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ABSTRACT

During motor vehicle operation, the image processing and pattern recognition of various external visual information to assist human vision is an effective method to improve safety and driving comfort. Research into image processing and pattern recognition, supported by advancing device and computer technology, is entering the age of practical application.

Against this background, we have developed a system to visually detect, recognize and transmit to the vehicle operator road signs,which are definable patterns, as the first step in the application of image processing and pattern recognition technology to the automotive sector.

The major points of this system are as follow:

1. A color processing system was adopted which reduces the effects of brightness and shadow, and implemented in dedicated hardware.
2. The development of dedicated hardware for template matching enables the real-time extraction and processing of defined patterns within the image.

1. OVERALL SYSTEM CONFIGURATION

Fig. 1 indicates the overall configuration of the developed system. The video camera installed in the vehicle inputs images of the exterior world to the high-speed image processor, which color-processes the incoming image signal and detects patterns with the characteristics of road signs. The host computer verifies the content of the selected patterns, compares the speed restriction on the road sign to the actual speed of the vehicle, and announces excess speed through a voice synthesis device when the vehicle is traveling in excess of legal speed, alerting the driver.

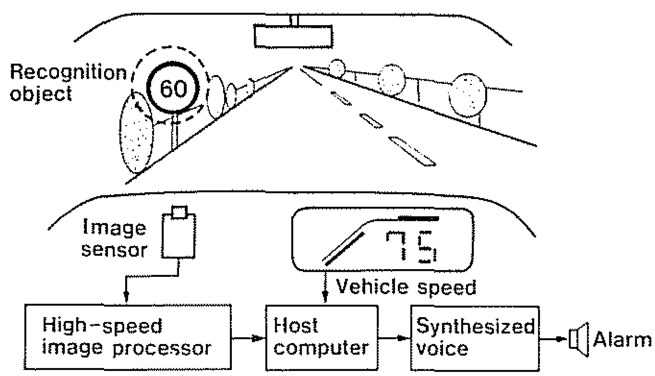

Figure 1. Road Sign Recognition System Overall Configuration

2. PROCESSING TECHNIQUE

The quantity of image data representing the outside world is massive. The input of all of this data to the computer for image processing would require similarly massive amounts of memory, and long processing time. In addition, as the images of the outside world input change constantly with vehicle motion, real-time processing is essential. In computers available today, it would be impossible to implement a system of this type due to processing speed and memory capacity constraints.

As a result, the critical problem encountered was how to cull essential data from the mass of input data. To resolve this problem, we adopted the following technique.

1. The input image is pre-processed to discard unnecessary data.
2. Dedicated hardware was developed to improve processing speed.

Based on this technique, the recognition methods that had to be developed were classified into four groups. The processing flow is indicated in Fig. 2.

(1). Image input: Input of outside images to the video camera.
(2). Characteristic extraction: Color processing is used to enable characteristic extraction and reduce information quantities.
(3). Road sign detection: Identification of defined patterns (road signs) from the image.
(4). Content recognition: Recognition of the content of the detected pattern.

To accurately detect road signs within the image of the outside world during vehicle movement, it is necessary to determine whether or not a road sign is present within the input dynamic image. A hardware system was developed that would allow high-speed processing (real-time processing) of the sequence from image input through road sign detection, and content recognition was handled through flexible software capable of high-level processing. The four processes are described below.

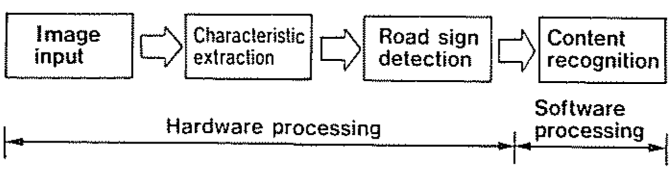

Figure 2. Processing Flow

2-1 Image input

Outside images are input by the video camera mounted inside the cabin. The input images are converted to NTSC-specification analog video signals (R,G,B and Synchronization signals), and passed to the high-speed image processor.

2-2 Characteristic extraction

<u>2-2-1 Problems in characteristic extraction</u>

The images of the outside world change constantly due to weather, sun angle and other conditions, and conventional binary processing based on tonal differences cannot handle the effects of brightness change. After experimental evaluation of a variety of methods for extraction of essential information, it was determined that color processing was highly effective not only for road signs, but for the processing of a wide range of natural imagery.

