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   RESEARCH METHODOLOGY

   RESULTS & DISCUSSION

   FINDINGS

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TEXTURE FEATURE EXTRACTION

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ABSTRACT

A feature is nothing but the significant representative of an image which can be used for classification, since it has a property which distinguishes one class from other. The extracted features provide the characteristics of input pixel to the classifier. Feature extraction is used in various pattern recognition applications. This paper aims to compile the recent trends on the usage of feature extraction methods used in the research of texture classification. The study shows that the signal processing methods, such as Gabor filters and wavelets are gaining popularity but old methods such as GLCM are still used but are improved with new calculations or combined with other methods.

KEYWORDS

Computer Vision, Feature extraction, Machine Learning, Pattern Recognition, Texture Classification.

1. INTRODUCTION

Feature extraction is the process to obtain different features from the given images. It is used in texture classification has a large variety of real world problems involving specific textures of different objects. Some of the real world applications that involve textured objects of surfaces include rock classification , wood species recognition, face detection, fabric classification, geographical landscape segmentation and etc. Texture classification techniques are grouped up in five main groups in general, namely 1) structural; 2) statistical; 3) signal processing; 4) model-based stochastic, and; 5) morphology-based methods.

Out of the five groups, statistical and signal processing methods are the most widely used because they can be directly applied onto any type of texture. The rest are not as widely used because the structural methods need to implemented on structured textures which are naturally rare, the model based stochastic methods are not easily implemented due to the complexity to estimate the parameters and morphology-based methods are relatively new and the process are very simple, they may not promise very good textural features. This paper describes the recent trends in feature extraction methods used in the research of texture classification.

2. FEATURE EXTRACTION METHODS

There are many different feature extraction methods that were introduced and used for texture classification problems. Most of these methods that were popularly used in recent years were statistical and signal processing methods.

2.1. GRAY LEVEL CO-OCCURRENCE MATRIX (GLCM)

This method was first proposed by Haralick in 1973 and still is one of the most popular means of texture analysis [10].The key concept of this method is generating features based on gray level co – occurrence matrices (GLCM). The matrices are designed to measure the special relationships between pixels. The method is based on the belief that texture information is contained in such relationships.

Co – occurrence features are obtained from a gray level co – occurrence matrix M, which keeps co – occurrence frequencies of pairs of gray intensity. The matrix M has the parameters d, θ. The value of element (i, j) in M is the frequency with which a pixel (x, y) in gray tone I has a pixel (x', y') in gray tone j in distance d. The angle between the two pixels is θ. It can be described as [10]:

$$M_{i,j} = \#\{((x, y), (x', y')) \in (L_x \times L_y) \times (L_x \times L_y) \mid \quad (1)$$

$$\| (x, y) - (x', y') \| = d, \; arctg\left(\frac{x-x'}{y-y'}\right) = \vartheta\} \quad (2)$$

$$L_x = \{1, 2, \ldots\ldots, W\}, \; L_y = \{1, 2, \ldots\ldots, H\} \quad (3)$$

Where # denotes the number of elements in the set, L_x and L_y denote the horizontal and vertical spatial domain and W and H are the width and height of the image. Normally, ϑ is quantized in four directions (0^0, 45^0, 90^0 and 135^0) [1].

Once the matrix is calculated, fourteen different categories of Haralick features are extracted at angle ϑ and distance d.

They are 1)Angular second moment, 2) Contrast, 3) Correlation, 4) Variance, 5) Inverse difference moment, 6) Sum average, 7) Sum variance, 8) Sum entropy, 9) Entropy, 10) Difference variance, 11) Difference entropy, 12) and 13) two information measures of correlation and 14) Maximal correlation coefficient[10].

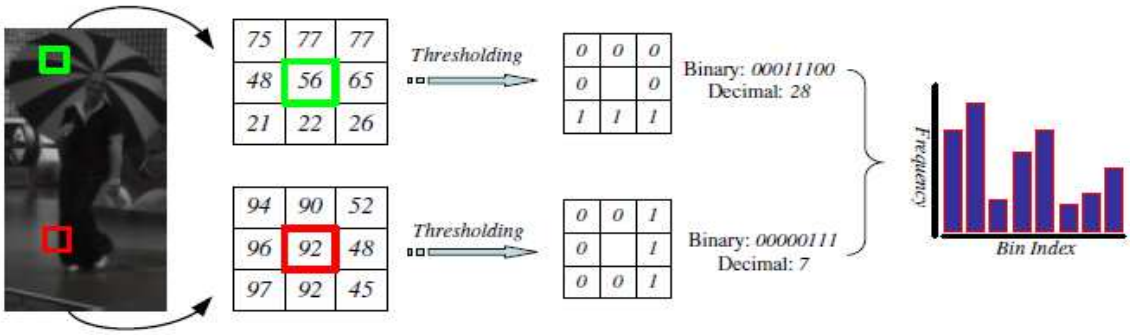
These features have been widely used in machine vision, for example in remote sensing, document image understanding and image database retrieval. The first feature " Angular second moment" measures textural uniformity, the second feature contrast implies the special frequency of textures and the third feature Correlation describes gray tone linear dependency which is a way to describe texture homogeneity.

