×5 or 8×8 basic sections. Which file is used is determined by the number of regional data. The size of the files are shown in figure 3. A file exists for each of the sections enclosed by a thick line, while the areas marked by broken lines represent the overlap with neighboring sections. In this way, although there is a considerable duplication of data due to the overlaps, the number of times the CD-ROM is accessed can be greatly reduced and search time can be minimized. Roads included in these files are expressway, national highways, and the main regional highway. These files cover the whole of Japan.

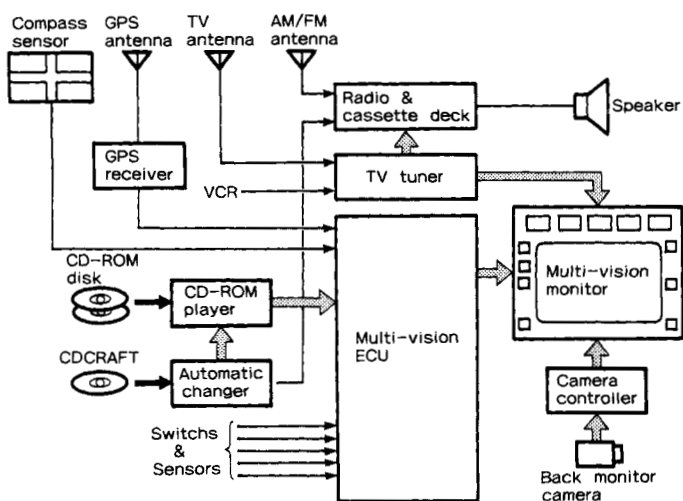


Figure 2

1. ROUTE GUIDANCE

The system is the first on-board system to incorporate a path finding and its presentation function. The route guidance function uses the map data base in the CD-ROM to calculate the recommended path from the current position to the destination. The road network map data base, the search algorithm, and the method of displaying the information on the map are explained below.

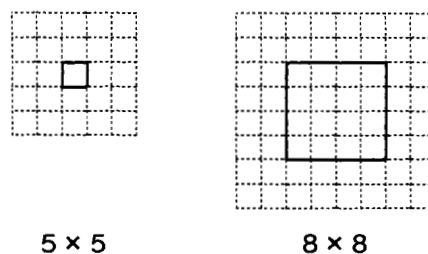


Figure 3 Basic Section File Size

(3) Detailed network files

The basic sections are further divided into 16 equal squares called detailed sections. Normally each file covers a square area whose sides are three detailed sections long. As in the case of the basic network, these detailed network files exist for all of the detailed sections, and the outer eight sections overlap with other areas. Roads included in these files are expressways, national highways, main regional highways, ordinary prefectural roads, and certain trunk roads, as determined by Shobunsha Co.,Ltd which is one of the biggest private map publishers. These files cover the whole of Japan.

The hierarchical structure of these three map data bases is shown in Figure 4.

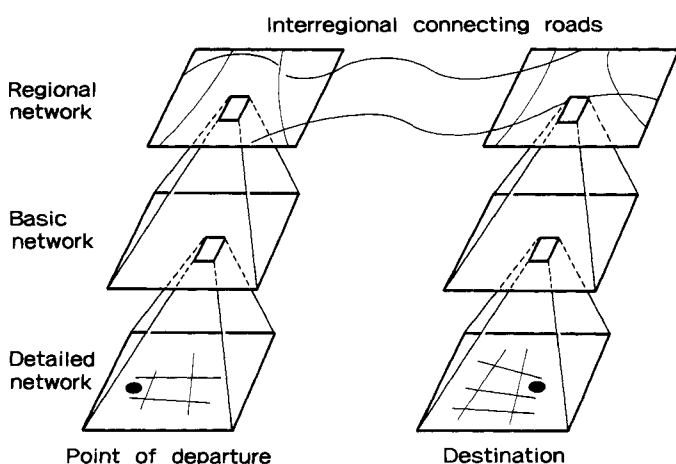


Figure 4 Route Guidance Data Base Hierarchy

1.2 ROUTE DETERMINATION ALGORITHM

The path is determined by using the dijkstra method. The following is an outline of the processing flow:

Step 1

The road network data base file to be used is determined in accordance with the crow-fly-distance between the origin and the destination.

Step 2

Labeling is performed for all of the points in the detailed network file that includes the destination.