Although the quantity of data to be processed increases, effects of brightness are lessened. For this reason, a theoretical evaluation of color processing was undertaken.

<u>2-2-2 Theoretical evaluation</u>

The R(Red), G(Green) and B(Blue) data indicating the color of an object can be expressed as:

$$R = \int \delta\, S(\lambda)\, \rho(\lambda)\, x(\lambda)\, d\lambda$$
$$G = \int \delta\, S(\lambda)\, \rho(\lambda)\, y(\lambda)\, d\lambda$$
$$B = \int \delta\, S(\lambda)\, \rho(\lambda)\, z(\lambda)\, d\lambda$$

where S = spectral distribution of the light source, λ = wavelength, ρ = spectral reflectance from object, x,y,z = camera sensitivity of each color and δ = light source irradiation ratio on object.

As term δ is the parameter for brightness, R, G and B are affected by brightness. However, when R+G+B is standardized,

$$r = R/(R+G+B)$$
$$g = G/(R+G+B)$$
$$b = B/(R+G+B)$$

hold true, making it possible to eliminate δ and yielding parameter r, g, and b not affected by brightness. Considering the vector space of R, G and B, it develops that all colors that can be represented by R, G and B can also be represented by r, g and b as triangles on a color chart, as indicated in Fig. 3.

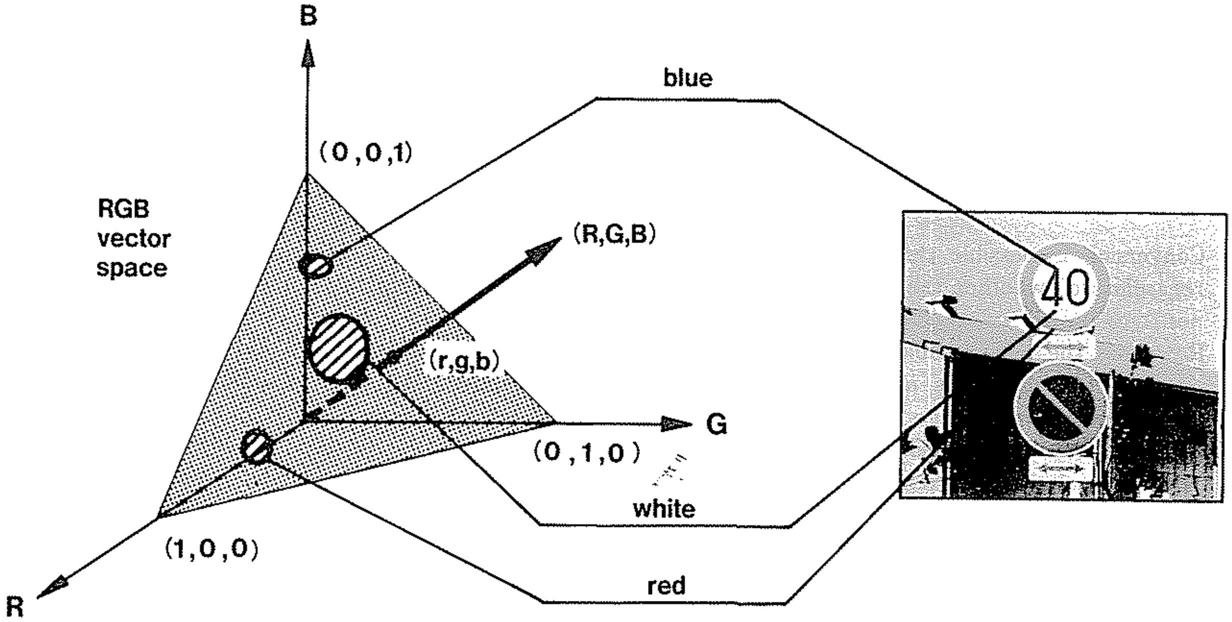

Figure 3. RGB Vector Space and Analysis of Road Sign by Color Chart

2–2–3 Road sign color processing

Based on the above logic, an analysis of road sign markers was performed on a color chart. When the individual pixels of a road sign within an outside image are plotted on a color chart, characteristic colors red and blue are within the regions indicated in Fig. 3., while other colors may be grouped into other regions. It is therefore assign points falling within the red region (Pr) and points within the blue region (Pb) and also Pi (Ri, Gi, Bi) is a point within the image, so that

$$Pr = (Ri > krg * Gi) \text{ AND } (Ri > krb * Bi)$$
$$Pb = (Bi > kbr * Ri) \text{ AND } (Bi > kbg * Gi)$$

where krg, krb, kbr and kbg are factors over 1, and thereby enabling the extraction of the characteristic colors of road signs.