In texture analysis community, this method is known by several names, including Co – occurrence measures, Gray Level Co – occurrence Matrices (GLCM), Spatial Gray Level Dependence Matrices (SGLDM) and the Harlick method.

2.2. LOCAL BINARY PATTERNS (LBP)

The idea of LBP (local binary pattern) is originally proposed by Ojala et al. in [15] for the aim of texture classification, and then extended for various fields, including face recognition, face detection, facial expression recognition etc. The most attractive advantages of LBP are its invariance to monotonic gray-scale changes, low computational complexity and convenient multi-scale extension. The philosophy behind LBP is simple and elegant: unify statistical and traditional structural methods.

FIGURE 1. ILLUSTRATION OF LBP. TYPICALLY THE BINARY CODES OBTAINED BY LOCAL THRESHOLDING ARE TRANSFORMED INTO DECIMAL CODES. NOTE THAT IN THIS EXAMPLE WE USE A THRESHOLD OF 30, WHICH IS SLIGHTLY DIFFERENT FROM THE ORIGINAL LBP. SEE TEXT FOR MORE DETAILS



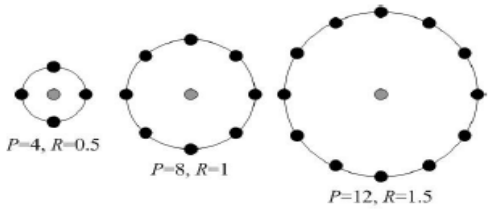
In Figure 1, we give an illustration for how LBP serves as local descriptor. Each neighbor pixel is compared with the center pixel, and the ones whose intensities exceed the center pixel's are marked as"1", otherwise as"0". In this way we get a simple circular point features consisting of only binary bits. Typically the feature ring is unfolded as a row vector; and then with a binomial weight assigned to each bit, the row vector is transformed into decimal code for further use. For clarity, we adopt the same notation $LBP_{P,R}$ as in [14], where R is the radius of the circle to be sampled (see Figure 2), and P is the number of sampling points. Examples for various choices of these two parameters can be found in Figure 2. It is obvious to see that LBP can be effortlessly extended to the multi-scale case. Denote the ring feature for image pixel (x, y) as $B(x, y) =< b_{P-1}, \ldots, b_1, b_0 >$, where $bi \in \{0, 1\}$. It is common to transform $B(x, y)$ into decimal code via binomial weighting:

$$LBP_{P,R}(x,I\ y) = \sum_{i=0}^{p-1} b_i\, 2^i \qquad (4)$$

which characterizes image textures over neighborhood of (x, y). And a 1D histogram for a target image region can be built by counting the frequencies of each value of LBP codes, which is finally normalized with L1-norm or L2-norm as image region representation.

An important special case of LBP is the uniform LBP. A LBP descriptor is called uniform if and only if at most two bitwise transition between 0 and 1 over the circulated binary feature. For example, 00000000 (0 transition), 11100011 (2 transitions) are uniform, while 01010000 (4 transitions), 01110101 (6 transitions) are non-uniform ones. An important observation was made by Ojala et al. [15] that in texture images, majority of LBP features can be categorized to be uniform. In practice, all non-uniform LBP are labeled with a single label, while each uniform LBP is cast into a unique histogram bin according to its decimal value.

FIGURE 2: MULTI - SCALE LBP. R: RADIUS OF SAMPLING CIRCLE. P: NUMBER OF SAMPLING PIXELS.



2.3. GABOR FILTERS

In 1946 Dennis Gabor proposed a method to represent signals in both the time and frequency domains. Unlike the Fourier series, this method allows the analysis of local information rather than just global information. However Gabor's analysis method went almost unnoticed until the early 1980's. It was proposed as a texture analysis method by Turner [6] and Clark et al. [17] in the middle 80's.

