Mixed-Mode CMOS Implementation of 2-D Pseudo-Gabor Wavelets for Facial Feature Extraction

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Abstract- **A CMOS implementation of 2-D pseudo-Gabor wavelets is presented. The mixed-mode circuitry, which is a generalization of the R-2R ladder D/A converter, is capable of generating analog features that are useful for face recognition. Experimental results from a 9 x 9 pipelined array fabricated in a 2 micron CMOS process are presented.**

I. INTRODUCTION

Feature extraction is typically the most critical part of any face recognition system. Without the appropriate features, the requirements placed on the classifier are intractable or even impossible to satisfy. One approach is to divide the feature extraction process into many local analyses, operating on local neighborhoods of the image and then recombine the results in the classification stage. Such local analyses perform quite well given the simplicity of the approach. In addition, such analyses are appropriate for silicon implementation.

Wavelets are often used for such local analyses [1], [2]. The dynamic link architecture [3] employed Gabor wavelets similar to the those found in "hypercolumns" in the V1 region of the mammalian visual cortex. The feature extraction process is modeled as a set of correlations (feature "jet") between these wavelets and a local piece of the image. Many jets are generated around the face, usually in a lattice arrangement [3].

Despite the fact that local feature extraction is ideally suited for parallel implementation, it is typically implemented serially and is therefore the *slowest* sub-system in the system. But such local analysis is *ideal* for parallel implementation because each operation can be independent of the others. As a result, there is a great opportunity to exploit this decoupled parallelism in silicon.

II BACKGROUND

The Gabor wavelet is described by (1). The frequency of the wavelet is determined by ω, size by σ, and orientation by x. To achieve various orientations, x is mapped into an alternate coordinate system according to the translation and rotation of the wavelet. Two quadrature wavelets are shown in Fig. 1.

$$Gabor_{x,y} = \exp\left[-\frac{(x-x_o)^2+(y-y_o)^2}{2\sigma}+i\omega(x-x_o)\right] \qquad (1)$$

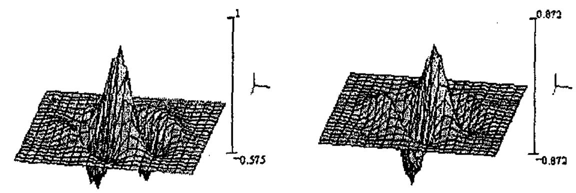


Fig. 1. Ideal Gabor wavelets

III METHODS

A. Generalized R-2R Ladder For Implementing a Single-Mesh Correlator

In order to approximate the envelope of a Gabor-like wavelet, one must produce a gaussian-like distribution. Due to the fact that such distributions occur naturally, it is possible to synthesize them without complex devices. The R-2R ladder network, which is conventionally used as a D/A converter, is one example: a one-dimensional, geometric voltage distribution develops spatially across the nodes of the network]. The R-2R ladder also provides a method of switching analog values in and out of a global sum without disturbing its natural voltage distribution; a requirement for implementing the linear summations of wavelet correlations. Furthermore, the R-2R ladder can be extended to two dimensions as shown in Fig. 2:

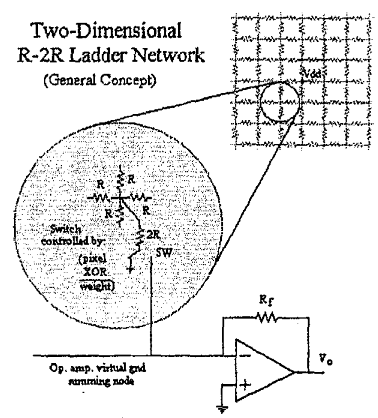
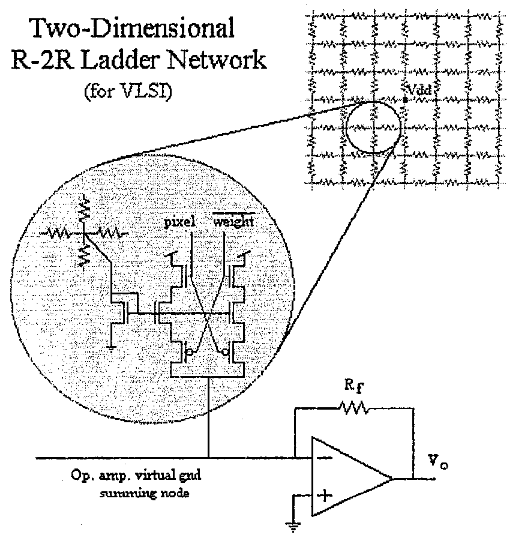
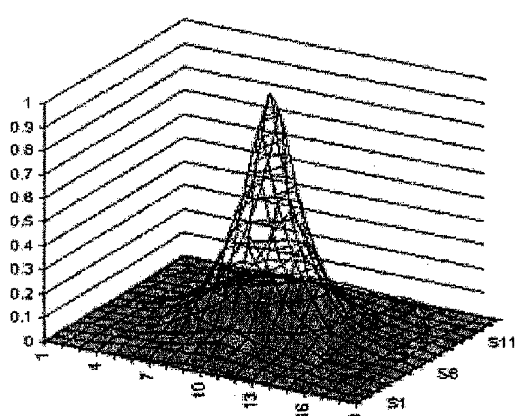


Fig. 2. The generalized R-2R ladder network in two dimensions.