2–2–4 Implementation through a look–up table

Theoretically it is possible to extract the characteristic colors through the above method. In reality, however, the output ratios for R, G and B are not equivalent, due to input/output characteristics of camera and filters to different brightness.

It is therefore necessary to introduce processing which compensates for these characteristics, but this cannot be accomplished through simple calculation. To resolve this problem, a look–up table technique enabling high–speed color calculation and compensated characteristic extraction was adopted.

Fig. 4 indicates the look–up table method.

A table is stored in the host computer in advance, with data fulfilling the Pr and Pb equations and already compensated. This table contents are transferred to high–speed memory.

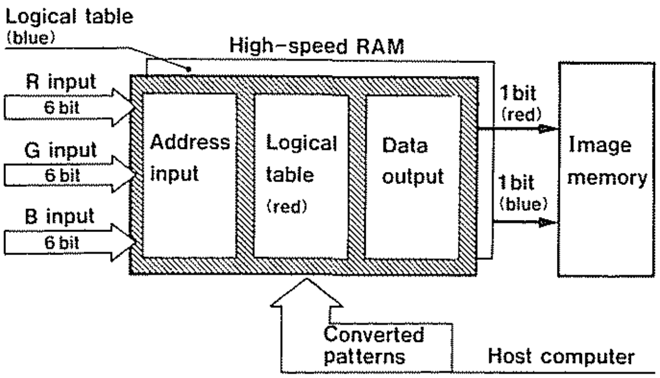

Figure 4. Look–up Table Technique

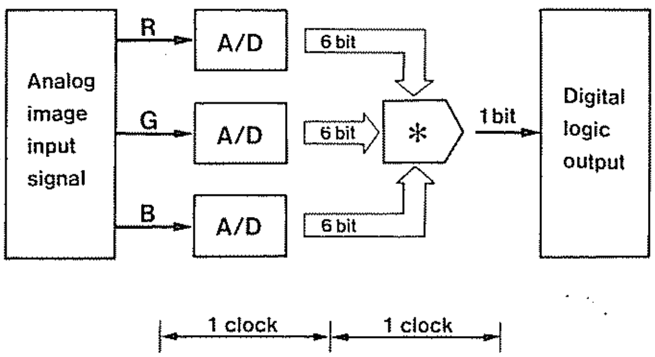

Figure 5. Logic Conversion Processing

Memory addressing is handled by the 6-bit digital R, G and B signals, yielding 1-bit logical data from the table. Thus, characteristic extraction is performed all in two cycles of the system clock (see Fig. 5).

2-2-5 Special features

This approach offers the following special features:

1. Conversion is possible through the logical table, regardless of whether the conversion is linear or not.
2. Rewriting the logical table enables extraction of any color characteristics, not merely those for road signs, and therefore the system enjoys a high degree of freedom in color calculation.
3. Color calculation is completed within memory access time, realizing high-speed processing.

2-3 Road sign detection

2-3-1 Scan area specification

It would require a tremendous amount of processing time to handle the entire image area, for which an analysis of the areas in which road signs appear was performed. As indicated in Fig. 6, road signs picked up by the mounted camera move from right to left, growing larger constantly (for right-hand drive situations, they would move from the left of the image to the right).

The scan area was defined as the area where these road signs would reach the size that they could be recognized, rather than scanning the entire area, and road sign recognition enabled.