Step 3

The node cost is reflected onto the higher layer, and labeling is performed for the network of that layer. Moreover, if there is a higher layer still, step 2 is repeated.

Step 4

The node cost is reflected onto the lower layer, and labeling is performed for the network of that layer. Moreover, if there is a lower layer still, step 3 is repeated.

Step 5

The path to the destination is determined by successively following the links with lowest cost from the origin.

1.2.1 DETERMINATION OF ROUTE DATA BASE FILE

Which road network data base files are to be used for the calculation is determined by the crow-fly-distance between the origin and the the destination, as shown in Table 1.

Distance between point of departure and destination	Regional network file	Basic network file	Detailed network file
Up to 4.5 km			1
4.5 to 13.5 km			2
13.5 to 22.5 km			3
22.5 to 54 km		1	2
54 to 125 km		2	2
More than 125 km	1	2	2

Table 1

As can be seen from the table, the maximum number of files required for calculation, even for long distances, is five. Supposing, to obtain on the path between Tokyo an Nagoya, which are 300 kilometers apart, it is necessary to use the Nagoya detailed network

file and basic network file, the Tokyo detailed network file and basic network file, and the regional network file for the part between Nagoya and Tokyo. Refer to Figure 4. For distances not exceeding 125 kilometers, a regional network file is not required. Although in such cases two basic network files are used, the system is designed so that a combination of highly efficient files is selected in accordance with the positional relation of the point of departure and the destination. An example is shown in Figure 5. In this matter, although a search is generally made for the oval area between the origin and the destination, since a substitution is made by a combination of rectangles, a maximum of two files is required to complete the search. The same applies for the detailed network files. As a result, the time required to calculate the paths is about one minute, irrespective of the distance.

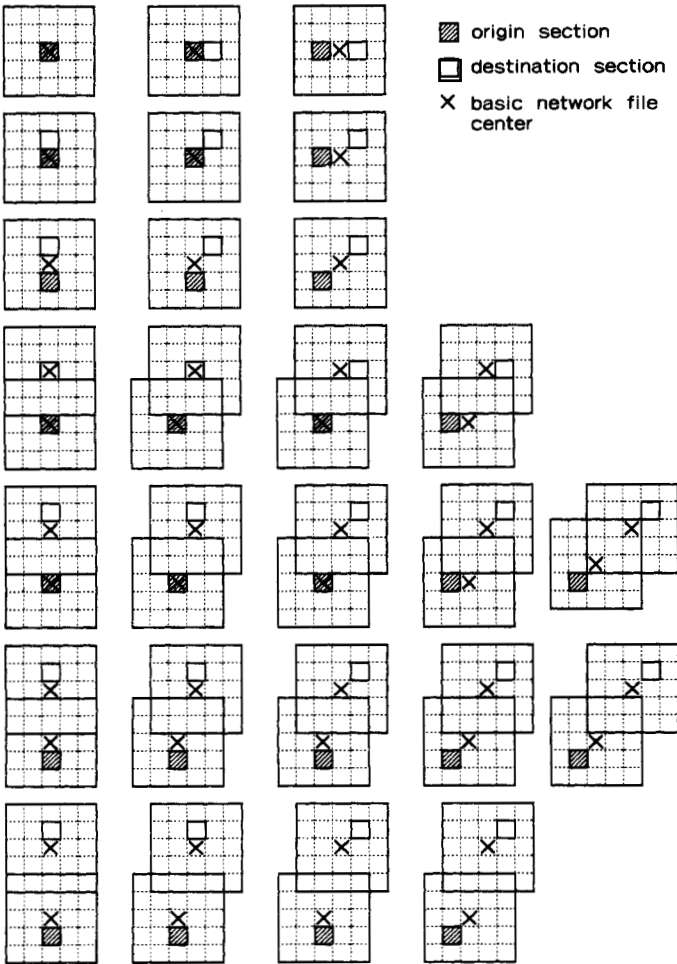


Figure 5 Combination of Basic Map Parts

1.2.2 LINK COST

Although the road network is extremely important in the path finding, the most important factor of all is the link cost for calculating the optimum path. The data items affecting the cost are shown in Table 2.

