A Prototype Software System for Multi-object Recognition and its FPGA Implementation

H. Ando, N. Fuchigami, M. Sasaki and A. Iwata

Graduate School of Advanced Sciences of Matter, Hiroshima University
1-3-1 Kagamiyama, Higashi-hiroshima, 739-8530, Japan
Phone: +81-824-22-7358, E-mail: ando, futigami, sasaki, iwa@dsl.hiroshima-u.ac.jp

1. Introduction

In order to recognize various objects such as humans, animals, and so on, we have to develop highly intelligent information processing systems. Robust image processing techniques are also required under variation in size, orientation, lighting condition, etc. Moreover, it is necessary to develop VLSI hardware systems with the latest integrated circuit technologies.

For the aim of achieving highly information processing, we have proposed a concept of multi-object recognition system based on 3D custom stack system (Fig. 1) presented in the 21st century COE of Hiroshima University [1]. The preliminary experimental results of face detection/recognition have already been obtained [2].

In this paper, as a first step toward realizing a future multi-object recognition system, we propose a real time human face detection/recognition software system based on eigenfaces methods. Moreover, we design object recognition LSI circuits including eigen-space generation circuits and DB matching circuits, and implement these circuits in FPGA.

![Figure 1: A concept of multi-object recognition system based on 3DCSS.](image)

2. Eigenfaces for face detection and recognition

One of the well-known face recognition methods is “Eigenfaces” based on PCA (Principal Component Analysis) [3, 4]. Let us explain the algorithm of this method briefly. An i-th face image consists of M pixels is represented as a vector \( \Gamma_i \). A preprocessed face \( \Phi_i \) is defined by \( \Phi_i = \Gamma_i - \Psi \), where \( \Psi \) represents the average face of N images in DB(database), that is \( \Psi = \frac{1}{N} \sum_{n=1}^{N} \Gamma_n \).

The “eigenfaces” can be calculated as the eigenvectors \( \omega_k \) of the covariance matrix \( C \) of DB, \( C = \frac{1}{M} \sum_{n=1}^{M} \Phi_n \Phi_n^t \), where \( \Phi^t \) is a transposed matrix.

A face image is transformed into so-called “eigen-space” \( \omega_k \) by a simple operation: \( \omega_k = a_k^t \Phi_i \). The eigen-space \( \omega_k \) forms a vector \( \Omega = [\omega_1 \, \omega_2 \, \ldots \, \omega_n] \) that describes the contribution of each eigenface for face image.

Face detection is performed by generally used thresholding methods. A reconstructed image \( \Phi_r \), defined by \( \Phi_r = \sum_{k=1}^{m} \omega_k \alpha_k \), is used as an input of evaluation function for thresholding. For example, Euclidean distance \( \varepsilon = \|\Phi_{in} - \Phi_r\| \) is often used as evaluation function, where \( \Phi_{in} \) is a preprocessed unknown input image. If the value \( \varepsilon \) is lower than a threshold, an unknown input image is classified as a human face.

Face recognition is also achieved with the similar method. If the face space vector \( \Omega_{DB} \) of i-th face image in DB leads to the minimum distance \( \varepsilon_{min} = \|\Omega - \Omega_{DB}\| \), we can know that the input face is the same as i-th face.

By the eigenfaces methods, only an object of the same kind as DB can be recognized. Therefore, we can recognize the various kinds of object by preparing DB corresponding with them.

3. Development of prototype software system based on eigenfaces methods

We developed the prototype software systems for multi-object recognition (Fig. 2). Note that the system is not necessarily limited to the application to human face. Our proposed algorithm in the case of human face recognition shown in Fig. 2(b) is as follows: First, an input image with RGB color spaces is resized to about 100×100 pixels in order to improve the processing time. Second, the candidate of face area is determined by skin color detection. Finally, at the inside area of the candidate region, face detection and recognition are achieved by using the methods explained in Sec. 2. After face detection/recognition was done, the candidate of face area is limited to a small area around the detected face region for the speed-up of the movie picture processing.

In the proposed algorithm, we used Euclidean distance and Correlation coefficient for evaluation functions. Only if both of the evaluation values are satisfied, a face can be detected and the detected face can be recognized. When this condition is not satisfied, the system answers that there is not a face or the detected face does not exist in DB.

We achieved the correct face detection and recognition from natural scenes with the developed software system as shown in Fig. 2(c) and (d). The processing time was about 10–30fps for the captured VGA image by using the latest personal computer.
4. Hardware implementation of object recognition processing

We designed LSI circuits corresponding to object recognition. As mentioned in Sec. 2, object recognition needs calculation of eigen-space, evaluation, and searching for minimum value. Therefore, the object recognition block can be realized by using the eigen-space generation circuits and DB matching circuits as shown in Fig. 3. The eigen-space $\omega_k = a_k^T \Phi$ are calculated by using subtracter, multiplier, accumulator and memory storing average face and eigenfaces. If one use the Euclidean distance for an evaluation function, the DB matching circuits consist of evaluation block including subtracter and multiplier, Winner-take-all (WTA) circuit block for searching for minimum distance, and memory storing eigen-spaces. In this way, the eigenfaces methods can be easily realized by conventional simple digital circuits.

The designed LSI circuits were implemented to the FPGA evaluation board (Fig. 4 (a)). The used FPGA device model was “Xilinx Virtex-II Pro(XC2VP7)”. The specifications of the implemented circuits are shown in Fig. 4 (b), where the evaluation function was the Euclidean distance. As a result, the operation time of one object recognition was about 212\(\mu\)s, where the object image size and the clock frequency were 20\(\times\)20 and 100MHz, respectively. Therefore, we can perform 100 objects recognition per 1ms by employing line-parallel processing.

5. Conclusion

The prototype software systems for multi-object recognition system were developed and real time human face detection and recognition were achieved. The processing time was about 10\(\sim\)30fps by using latest personal computer. Moreover, we designed the object recognition LSI circuits and implemented these circuits to FPGA. The operation time of one object recognition was about 200\(\mu\)s.

We are scheduled to extend the software so that various objects can be recognized and to complete the hardware system including an image input device and object detection circuits.

References

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Object recognition algorithm based on principal component analysis

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Prototype software system based on eigenfaces methods

We developed the prototype software systems for multi-object recognition. Note that the system is not necessarily limited to the application to human face. We achieved the correct face detection and recognition from natural scenes with the developed software system. The processing time was about 10–30fps by using the latest personal computer.

System configuration

| Processor | Dual Xeon 3.06GHz |
| Image capture device | USB Camera |
| Operating system | Windows XP |
| Programming language | Visual C++7.0 and DirectShow |

Hardware implementation of object recognition processing

We designed LSI circuits corresponding to object recognition. Object recognition needs calculation of eigen-space, evaluation, and searching for minimum value. Therefore, the object recognition circuit block can be realized by using the eigen-space generation circuits and DB matching circuits.

Conclusion

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We are scheduled to extend the software so that various objects can be recognized and to complete the hardware system including an image input device and object detection circuits.