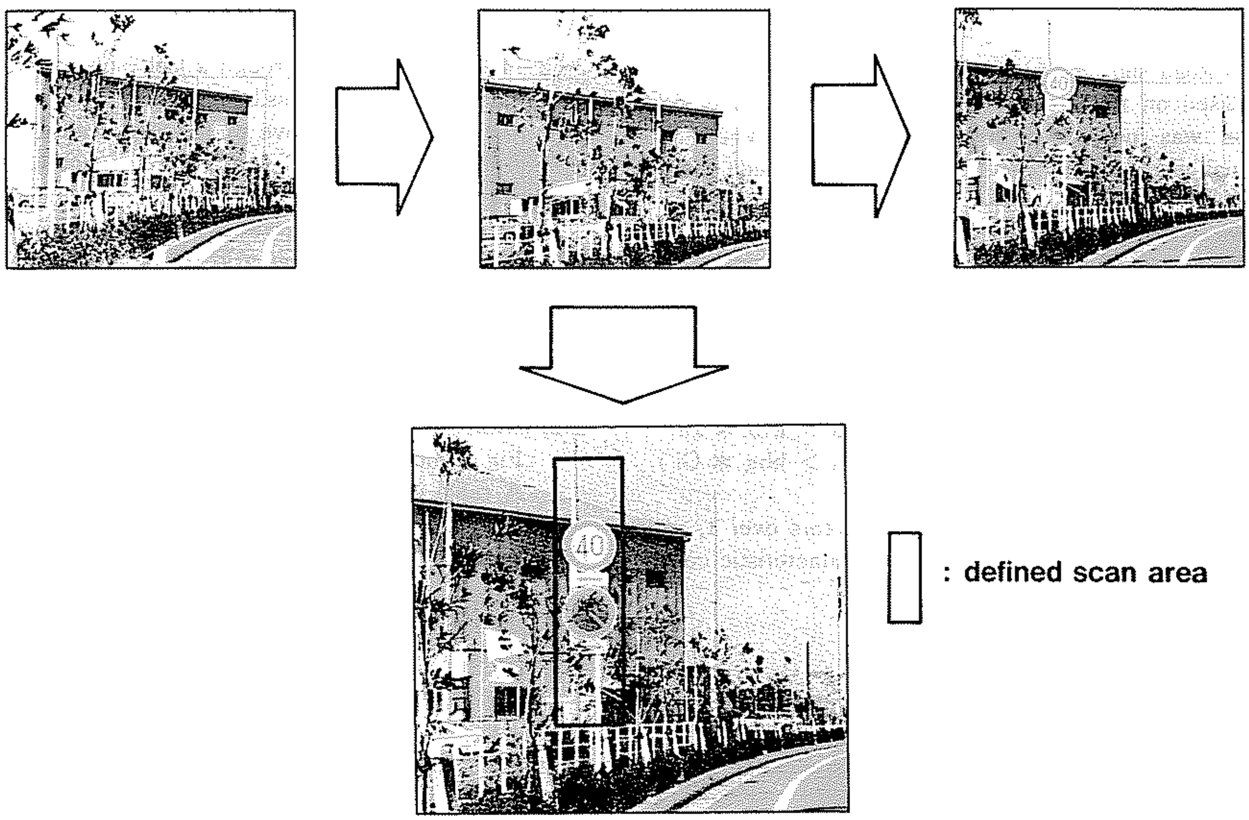

Figure 6. Scan Area Analysis

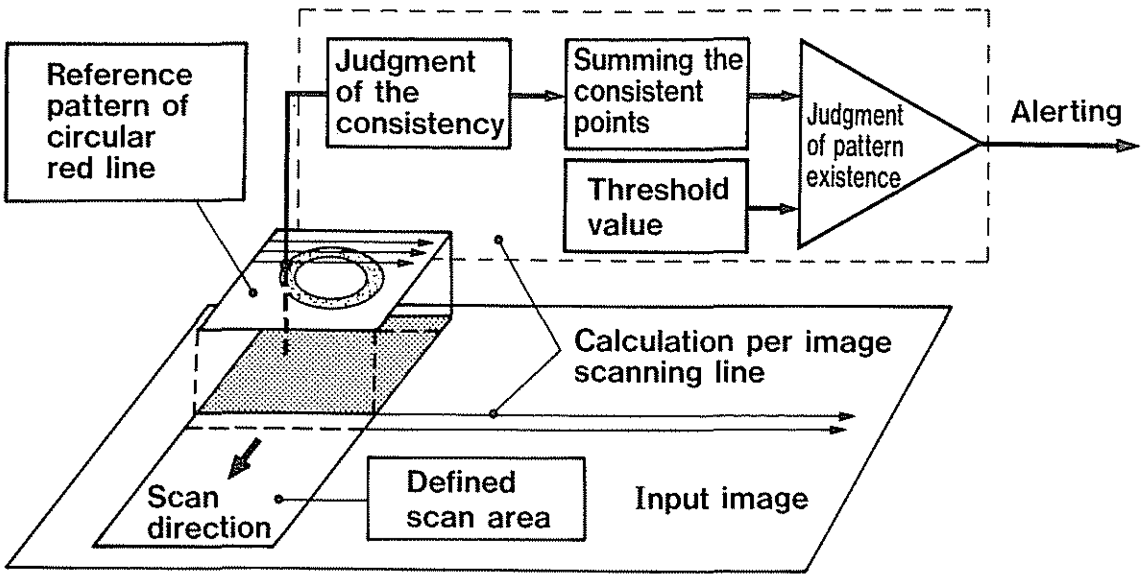

Figure 7. Template Matching Technique

2−3−2 Road sign detection technique

Road sign detection techniques were evaluated for the defined scan area. Extraction conditions were:

1. Extraction of defined patterns.
2. Simple and high−speed processing.

The template matching technique, with its simple algorithm and high−speed processing, was selected.

2−3−3 Implementation through template matching

The template matching technique is indicated in Fig. 7. When the image scanning line is within the defined scan area, the red and blue 1−bit data generated through characteristic extraction is input to the image memory. When the image scanning line is outside the defined scan area, the system performs matching calculations for the input image and the reference pattern. If a pattern is extracted with a correspondence above a pre−set value, the host computer is alerted. This processing sequence is performed for every scan line.

2−3−4 Special features of detection technique

1. It is possible to perform matching calculation and determine the presence of patterns for detection for every scan line.
2. By rewriting the reference pattern and the correspondence value, extraction processing for a variety of pattern shapes and matching levels is possible.
3. Road sign detection is possible within a single field (1/60th of a second).

2−4 Content recognition

2−4−1 Content recognition technique

When road sign detection is performed by the high−speed image processor, the host computer compares input images against the memory to recognize road sign content. The following conditions apply to content recognition:

1. The number of patterns to be recognized is low.
2. Patterns to be recognized are subject to positional deviation, size deviation, and faded and abnormal characters.
3. High−speed processing is essential.

An extended logical matching technique capable of meeting these requirements was adopted.

2−4−2 Extended logical matching technique

The extended logical matching technique is as described below.

1. Fig. 8 indicates the content of the image memory detected by the high−speed image processor. The region marked with '+' is the red extraction region, and the region marked with '@' is the blue extraction region. The '#' symbol indicates value of the histogram generated for the blue extraction region in the horizontal and vertical directions. The position and the size of recognition object are determined by calculating the marginal distribution of the above histogram.
2. As indicated in Fig. 9, the defined area is divided into four and six sub−areas, and the area and center of gravity of each is determined to calculate the structural characteristics of the road sign. The reason for the duplicate division is that a single analysis is incapable of responding to size changes and noise, yielding a higher failure or error rate.
3. The characteristic values determined in step 2 are compared with the standard values stored in the database, and the pattern with the highest correlation becomes the recognized data.

The host computer compares the vehicle speed and the recognized speed limit, and passes the information to the voice systhesizer where required.