The link cost is calculated by inserting these values into the following equation:

$$\text{cost} = (A+B+C) \times C \times E \times F$$

	Data item
A	Link length
B	Cost of turning right and left
C	Traffic restriction cost
D	Road type factor
E	Road width trap factor
F	Toll road priority factor

Table 2 Network Cost

1.3 DISPLAY METHOD

The path was displayed by means of road markings consisting of small circles. The pass must be presented in any scale of map display, that is, from 1:2,560,000 to 1:10,000 in case of the drive from between Tokyo and Nagoya. Therefore representative points which are describing the shape of the path, are preferable to the smallest number. Such a data compression has been realized, as the space on 1:10,000 scale map, these markings were spaced at approximate 800-meter intervals on expressways and at approximate 200-meter intervals on ordinary roads, as the space of 1:2,560,000 scale map, these markings were spaced at 12,800-meter intervals on expressways and at 3400-meter intervals on ordinary roads. Examples of these displays are shown in Figure 6.

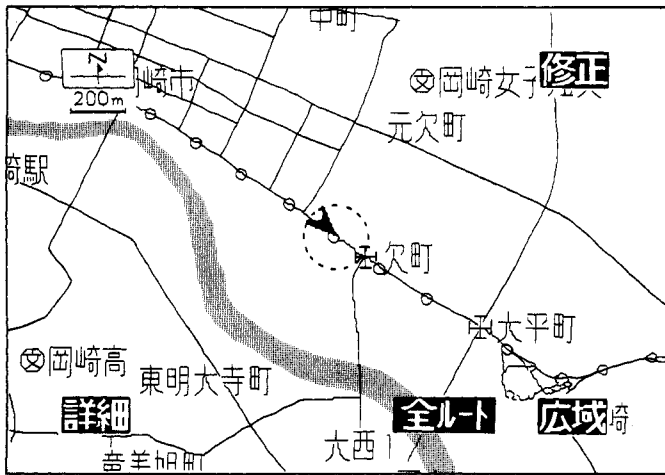


Figure 6

1.4 EVALUATION RESULTS

Fifteen points around Osaka were selected and two path finding were made, one with expressway priority and one without (420 routes). Firstly, of the 420 routes, those which were considered to be reasonable were taken as correct responses. Next, 27 courses were selected as model routes from those routes which were considered doubtful and their suitability was determined from the results of a survey among taxi drivers and other professional drivers and by actually driving along the routes. The evaluation items were ease of following the route, safety, and time, and the suitability of a route was determined by taking the averages of these. The correct response ratio and the suitability of routes which were not the correct response are shown in Table 3.

Correct response ratio	Ordinary roads	64.3%
	Priority given to expressways	71.8%
Suitability of routes which were not the correct response	Ordinary roads	76.7% (minimum value 53.7%)
	Priority given to expressways	85.7% (minimum value 81.8%)

Table 3

Using the above results, the degree of expectation corresponding to the system was calculated from the following equation:

$$\text{Degree of expectation} = \text{correct response ratio} + \text{incorrect response ratio} \times \text{minimum value of suitability}$$

The resultant degrees of expectation are:

Ordinary roads: 83.5 %

Priority given to expressways: 91.8 %

Accordingly, it may be said that, with the path finding, on the whole the correct route was found 80 or 90 per cent of the time.

2. VEHICLE POSITION DETECTION

There are two main methods of vehicle position detection, the independent method, dead reckoning and map matching, and a radio method; the global positioning system or GPS. By using these methods in combination, they can be made to compensate for one another, as well as enable vehicle position detection. The relation between the two methods is shown in Figure 7.

2.1 DEAD RECKONING METHOD

As shown in Figure 7, this system uses a compass sensor, wheel sensors mounted on the left wheel and the right wheel, and a steering sensor. The compass sensor can detect the absolute bearing, but has the drawback of being susceptible to local geomagnetic variations. Because of this, compensation for the reduction in the magnetization of the vehicle is necessary. The wheel sensors on the left wheel and the right wheel output a pulse about every 4.1 centimeters. These sensors detect the distance traveled by the vehicle and can also detect the relative bearing by means of the pulse difference between the two sensors. The steering sensor is used to detect the relative bearing at low speeds, when no output can be obtained from the wheel sensors. The present system calculates