A Gabor filter is a harmonic oscillator, composed of a sinusoidal plane wave of a particular frequency and orientation with a Gaussian kernel [3]:

$$\Psi(x, y; \sigma, u, v) = \{exp\frac{-(u^2+v^2)}{2\sigma^2}\ (x^2 + y^2)\}\exp\ i(ux + vy) \qquad (5)$$

Where (x, y) are the variables representing position in the spatial domain, (u, v) are the spatial frequencies and σ is the width of the Gaussian. The Gabor transform, $G(u, v)$, of an image fragment, $I(x, y)$, is defined as the convolution of a Gabor kernel ψ with I:

$$G(u, v) = \int\int \psi(x, y; \sigma, u, v)\, I(x, y)\, dx\, dy \qquad (6)$$

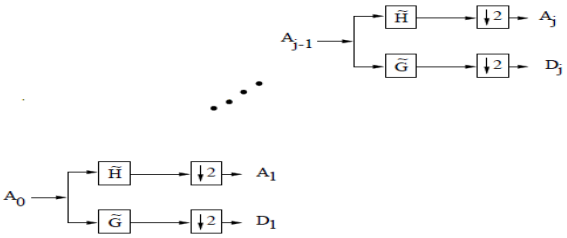
The Gabor filter is frequency and orientation selective. The orientation of the filter, which is defined as $\vartheta = tan^{-1} v / u$ and the size of image fragments are adjustable. The Gabor features are generated from filtered images proposed by a Gabor filter at a certain size and a certain angle, for example the energy or variance of the filtered images. Gabor filters have been applied in various domains in machine vision, such as texture analysis, face recognition and handwriting recognition. Gabor filters are considered a powerful analysis tool.

2.4. WAVELET TRANSFORM

Wavelet transform is a type of signal representation that can give the frequency content of the signal at a particular instant of time. In this context, one row/column of image pixels can be considered as a signal. Applying a wavelet transform on such a signal decomposes the signal into different frequency sub-bands (for example, high frequency and low frequency sub-bands). Initially, regions of similar texture need to be separated out. This may be achieved by decomposing the image in the frequency domain into a full sub-band tree using filter banks [9]. Each of the sub-bands obtained after filtering has uniform texture information. A filter bank based on wavelets could be used to decompose the image into low-pass and high-pass spatial-frequency bands [12].

We will now briefly review the wavelet-based multi-resolution decomposition. To have the multi-resolution representation of signals we can use a discrete wavelet transform. We can compute a coarser approximation of input signal A_0 by convolving it with the low pass filter H and down sampling the signal by two [13]. By down sampling, we mean skipping every other signal sample (for example a pixel in an image). All the discrete approximations A_j, $1 < j < J$, (J is the maximum possible scale), can thus be computed from A_0 by repeating this process. Scales become coarser with increasing j. Figure 3 illustrates the method.

FIGURE 3: BLOCK DIAGRAM OF MULTI-RESOLUTION WAVELET TRANSFORM



We can extract the difference of information between the approximation of signal at scale *j -1* and *j*. D_j denotes this difference of information and is called detail signal at the scale *j*. We can compute the detail signal D_j by convolving A_{j-1} with the high pass filter *G* and returning every other sample of output. The wavelet representation of a discrete signal A_0 can therefore be computed by successively decomposing A_j into A_{j+1} and D_{j+1} for $0 \le j < J$. This representation provides information about signal approximation and detail signals at different scales. We denote wavelet representation of signal A_0 after *K* levels as $\{A_k, D_k, D_{k-1}, \ldots, D_1\}$, $1 \le k \le j$. The idea of using multi-resolution property of wavelets in clustering is to use the features of the wavelet coefficients at the coarse scale levels.

Corresponding to the lowpass filter, there is a continuous-time scaling function $\phi(t)$, and corresponding to the highpass filter, there is a wavelet $\omega(t)$. The dilation equation produces $\phi(t)$, and the wavelet equation produces ω (t) [4]. For example, for Haar wavelet transform with $H = [1/\sqrt{2}, 1/\sqrt{2}]$, and $G = [1/\sqrt{2}, -1/\sqrt{2}]$, the dilation equation is,

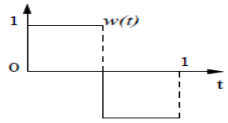
$$\phi(t) = \phi(2t) + \phi(2t - 1) \quad (7)$$

and the wavelet equation is

$$\omega(t) = \phi(2t) - \phi(2t - 1) \quad (8)$$

Figure 4 shows the Haar wavelet $\omega(t)$.

