Leather Inspection Through Singularities Detection Using Wavelet Transforms

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Abstract. The major problem in leather inspection is to separate defects from the background exhibiting a wide range of visual appearances. Leather defects, characterized by oriented structures, cannot be easily discriminated from the structures typical of the normal surface. Though gaussian filters generally represent a successfull tool to smooth out the structures on the background, a wrong choice of the resolution can preclude the detection of defective regions (singularities) in the subsequent analysis. However, wavelet transforms can be profitably used for studying the evolution of singularities across different scales. Suitable kernels for this transform does allow multiscale singularities analysis through the detection of local maxima in wavelet transform modulus.

1 Introduction

The proposed system address the *receiving inspection* problem of raw leather, with the aim of detecting, locating and classifying defects. The method is based on the analysis of oriented textures, a recurrent characteristic in this particular application context. Leather, due to its natural origin, does exhibit a wide range of visual appearances (it is not homogeneous in color, thickness, brightness, and finally in wrinkledness) depending on the original skin characteristics and on many parameters tied to the subsequent curing processes. Textural **background** of leather surface consists of a complex structure similar to a composition of classical basic classes considered in literature [2]: *strongly ordered textures* obtained as regular placement of primitive elements, *weakly ordered textures* with some degree of varying orientation specificity and *disordered textures* with neither repetitiveness nor orientation. However, the structure of **defects** occurring on leather surface (fold, lash, gored, wart, eczema) depends on the particular event (often due to natural reasons) which generated them. Therefore, separating defects from background is not an easy task. Both **directionality and local variation** of intensities must be exploited for efficiently solve this problem. In fact, leather defects produce sharp variation points (or edge points) with high directionality. The solution is related to an analysis of the derivatives of the image smoothed with a Gaussian filter. The gradient vector of the smoothed image indicates at each point the direction along which the derivative has the largest absolute value. Points with maximum modulus are inflection points (sharp variation points) of the smoothed image. Directionality is efficiently estimated through the *coherence image* [3] measuring locally the accord between image gradient orientations. Because we are interested in sharp intensity variations with high directionality, we have to search through local maxima associated to high coherence values for finding defect edges. Actually, different kind of leather with different defects exhibit different textural contents at different scales. At finer scales, patterns have a lot of edges on the background, while generally at coarser scales edges corresponding to defects dominates. Since the description of texture may vary according to the scale, its analysis must be done at several resolutions. Several attempts [4][5][6] [7] [8][9][10] have been made to incorporate multiresolution processing in computer vision algorithms. The **wavelet theory** provides a framework for combining the information about modulus maxima produced by sharp variations across different scales and for characterizing the associated edges. Detecting edges through local maxima derivatives is equivalent to finding local maxima of suitable wavelet transform modulus. In mathematics, the local regularity of a function is often evaluated using Lipschitz exponents. Mallat et al. [1] have proved that local maxima of wavelet transforms detect all the singularities of signals and that the corresponding local Lipschitz exponents can be estimated from the evolution across scales of these local maxima. The proposed method combines several information for removing textural background. Image singularities are discriminated by analyzing maxima of a wavelet transform, indicating the location of edges. Further elements for this discrimination are provided by the geometrical properties of the maxima curves and the evolution across scales of the wavelet transform values along these curves. Finally even the coherence of gradient vectors is profitably used for increasing the evidence of defective regions. In the following sections after a short review of the edge detection by wavelet transform theory we describe as wavelets can be used to evaluate local regularity of functions from a multiscale representation (section 2). The proposed strategy for leather inspection relies on the integration between singularity detection and characterization using wavelet transforms and a-priori knowledge about geometrical properties of edges in the image (section 3). Finally, experimental results obtained on images acquired with a TV camera from defected pieces of leather are shown (section 4).

