研 究 速 報

VISION-BASED COMMAND COMMUNICATION FOR UNDERWATER ROBOTS

海中ロボットの視覚に基づくコマンド通信

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I. Introduction

A reliable sensing system is an important aspect in underwater robots. The sensors of the sensing system should not rely on the accurate functioning of external systems for their operation. Measurement errors can be reduced by measuring parameters of interest directly rather than using relative information. The above mentioned conditions are best satisfied with visual sensors. A special feature in optical sensors is that it does not add energy to the surrounding environment. Furthermore, optical information travels at the speed of light so that the band width and latency of visual sensing are introduced only by the camera and subsequent processing. In underwater environments there are no active light sources. Therefore the use of vision with light sources will be ideal for command communication underwater.

This paper describes a vision system, schematically illustrated in Fig. 1, for underwater robots to recognize the commands given to it in the form of a pattern. A set of five square EL (Electro Luminescent)-panels, as shown in Fig. 2 is used to generate the command patterns. The illuminating color of the panel is selected as green since attenuation of green light in water is considerably low. In the case of robot-to-robot communication the panel set is mounted in front of each robot as shown in Fig. 3, and in the case of man-to-robot communication the panel set can be carried by the diver. This type of panel mounting can be utilized in multi-robot systems, and in man-machine interacting systems[1]. The EL-panel's ON/OFF pattern corresponds to a pre-defined control command which can be used for interactive or cooperative task execution in multi-agent systems.

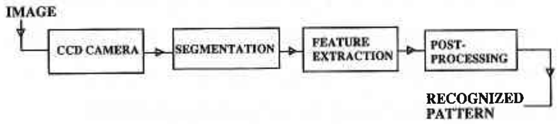

Fig. 1　Block Diagram of the Vision System

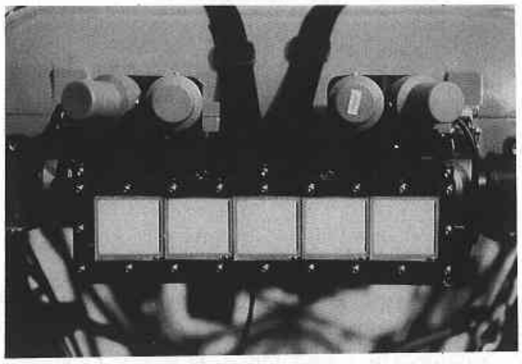

Fig. 2　The EL-Panel

Figure 1 shows the block diagram of the vision system. The image is sensed by the CCD camera. Next, the image is pre-processed to isolate the important features by the segmentation system. The feature extracting system then extracts the important features enabling the post-processing system to recognize the pattern.

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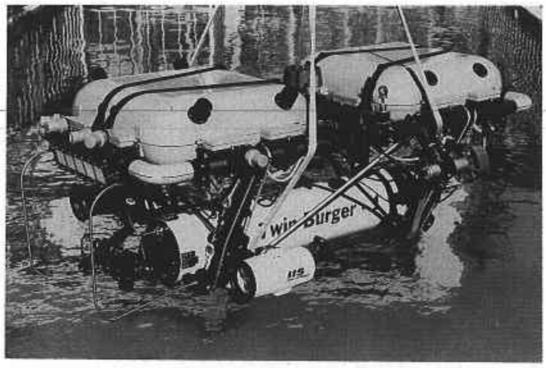


Fig. 3　The Underwater Robot Twin-Burger

II. The Problem Defined

Since human vision simulation by digital image analysis and computer vision is a difficult task, the vision based problem should be defined properly[2),6)]. The target system recognizes the patterns produced by the EL-panel set under the following defined environmental conditions:

1. The illuminating intensity of an EL-panel is higher with respect to the surrounding environment.
2. The distance between the camera and the EL-panel set is about 1m.
3. Rotation of the panel in the panel surface plane is less than 45 degrees with respect to the horizontal.
4. The camera glass surface and the panel glass surface are closely parallel.

III. The Hardware Used

The experimental system consists of a T800 transputer network, as shown in Figs. 4 and 5, for parallel processing, considering the CPUs of the Twin Burger vehicle as the test bed[3)]. The image acquisition system is organized with a color CCD camera and a IMS B429 TRAM for image capturing and front-end image processing which is provided by two IMS A110 DSP chips. The IMS B429 is programmed for edge enhancements and histogram manipulations using the IMS F004 library procedures. In order to observe different stages of the image, the IMS B419 graphics TRAM with the G300 color video controllor is used[9),10)].

IV. Segmentation System

The objective of the segmentation system is to isolate discrete objects from the image for further analysis and classification. Considering the defined condition 1, edge detection has to be considered as pre-processing. The edge detection serves to simplify the analysis of images by drastically reducing the amount of data to be processed, while preserving useful structural information about object boundaries[5),7)].