FIGURE 4: THE HAAR WAVELET *Ω (T)*

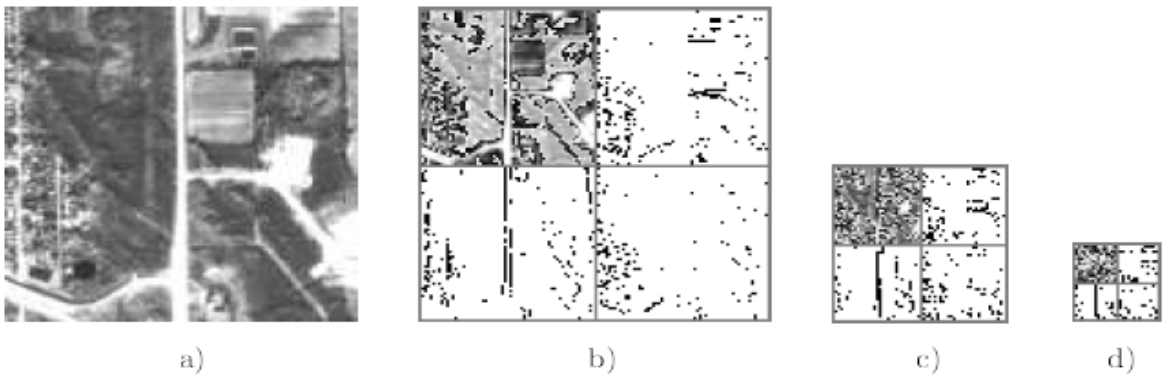


We can easily generalize wavelet model to 2 dimensions for images, in which we can apply 2 separate one-dimensional transforms [5]. The image is first filtered along the horizontal *(x)* dimension, resulting in a lowpass image *L* and a highpass image *H*. We then down sample each of the filtered images in the *x* dimension by *2*. Both *L* and *H* are then filtered along the vertical *(y)* dimension, resulting in four subimages : *LL*, *LH*, *HL*, and *HH*. Once again, we down sample the subimages by *2*, this time along the *y* dimension. The two-dimensional filtering decomposes an image into an average signal *(LL)* and three detail signals which are directionally sensitive: *LH* emphasizes the horizontal image features, *HL* the vertical features, and *HH* the diagonal features.

Figure 5-a show a sample airphoto image. Figures 5- b, c, and d show the wavelet representation of the image at three scales from fine to coarse. At each level, sub-band *LL* (the wavelet approximation of the original image) is shown in the upper left quadrant. Sub-band *LH* (horizontal edges) is shown in the upper right quadrant, sub-band *HL* (vertical edges) is displayed in the lower left quadrant, and sub-band *HH* (corners) is in the lower right quadrant.

Feature extraction and clustering methods can use any appropriate wavelet transforms such as Haar, Daubechies, Cohen-Daubechies-Feauveau or Gabor wavelet transforms

FIGURE 5: MULTI-RESOLUTION WAVELET REPRESENTATION OF AN AIR PHOTO IMAGE: A) ORIGINAL IMAGE; B) WAVELET REPRESENTATION AT SCALE 1; C) WAVELET REPRESENTATION AT SCALE 2; D) WAVELET REPRESENTATION AT SCALE 3.



Applying wavelet transform on images results in wavelet coefficients corresponding to each sub-band. We can extract different features from wavelet coefficients of each of these sub-bands. Next subsection explains the features that we used in the experiments.

2.5. INDEPENDENT COMPONENT ANALYSIS

Assume a set of training images $X = [x_1, x_2, \cdots, x_n]$, where each column vector x_i represents an image and the total number of training samples is n. The general model of ICA can be described as follows:

$$X = AS \quad (9)$$

where $S = [s_1, s_2, \cdots, s_n]$ is the coefficient, *A* is a square mixing matrix and its column vectors are basis functions. The independent component analysis is to find a separating matrix W_I, so that

$$U_I = W_I X \quad (10)$$

approximates the independent component *S*, possibly per muted and rescaled. The components of *S* are as mutual independent as possible.