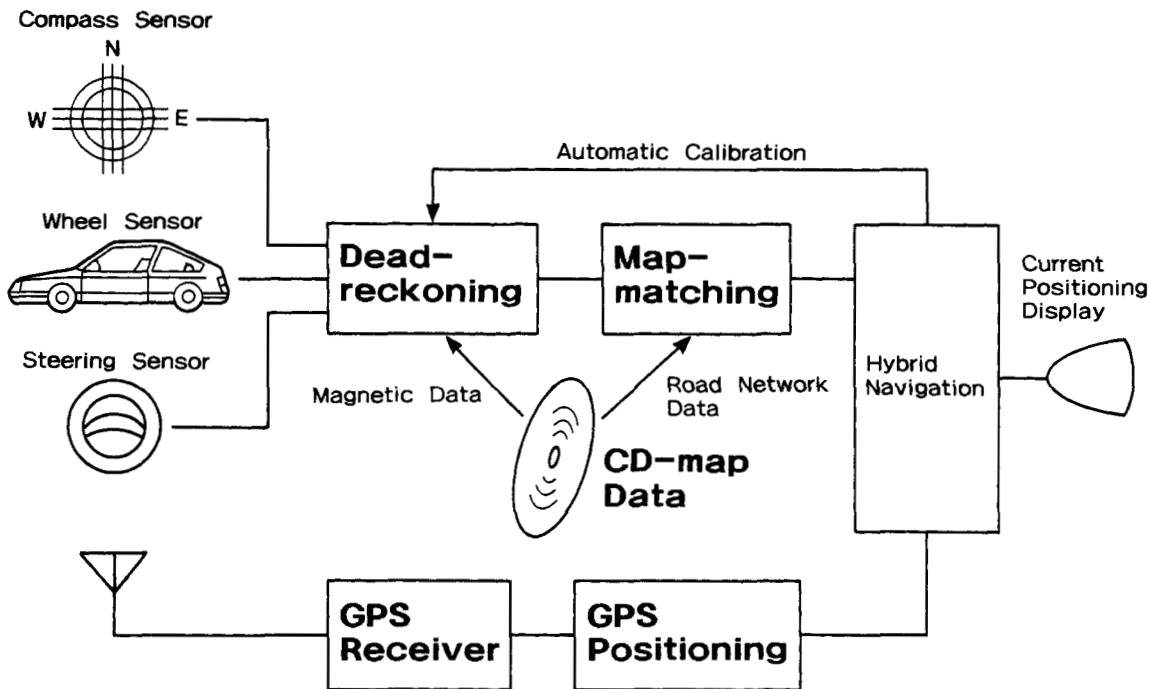


Figure 7 Automatic Current Positioning

the bearing by combining the absolute bearing and the relative bearing. Basically, the compass sensor is used when it is determined that it can provide an accurate value for the bearing, while the relative bearing is used at other times. The compass sensor is used when the level of the earth's magnetic field is suitable and, at the same time, when it is determined that the variation in the compass sensor is suitable according to the amount of variation in the relative bearing.

2.2 MAP MATCHING

In map matching, the path obtained by dead reckoning is compared with the shape of the road on the map data base on the CD-ROM, and the position of the vehicle is automatically corrected to the most probable and predictable on the road.

The most important items in map matching are the map matching algorithm and the contents of the map data base. In the present system, high-precision map matching has been achieved by incorporating into the data base all urban roads 3.0 meters wide or over and all other roads 5.5 meters wide or over for all of Japan.

The map matching algorithm is described in the following. Basically, in map matching, increases and decreases in the value of the calculated distance between the path of the vehicle and the verified point are detected, and the point where the difference between the verified point and the vehicle path is shortest is obtained by using this value as a trigger. Next, if that distance lies within the circle whose radius is given by the following equation, matching determination processing with the road shape is performed:

$$r = p1 \times \ell 1 + p2 \times \ell 2 + p2 \times \ell + e1 + e2$$

Where

r: verified circle radius

$\ell 1$: travel distance between verified circles

$\ell 2$: distance between verified point and bend lead-in

i: travel distance after separation

p1: bearing error factor

p2: distance error factor

e1: road width, map error

e2: positional error

In map matching processing, at the distance travel time point between verified points, the degree of shape matching between the road shape formed by several consecutive verified points and the corresponding vehicle path is estimated on the basis of mentioned above, and of the value obtained is larger than a prescribed value, the position of the vehicle is corrected on the road. This principle is shown in figure 8. If there are several similar shapes on the map, the degree of matching of the shapes for each road is calculated and the result is output as the map matching probability value.