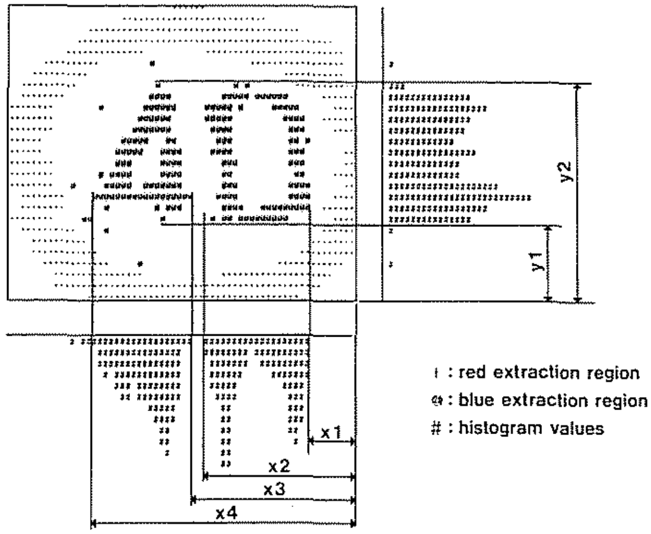

Figure 8. Estimation of Road Sign Position and Size

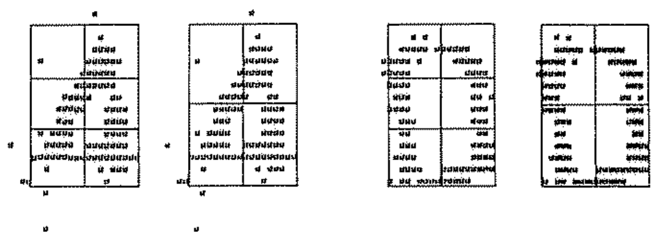

Figure 9. Content Recognition through Extended Logical Matching

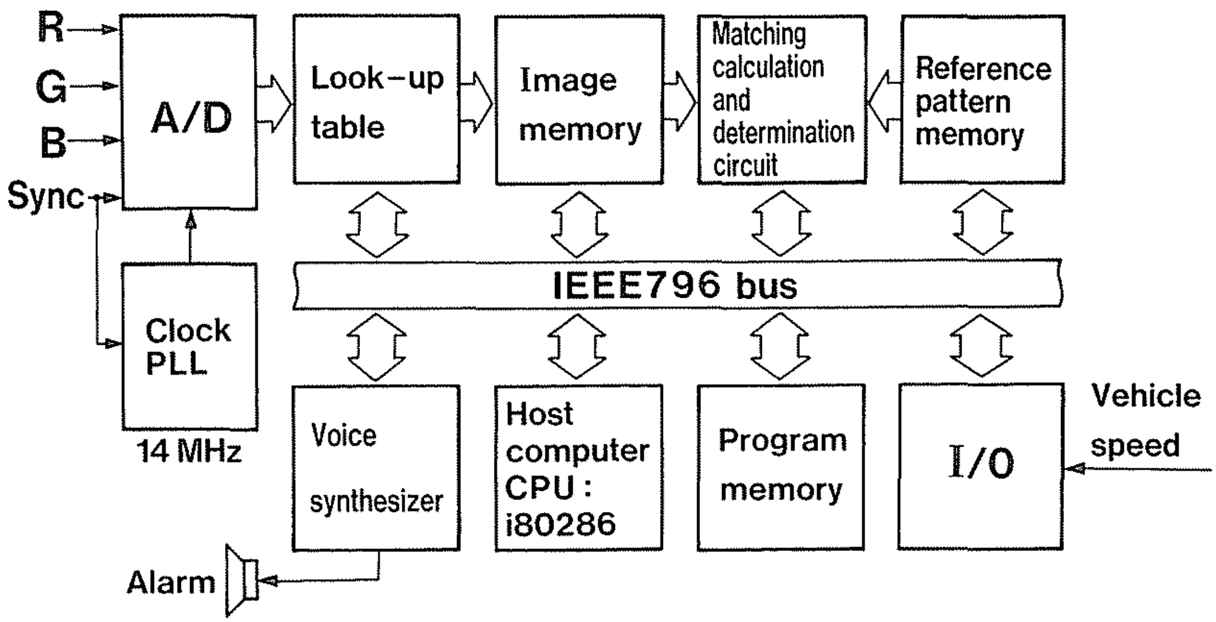

Figure 10. Overall Hardware Configuration

3. SYSTEM CONFIGURATION OF THE HIGH-SPEED IMAGE PROCESSOR

Fig.10 indicates the system configuration of the high-speed image processor. The host computer using an i80286 processor is connected to the image processor via IEEE796 bus. The master clock is 14MHz and is phase-locked by the NTSC Synchronization signal.

The look-up table memory and image memory are each 32KB in capacity, and have a 70ns access time. The high-speed image processor consists of about 200 gate ICs and PLA ICs. The development languages were Assembler and C, with processing requiring high-speed processing such as data transfer written in Assembler.

4. CONCLUSION

4-1 Characteristic extraction

To eliminate the effects of brightness and shadow, a color processing technique using color image data was evaluated, and the development of dedicated hardware enabled high-speed real-time color image processing.

4-2 Road sign detection

Speed limit road signs are surrounded with a circular red line, and the development of the algorithm to determine the presence of road signs through matching for the defined region was carried out, along with the development of the dedicated hardware.

4-3 Road sign recognition

The extended logical matching technique was used to decrease the effects of position and size deviation on the extracted position.

4-4 Processing time

From image input to road sign detection is 1/60th of a second, and content recognition is 0.5 seconds (see Fig. 11).