Gradient Operator Method

An edge in an image corresponds to an intensity discontinuity in the scene. For a continuous image, its derivative has a local maximum at the position of the edge. Therefore, one edge detection technique is to measure the gradient of the image. This is called the gradient operator method. The gradient operators are selected in such a way that the gradients are obtained only in specific directions (compass gradients), i.e.

$$\begin{pmatrix} -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 \\ 2 & 2 & 2 & 2 & 2 & 2 \\ 2 & 2 & 2 & 2 & 2 & 2 \\ -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 \end{pmatrix}$$

This is mainly to reduce the noise generated by edges from unnecessary directions. This method is suitable when the gray-level transition is quite abrupt in the image. When images do not have abrupt gray-level transitions, a second-order derivative such as the Laplace operator might be

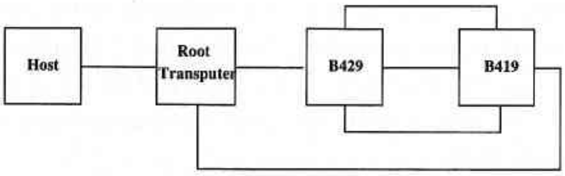


Fig. 4　The Transputer System

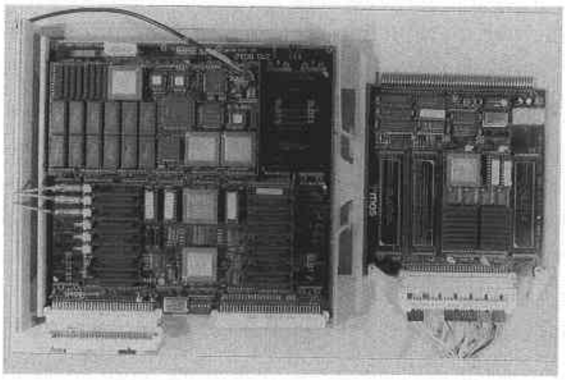


Fig. 5　The Transputer Circuit

useful. But it is observed that the Laplace operator is sensitive to noise compared to the results by the proposed operator method. The image is further processed by a binary transformation to highlight the selected edges.

V. Feature Extracting System

In order to recognize the EL panel's location, the Hough transform criterion is introduced[4),8)].

Hough Transform (HT)

The HT converts a difficult global detection problem into a more easily solved local peak detection problem in a parameter space. It should be emphasized that the HT can be implemented in parallel processors because each image point is treated independently. Due to independent combination of available data, it can recognize partial or slightly deformed shapes. Although the disadvantages of the HT are its large storage and computational requirement, the Twin-Burger computer system architecture can minimize the effect of these disadvantages.

The equation of a straight line can be written as:

$$r = x\cos(\theta) + y\sin(\theta) \qquad (1)$$

For a straight line in the image plane (x, y), r and θ are parameters as shown in Fig. 6. Therefore one straight line in the image plane corresponds to a point in the r, θ plane as shown in Fig. 7. In HT each pixel in the image plane is transformed to the r, θ plane. Points with larger votes p(θ, r) correspond to straight lines and only these points have to be considered for further processing. In the image of the

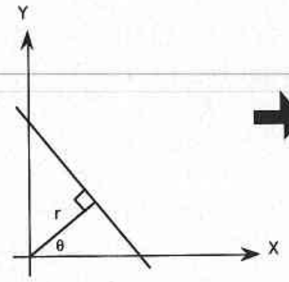


Fig. 6 The Image Plane

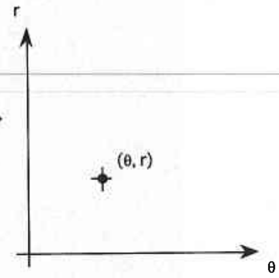


Fig. 7 The Hough Plane

EL-panel set, there are two dominating lines corresponding to the longer sides. These two lines can be extracted from the r, θ plane by thresholding the votes p (θ, r).

VI. Pattern Recognition and Decision Making System

Once the two straight lines are extracted from the HT, the distance (d) between the two lines and the gradients of the lines can be calculated from the r, θ plane as shown in Figs. 8 and 9. The following simple method is introduced to identify the pattern produced by the EL-panel set.

Based on d and θ, the equation of the line passing halfway between the extracted lines can be determined. Scanning is done along this line from left to right until a high intensity is reached. Presently the left most panel is illuminated for every command in order to detect the left edge of the panel set. After detecting the left edge of the panel it is possible to calculate the right edge position of the panel set, which will indicate whether the panel is out of the frame or not. If the panel set is in the frame, thresholding is done in steps of d