Many methods have been proposed to learn the separating matrix W_I. For example, Bell and Sejnowski [2] developed a simple learning algorithm based on the information maximization, and it is improved by Amari [11] with a natural gradient method for better convergence. Their learning algorithm for W_I can be summarized as the following:

$$\Delta W_I = (I + g(y)\, y^T)\, W_I \quad (11)$$

Where, $y = W_I X$ and $g(y) = 1 - \frac{2}{1+e^{-y}}$

Before the learning procedure, a preprocessing operation W_P, known as whitening or sphering, is required for most ICA learning algorithms. The transformed data is zero- mean, decorrelated data:

$$W_P X X^T W_P^T = I \quad (12)$$

This transformation can be accomplished by eigen value decomposition. In fact, when $W_P = \Lambda^{-1/2} V^T$, the Eq.(4) can be satisfied. Here, Λ and V are the eigen values matrix and eigenvectors matrix of the covariance matrix of X, respectively.

2.6. REGION COVARIANCE MATRIX

Region covariances were introduced by Tuzel et al. [16] as a novel region descriptor for object detection and classification. Given an image I, let φ define a mapping function that extracts an n-dimensional feature vector z_i from each pixel $i \in I$, such that

$$\varphi(I, x_i, y_i) = z_i, \qquad (13)$$

where $z_i \in R^n$, and (x_i, y_i) is the location of the ith pixel. A given image region R is represented by the $n \times n$ covariance matrix C_R of the feature vectors $\{z_i\}_{i=1}^{|R|}$ of the pixels in region R. Thus the region covariance descriptor is given by,

$$C_R = \frac{1}{|R|-1} \sum_{i=1}^{|R|} (z_{i-\mu R})\ (z_{i-\mu R})^T \qquad (14)$$

where, μR is the mean vector,

$$\mu R = \frac{1}{|R|} \sum_{i=1}^{|R|} z_i \qquad (15)$$

The feature vector z usually consists of color information (in some preferred color–space, usually RGB) and information about the first and higher order spatial derivatives of the image intensity, depending on the application intended.

Although covariance matrices can be positive semi–definite in general, the covariance descriptors themselves are regularized by adding a small constant multiple of the identity matrix, making them strictly positive definite. Thus, the region covariance descriptors belong to S^n_{++}, the space of $n \times n$ positive definite matrices which forms a connected Riemannian manifold. Given two covariance matrices C_i and C_j, the Riemannian distance metric $d_{geo}(C_i, C_j)$ gives the length of the geodesic connecting these two points on this manifold. This is given by [7],

$$d_{geo}(C_i, C_j) = ||\log(C_i^{-1/2} C_j C_i^{-1/2})||_F \qquad (16)$$

where $\log(\cdot)$ represents the matrix logarithm and $||\cdot||_F$ is the Frobenius norm. Many existing classification algorithms for region covariances use the geodesic distance in a K-nearest-neighbor framework. The geodesic distance can also be used with a modified K-means algorithm for clustering.

Methods for fast computation of region covariances using integral images [8] enable the use of these compact features for many practical applications that demand real–time performance. For texture characterization, spatial derivatives are suitable features [16], whereas for face recognition, region covariances are constructed from outputs of a bank of Gabor filters. Covariance descriptors are used for probabilistic tracking using particle filtering, multi–object tracking using region covariances and particle filters, improve the classification accuracy, for pedestrian detection and semi- supervised clustering.

2.7. OTHER FEATURE EXTRACTIONS

There are many other feature extractions that are not popularly used in recent years which some are recently proposed, including model-based stochastic methods, e.g. fractals and Markov random field. Also includes some other methods, e.g. Sequential Approximation Error Curves (SAEC) , Basic Image Features, Spectral Correlation Function (SCF), Legendre Spectrum and Multiscale Blob Features (MBF).

3. CONCLUSION

It is easily noticeable that signal processing methods are very popularly used in the recent years, especially for Gabor filters and wavelets. Although these methods require more computation as they are examining the frequency domain, the accuracy obtained is good and usually outperform older and simpler techniques. The old technique like GLCM is however yet to be forgotten in the field of texture classification because it is one of the simplest textural feature which is old but is computationally inexpensive. It remains to be mainly used as a baseline algorithm for comparative studies especially when a new application of texture classification is experimented. The GLCM is however more commonly used in some improved or combined ways recently but none of these variants have grown into a major trend.

The major trend of the research today in terms of feature extraction for texture classification is accuracy- oriented, however usually the newer algorithms that promises better accuracy is much more complicated in its calculations and often sacrifices the speed of the algorithm. The signal processing methods for example is a relatively slow algorithm with a higher accuracy. The region covariance matrix is new in the area of texture classification. It has the potential to become the next trend due to its fast computations using integral images.

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