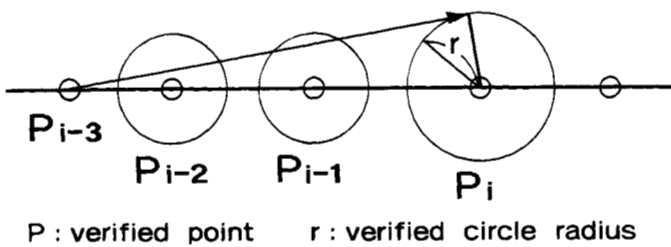


Figure 8

2.3 RADIO NAVIGATION

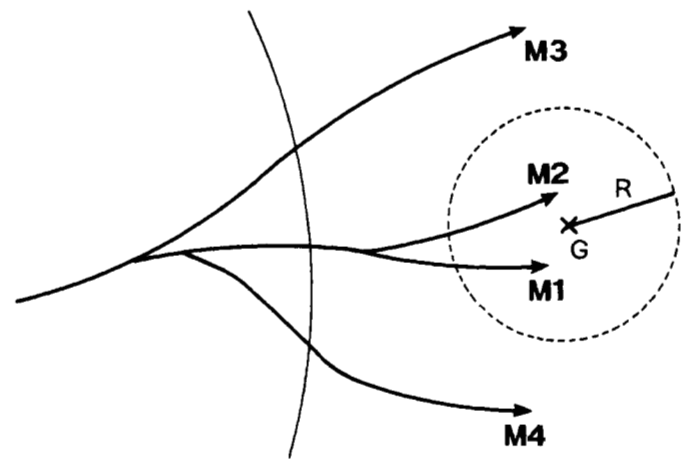
The radio navigation system of the present system utilizes the global positioning system (GPS). The GPS receiver picks up time and orbit signals from three U.S. Department of Defense satellites. The time lag allows the ECU to calculate the vehicle's distance from each satellite. In theory, once the distance to the satellites is learned, the intersection of those lines can be calculated, which establishes the position of the receiver (vehicle). Actually, the receiver forms the fourth point so that a position can be calculated in three dimensions to an accuracy of 30 ~ 200 meters. Apart from the measured position, the output from the GPS receiver includes the estimated error radius calculated from the satellite status.

Because the measured position is output using the WGS-84 system, it must be converted into the Tokyo geodetic system. These conversion data are stored on the CD-ROM.

2.4 VEHICLE POSITION DETERMINATION

The following describes the method of determining whether positioning of the vehicle by map matching or by the GPS is to be used.

Although map matching can indicate the position of the vehicle on the road, it cannot indicate the absolute position because this is calculated relative to the starting point. On the other hand, although the GPS can measure the absolute position, it cannot indicate the current position on the road. A large-scale (1:10000) map is displayed, and its appearance is not good unless the position of the vehicle is indicated on the road. Accordingly, the result of map matching is ignored. An outline is shown in Figure 9.



G : GPS measured position

M1-M4 : Map matching proposed position

Figure.9 Vehicle Position Determination

M1, M2, M3 and M4 on the map are proposed positions in the multiple traces obtained by map matching, and the estimated accuracy values are placed in the order $M1 > M2 > M3 > M4$. By making the GPS measured position coordinate G the center, M1 and M2, which lie inside circle R calculated from the estimated error radius, become the proposed positions. M1, whose map matching precision value is high, is used as a proposed position. The probability of M3 and M4, which lie outside circle R, is extremely low, and the road trace is interrupted. Accordingly, the effective roads

remain in the memory. Furthermore, if no proposed position inside the circle is obtained by map matching, all of the road traces are interrupted and a new road search is begun from the circle center G.

2.5 SENSOR COMPENSATION

(1) Compass sensor compensation

The compass sensor must always be compensated to the earth's magnetic origin in accordance with the magnetic condition of the vehicle body. This is done using the wheel sensor output and the GPS measured position.

(2) Wheel sensor compensation

Distance compensation and left and right turning compensation of the wheel sensors must be performed. This is done using the map matching output, GPS measured position and compass sensor output.

3. SETTING OF DESTINATION USING CDCRAFT

CDCRAFT is an abbreviation of CD and CRT Applied Format. It is a CD software format which operates in an on-board information system which incorporates a CD-ROM reading unit. This format was developed jointly by Nissan Motor Co.,LTD., Sumitomo Electrical Industries, Toyota Motor Corporation, and Nippondenso Co.,LTD and has the following aims:

(1) Compatibility guarantee

The format protects the on-board system from adverse effects, even if the CD software created by a third party is run. That is, the operation of the CD software is checked at every step.