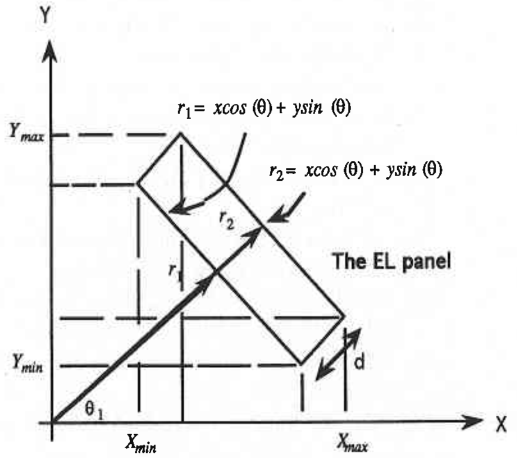


Fig. 8 The EL-Panel in the Binary Plane

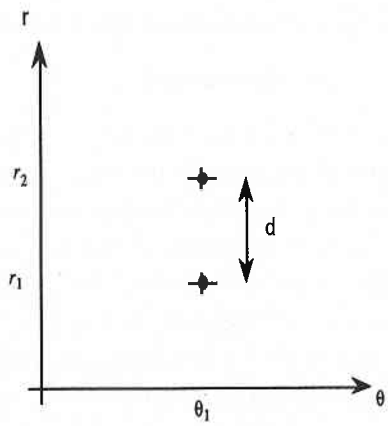
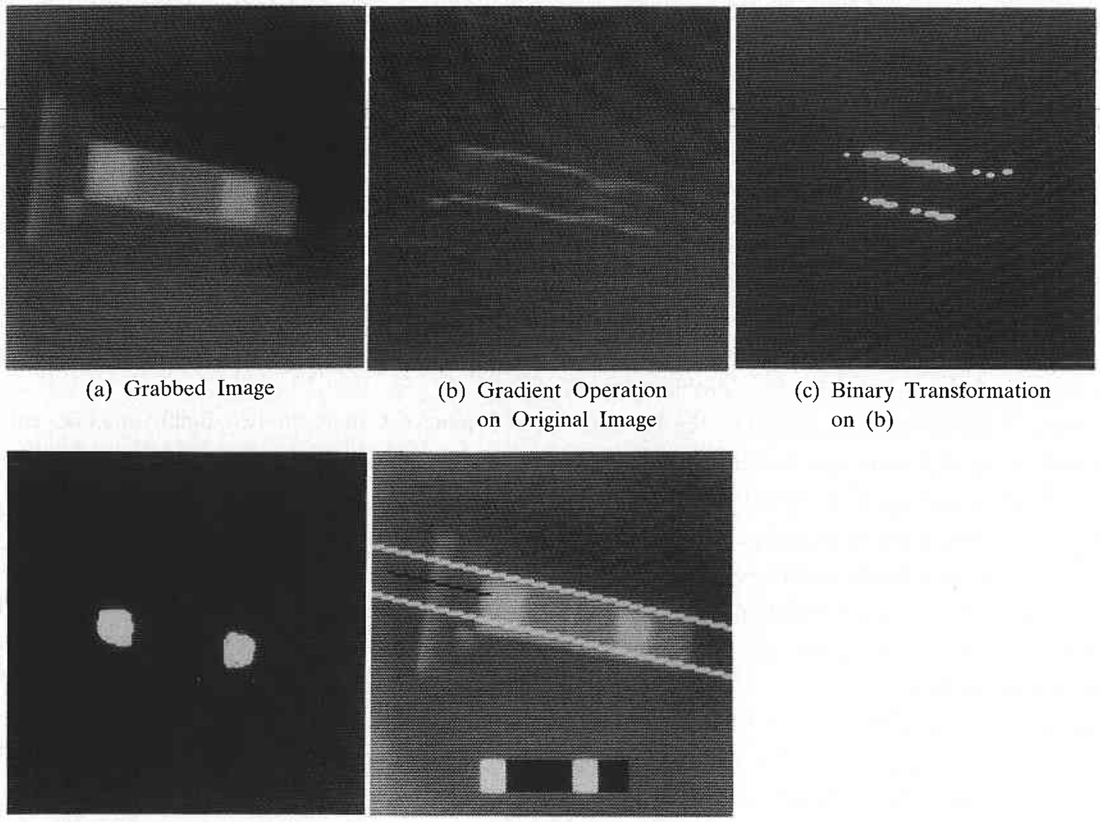


Fig. 9 The Hough Plane



(a) Grabbed Image　(b) Gradient Operation on Original Image　(c) Binary Transformation on (b)

(d) Binary Transformation on Original Image　(e) Detected Frame

Fig. 10 The Images at Different Stages of Image Processing

along the half way line starting from the left edge for a distance of 5d. If the panel set's right edge is out of the frame, using the camera control loop or the vehicle movement control the panel set is brought into the frame. The image at different stages are shown in Fig. 10, where Hex 12 is recognized through the proposed sequence.

VII. Conclusions

The proposed system combines the gradient operation with the Hough transform to detect the image in real-time. It is shown that the system appropriately recognizes the pattern of the EL-panel set fitted at the front of the underwater robot, under the specified conditions. The decision making time on transputers in Fig. 4 is approximately 2 sec, which is not fast but acceptable considering the performance of the target underwater robot.

(Manuscript received, May 31, 1994)

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