An architecture that is better suited for VLSI is shown in Fig. 3. In this circuit, (Fig. 3a) a switched current mirror is used to form the pseudo-gaussian voltage distribution and to conduct current into a common transresistance according to the binary correlation of local pixels and weight template bits. Essentially, the pseudo-gaussian voltage distribution that develops across the lattice provides a weighted digital correlation between a programmed template and a local binary image. Although the voltage distribution is not a Gabor wavelet, it is very similar to the *envelope* of the Gabor wavelet as shown in Fig. 3b.



(a)



(b)

Fig. 3. The generalized R-XR ladder network for VLSI. (a) circuit architecture (b) resulting (natural) 2-D voltage distribution.

B. Dual-Mesh Architecture

The architecture shown in Fig. 3 only conducts current into the common transresistance if the local pixel and weight are correlated. No current is conducted when they are uncorrelated. To obtain a better approximation of the Gabor wavelet, there must be a means of subtracting an analog current from the global sum when two local cells are uncorrelated. A cell that employs two complementary meshes is shown in Fig. 4. If the local image and weight template are uncorrelated, one of the top legs conducts current *into* the common summing node. Alternately, if the local image and weight template are correlated, one of the bottom legs conducts current out of the common summing node. The amount of current in each case is determined by the appropriate lattice voltage, denoted as $V_{in}+$ (upper positive lattice) and $V_{in}-$ (lower negative lattice). The vertical gate-drain connected NMOS transistors that allow the pseudo-gaussian distribution to form (shown in Fig. 3a) are not shown in Fig. 4.

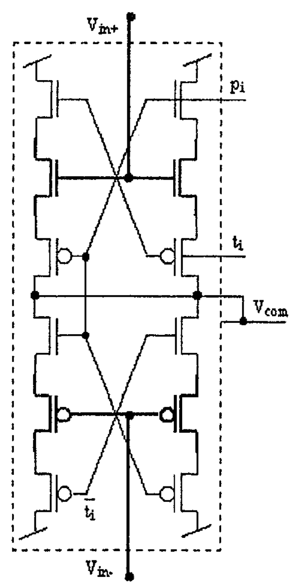


Fig. 4. Local dual-lattice correlation cell (CC).

IV. Experimental Results

A 9 x 9 pipelined dual-lattice correlator was designed and fabricated in the 2.0 µm double-metal, double-poly n-well ORBIT process provided by MOSIS. The schematic is shown in Fig. 5 and the layout and microphotograph of one correlation cell are shown in Fig. 6.

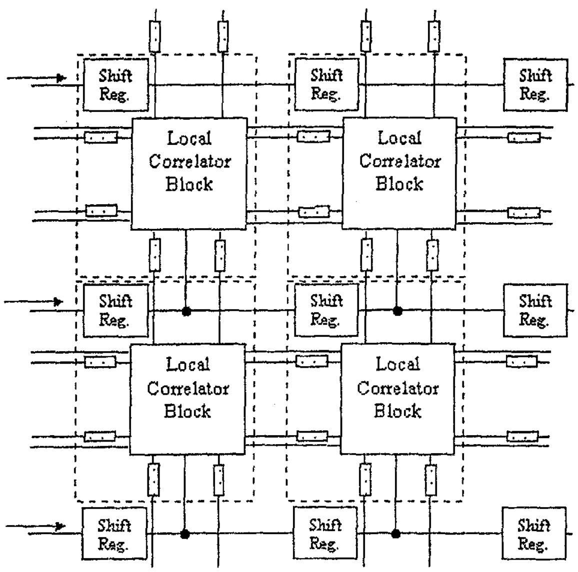


Fig. 5. Schematic of part of the pipelined 2-D dual-mesh correlator design.

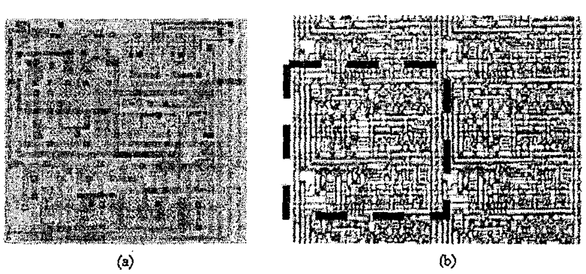


Fig. 6. Layout of one correlation-cell and corresponding microphotograph of the chip.