(2) On-board system protection

It is planned to expand the market for on-board information systems by guaranteeing the compatibility of CD software among manufacturers and on-board systems.

3.1 CDCRAFT FUNCTIONS

(1) Basic functions

i) Calculation

Performs integer calculation, logical calculation, and logical testing.

ii) Storage operations

Performs stack operations, memory access operations, automatic variable access, and heap area operations.

iii) Program control

Performs syntax processing, branch orders, and file unit operations.

iv) Interruption control

Controls timer interruptions and operation prohibition condition establishment interruptions. The timer interruption interval can be specified in units of 100 ms.

v) Standard function support

Triangular functions, square roots, character operations, error information acquisition.

vi) On-board system identification

Different hardware resources and function item information acquisition in accordance with on-board system.

(2) Service functions

i) Graphic operations

Graphic pages and display pages are set in a graphic area usable by the CD software, enabling a variety of operations. The graphic area consists of 512 x 480 dots.

ii) Standard input and output operations

Operations related to standard input and output devices are performed by means of touch switches and mechanical switches.

iii) Map access

Performs operations such as map data access and map coordinate conversion.

iv) Vehicle information acquisition

Acquires information such as current position, distance traveled, speed, bearing, rear signals, and

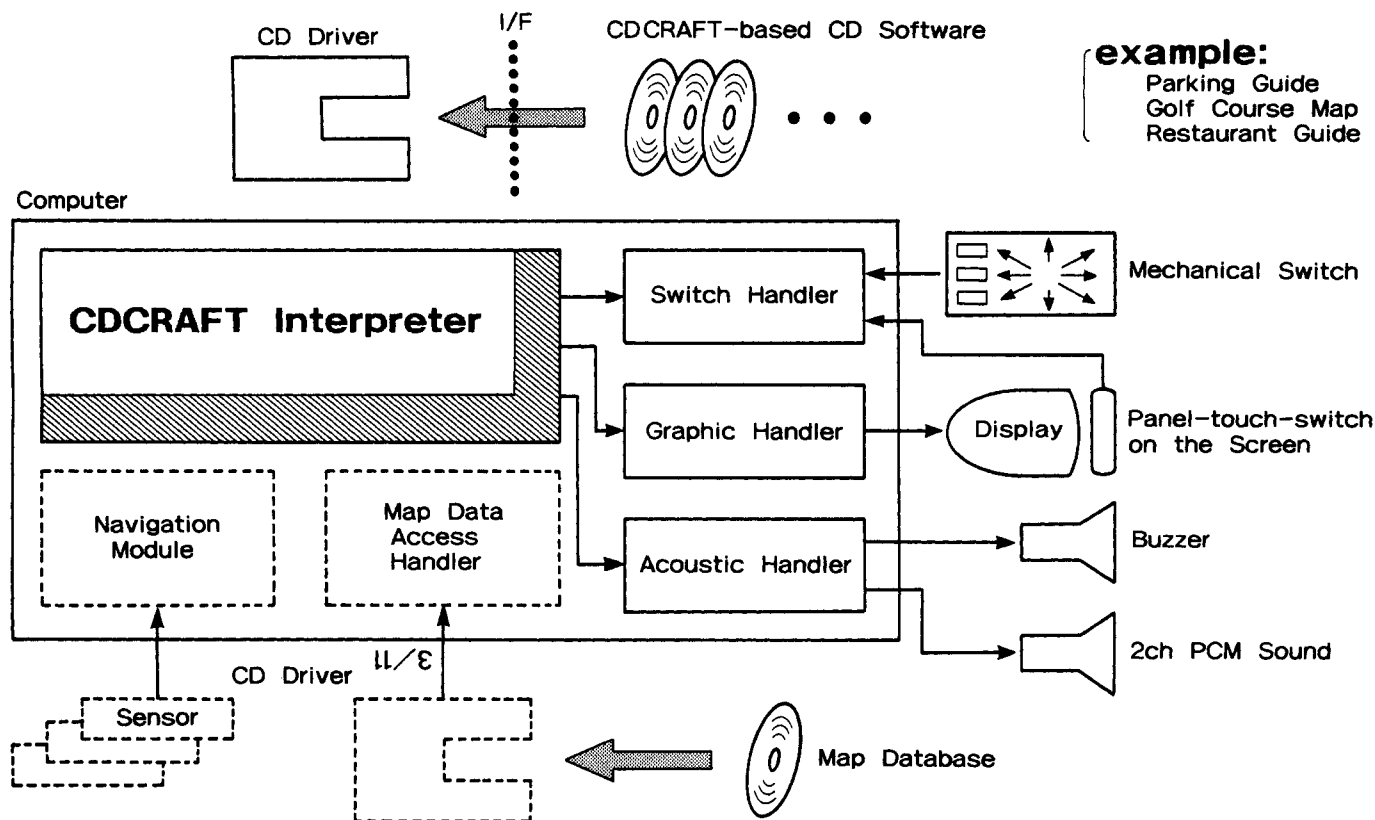


Figure 10 Configuration of CDCRAFT

light condition.

v) Memo data access

Performs reading and writing of required memo data from and into the on-board system. Memo data include destination, registered places, etc.

vi) Audio operations

Performs PCM audio output and beep tone output. The configuration of CDCRAFT is shown in Figure 10.