2 Edge detection and Local Regularity Characterization through wavelet transforms

Most multiscale edge detectors smooth the signal at various scales and detect sharp variation points from their first or second order derivatives. Extrema of the first derivative correspond to zero crossing of the second derivative and to inflection points of the smoothed signal.
A 2D smoothing function is any function $\theta(x, y)$ whose integral over x and y is equal to 1 and converges to 0 at infinity. We choose $\theta(x, y)$ equal to a Gaussian.

Let us relate this edge detection schema to a 2D wavelet transform. We suppose that $\theta(x,y)$ is differentiable and define $\psi^1(x,y)$ and $\psi^2(x,y)$ as the first partial derivative of $\theta(x,y)$ with respect to x and y respectively. These two functions can be considered to be wavelets because their integrals are equal to 0. A wavelet transform is computed by convolving the signal with a wavelet dilated by a scaling factor s. The wavelet transform $W_s f(x,y)$ of $f(x,y)$ at the scale s has two components defined by the convolution of f with the two wavelet functions ψ^1 and ψ^2. The wavelet transforms $W_s^1(x,y)$ and $W_s^2(x,y)$ of $f(x,y)$ can be proved to be proportional to the two components of the gradient vector $\nabla(f * \theta_s)(x,y)$ of the signal smoothed at the scale s. Hence, they can be used for locating edge points. The direction of the gradient vector at a point indicates the direction along which the directional derivative of $f(x,y)$ has the largest absolute value. Edge points (inflection points of the surface $f * \theta_s(x,y)$) are points where the modulus of the gradient vector is locally maximum.
These local maxima define lines, in the scale-space (s,x,y), indicating the locations of singularities. All the singularities of $f(x,y)$ can be located by following the maxima lines when the scale goes to 0.

A remarquable property of the wavelet transform is its ability to characterize the local regularity of a function using Lipschitz exponents.
A function $f(x,y)$ is said to be uniformly Lipschitz α over an interval $]a,b[\times]c,d[$ if and only if there exists a constant A such that for any $(x,y) \in]a,b[\times]c,d[$ and any scale s,

$$\|W_s f(x,y)\| \leq A s^{\alpha} \tag{1}$$

If $f(x)$ is differentiable at (x_0,y_0), then it is Lipschitz $\alpha = 1$. As the uniform Lipschitz regularity approaches 0, the corresponding singularity becomes less and less regular. If $f(x,y)$ is discontinuous but bounded in the neighborhood of (x_0,y_0), its uniform Lipschitz regularity in the neighborhood of (x_0,y_0) is 0.
Equation 1 is a condition on the asymptotic decay of $\|W_s f(x,y)\|$ when the scale s goes to zero.
Information about Lipschitz regularity can be supplied by the decay of $\|W_s f(x,y)\|$ in the neighborhood of maxima lines: the values of local maxima can be used for estimating the Lipschitz exponents of signal irregularities. From the equivalence of equation 1 with the following

$$\log \|W_s f(x,y)\| \leq \log(A) + \alpha \log(s) \tag{2}$$

we derive the Lipschitz regularity at a point (x_0,y_0) is the maximum slope of straight lines that remain above $\log \|W_s f(x,y)\|$, on a logarithmic scale. The Lipschitz exponents are computed by finding the coefficient α such that As^{α} approximates at best the decay of $\|W_s f(x,y)\|$ over a given range of scales larger than 1. It has been proved [1] that if a signal is singular at a point (x_0,y_0) there exist a sequence of wavelet transform modulus maxima that converge to (x_0,y_0) when the scale decreases. Hence, we detect all the singularities from the positions of the wavelet transform modulus maxima. Moreover, the decay of the wavelet transform is bounded by the decay of these modulus maxima, and we can thus measure the local uniform Lipschitz regularity from this decay. If the uniform Lipschitz regularity is positive, the amplitude of the wavelet transform modulus maxima should decrease when the scale decreases. If the wavelet transform maxima increase when the scale decreases, singularities can be described with negative Lipschitz exponents, meaning that they are more singular than discontinuities.