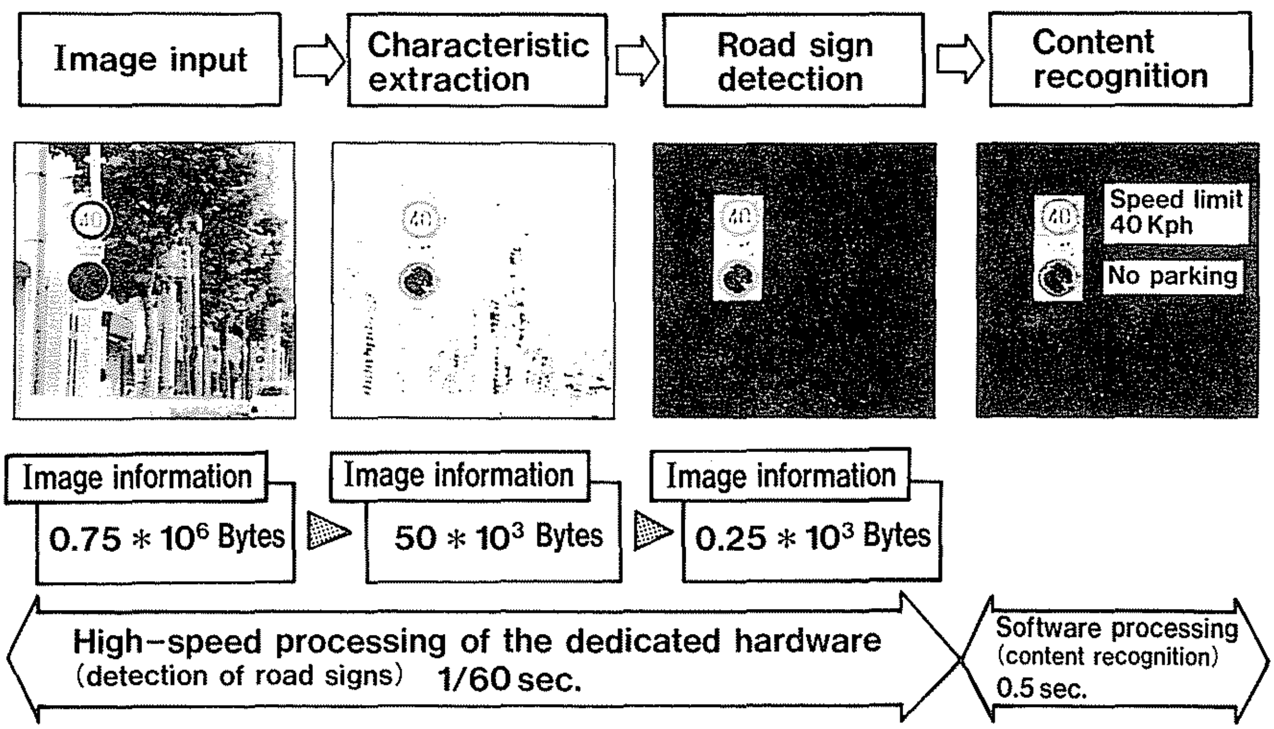

Figure 11. Processing Results

5. SUMMARY

A real-time image processing system handling natural images was developed, with the following features:

1. A pre-processing technique is used, based on color information.
2. It is possible to extract defined patterns from the image.

This image processing system can be applied to a wide range of applications in the processing of natural images, not only to road sign recognition.

Future research and development topics, as indicated in Fig. 12, include the following topics, which will serve to promote the development of an "intelligent" automobile:

1. Parallel processing of input images for recognition of multiple items.
2. High-level processing utilizing artificial intelligence concepts.

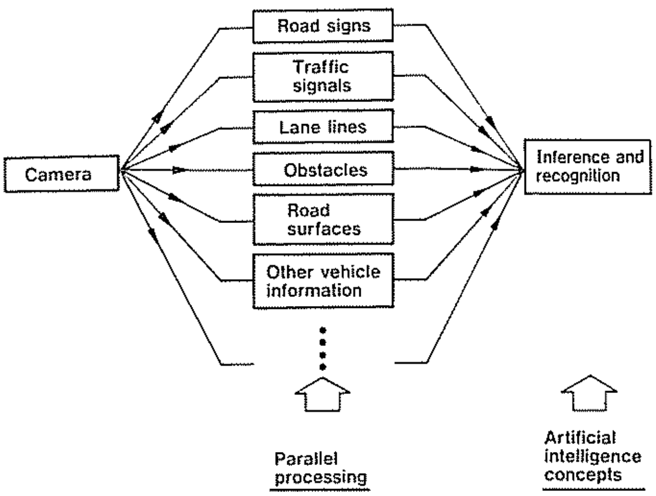

Figure 12. Future Research Themes

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