3.3 EXAMPLE OF DESTINATION SETTING USING CDCRAFT

The address structure in Japan, in descending order, is: prefecture, city, large section, subsection, lot. All of these are defined as areas. Unlike in the U.S.A., where roads are used in addresses, if lots are used to build the data base, the data base would become too large. In the present system, a map search has been made possible by including in the data base address information up to the large section level. However, a

search at this level is still unsatisfactory for specifying points. As a result, it is expected that third-party software will be introduced for individual applications. Such applications might include restaurants gas stations, parking lots, for example. In the example shown below, hot springs have been selected, and the following is a destination setting example using Shobunsha's CDCRAFT "Hot Spring Master."

- (1) The "Hot Spring Master" begins to the accompaniment of background music and an illustration of a hot spring displayed on the screen. Screen is shown in Figure 11.
- (2) A mascot girl then appears on the screen and explains orally how to use the "Hot Spring Master." Screen is shown in Figure 12.
- (3) The required region is then selected by means of touch switches from a map of the whole of Japan. Screen is shown in Figure 13.



Figure 11

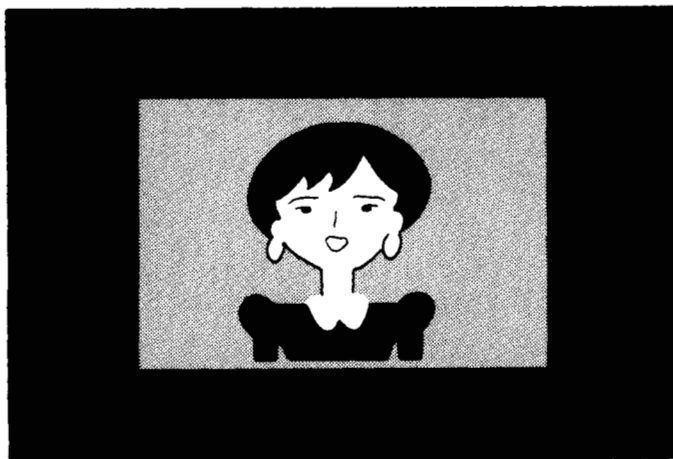


Figure 12

どの県ですか

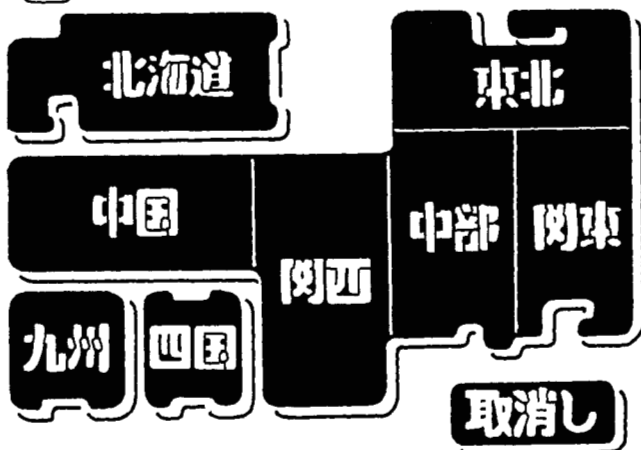


Figure 13

- (4) The required prefecture is then selected by means of touch switches from a map of the selected region. Screen is shown in Figure 14.
- (5) The required hot spring is then selected by means of touch switches from a list which can be scrolled up and down. At the same time, the software provides other information, such as the special features of each hot spring, an illustrative map, a list of accommodation with names, addresses, and telephone numbers. Screen is shown in Figure 15.