In order to test the 9 x 9 dual-lattice correlator, a 16-bit ISA interface board with an 8-bit A/D converter was built. In addition, custom software and drivers were written. The test results, which are presented in the next several sections, were encouraging.

A. Sensitivity Measurements

Due to the large number of cells in the array and limited silicon area, the lattice potentials could not be observed directly. Instead, a sensitivity analysis was performed at each position in the array to determine the combined effect of the two lattices, as shown in Fig. 7. For each position in the array, the effect of a local decorrelation was measured and graphed. The overall character of the net distribution is similar to the envelope of the Gabor wavelet.

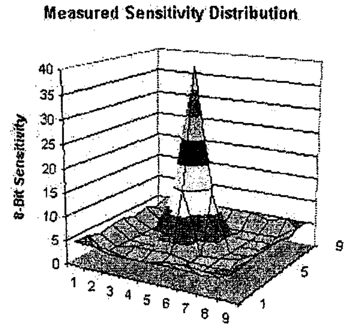


Fig. 7. Measured sensitivity distribution. Bias voltages were as follows: negative center: 0V, negative edge: 1.45V, reference voltage: 2.5V, positive edge: 4V, and positive center: 5V.

B. Filtering and Feature Extraction Results

The dual-lattice correlator was then used to filter images from the FERET database for a set of weight templates with various orientations, as shown in Fig. 8. First, the images were contrast enhanced, softened, and thresholded. Then they were reduced in size to 32 x 48 sq. pixels. As expected, some orientation preference was exhibited, but due to the small region of support, preference was limited. Larger designs will have larger regions of support and thus greater preference.

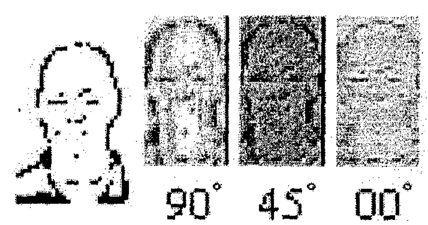


Fig. 8. Experimental filtering results for various orientations.

The dual-lattice correlator was then used to extract features from a set of 20 random faces in the FERET database to test the quality of recognition using a linear combiner classifier with local search capability. For such a small array, surprisingly good results were obtained. First, a set of jets arranged in an elliptical lattice as shown in Fig. 9 was extracted from each of 20 subjects. Then in two different trials, a different image of one of the 20 subjects was presented to the system to determine identity. In each case, the matching score for the correct subject was greater than 92% while the next closest matching score was 88%. Typical matching scores for impostors were between 79% and 86%. The results of two random subjects are shown in Fig. 10. No scale variance was considered since the system was not designed to treat such variance.

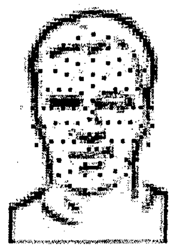


Fig. 9. A reduced-size, contrast enhanced and thresholded face from the FERET database. Each point in the lattice marks the location of a feature "jet".

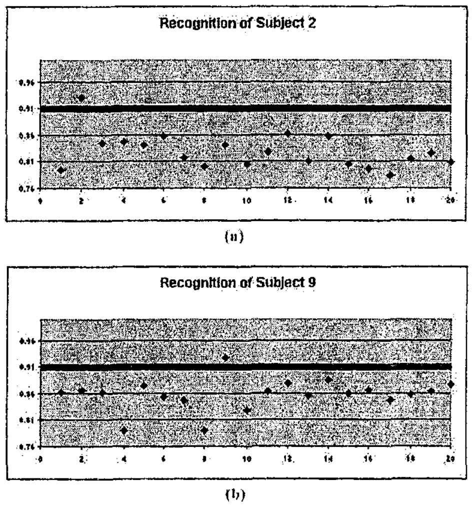


Fig. 10. Experimental face recognition results of two random subjects in the FERET database.

V. CONCLUSIONS

In this paper a CMOS integrated circuit was presented for implementing pseudo-gaussian distributions and switched pseudo-Gabor wavelet correlators. The architecture presented had much in common with the R-2R ladder, a well-known D/A converter circuit. Sensitivity measurements showed that the array possessed an effective pseudo-gaussian voltage distribution. Orientation filtering tests showed that the pseudo-wavelet did exhibit orientational preference for small, processed images. Finally, the pseudo-wavelet was applied to the task of face recognition and it was shown that same-subject trials consistently produced higher matching scores than cross-subject (impostor) trials for images in the FERET database.

ACKNOWLEDGMENTS

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