どの県ですか

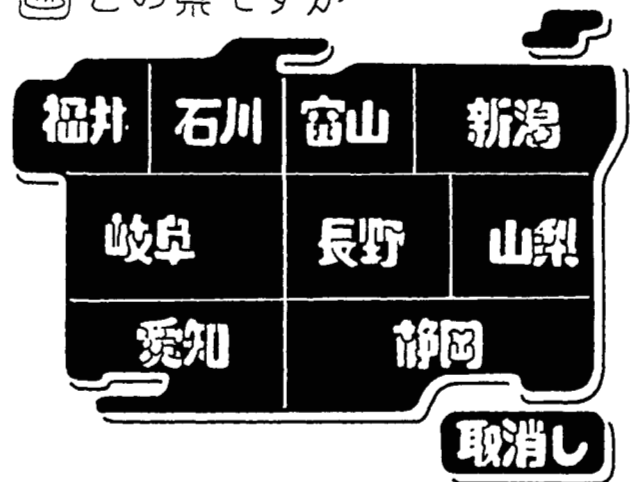


Figure 14

どの温泉ですか

1/3 ページ

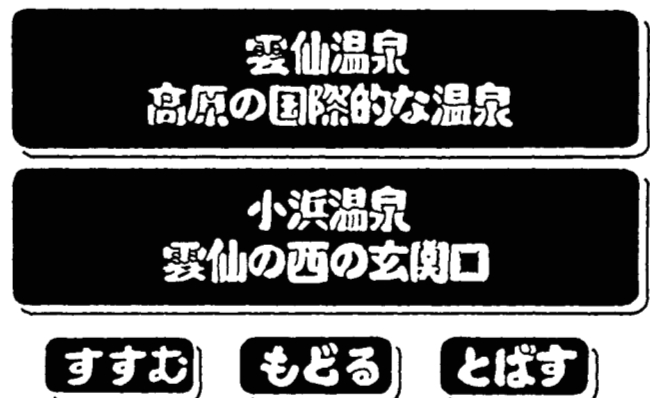


Figure 15

- (6) When the required hot spring has been selected, its location is registered into the memory of the on-board system by pressing the "Register" switch. Screen is shown in Figure 16.
- (7) A result like the one shown on the right is obtained by using the location registered in (6) and by executing the route guidance function. Screen is shown in Figure 17.

☑ 上か下の欄を押すと温泉が登録されます。

やめる

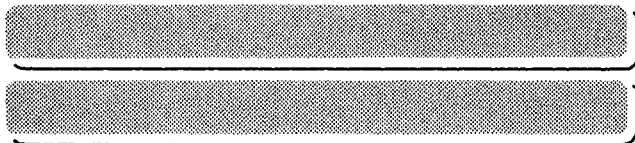


Figure 16

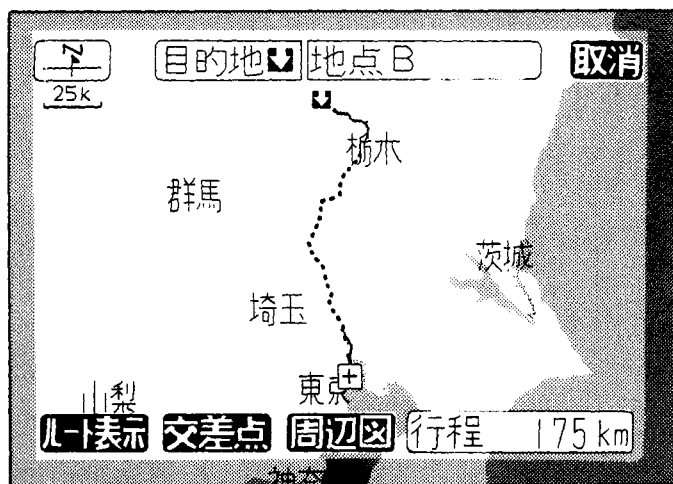


Figure.17

4. CONCLUSION AND FUTURE DEVELOPMENTS

The authors have developed an on-board navigation system which incorporates a route guidance function. In the future, a dynamic route guidance function should be created by setting up an infrastructure and linking up with information on traffic restrictions etc. In such a system, the reduction of path finding time is indispensable. The target is to develop a real-time route guidance system.

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Toyota Petition '628 Exhibit 1019