3 Textural Background removal

Convolving an image with a Gaussian filter can remove part of the textural background but also removes high frequencies smoothing the signal singularities. In our application context, defects are singularities with positive Lipschitz regularity, while discontinuities on the background are singularities with negative Lipschitz exponents, then the values of the wavelet local maxima located on the background decrease on average, when the scale increases. In the neighborhood of singularities with positive Lipschitz exponents, the local maxima of wavelet transform have an amplitude increasing or remaining constant when the scale increases. In order to remove the background components, we suppress all the maxima that do not propagate along enough scales or whose average amplitude increases when the scale decreases.
We use also an a-priori knowledge on the geometrical properties of the image singularities in the image plane. As previous announced, leather defects are sharp variation points (or edge points) with high directionality. Therefore smooth changes occur in the gradient vectors along edges. Directionality can be estimated efficiently by analyzing the *coherence image* computed as described by Rao and Schunck [3]. The coherence measures locally the accord between image gradient orientations. It is essentially based on normalizing and projecting the gradient vectors of a given neighborhood on a given orientation. In our case we compute the coherence of the orientation of sharp points (with module maxima) with respect to neighboring gradient orientations. If the vector is coherent, its normalized projections will be close to one; otherwise they will tend to cancel producing results close to zero. Being $\alpha(x_0, y_0)$ the gradient direction at point (x_0, y_0), the measure of coherence in that point is given by

$$G(x_0, y_0)\frac{\sum_{(x,y)\in W} \| G(x,y)\cos(\alpha(x_0,y_0) - \alpha(x,y)) \|}{\sum_{(x,y)\in W} G(x,y)} \tag{3}$$

Leather defects are selected between sharp variation image points with high coherence values.

Lipschitz regularity is estimated by considering at each scale points with maximum module and high coherent argument. These points define curves in the scale-space (s, x, y). We say that a point propagates from a scale s to a scale $s+1$, if and only if, they belong to the same curve in the scale space. This propagation algorithm is particularly useful to compute the Lipschitz exponents of singularities. The algorithm removes the points that do not propagate up to the scale 2^3 or propagate with an average modulus value that increases when the scale decreases (that is having negative Lipschitz regularity). At each level the remaining local maxima are organized into chains by grouping neighboring points on the base of the gradient orientation given by $A_s f(x, y)$ which is supposed to vary smoothly along edges in the image, after smoothing by $\theta_s(x, y)$. All the chains whose length is smaller that a given threshold are assigned to the background and removed. The following step does average the values of the remaining maxima along each maxima chain. This operation is legitimate by the knowledge about most interesting features that have maxima curves along which both angle and modulus vary smoothly. This operation does not affect the location of singularities but the variation of their types along edge curves.

4 Experimental Results

Fig.1 shows the effect of combining the wavelet maxima decay across scales and the strong directionality exhibited by defects for removing the background. The first information can remove most of the noise and part of the background but it is not sufficient for a complete isolation of the cut present on the piece of leather. In Fig.2 the evolution of local maxima across scales is shown for the same example. As can be seen the correspondence between adjacent scales can be used for filtering out some structures of background. Nevertheless, even at the coarser scale there is still too much texture related to the normal appearance of the background. The coherence information is important for allowing the detection of the defect edges. The following pictures show that the method does prove satisfactorily in a quite wide range of situations, due to the generality of its assumptions. Other kinds of defects are detected on different kinds of normal leather (Fig. 3-5). For all these examples the local maxima at the finer scale and the final result (after combination of the criteria on the edge smoothness and on the directionality of defects) are shown.

5 Conclusions

This paper describes the application of a multiscale edge detection scheme to leather inspection. The method combines several information for reaching a more robust separation between defects and background. Lipschitz exponents are used for characterizing singularities, providing also a tool for dealing with the noise in the images. Local maxima evolution across scales does provide a further criterium for filtering out structures due to background. The analysis of chains, joining at each scale the edge points, both in terms of their propagation from one scale to another and in terms of their smoothness are used for selecting the potential defective regions. Finally the stronger directionality exhibited by defects is exploited by evaluating the coherence of gradient directions in the edge points.

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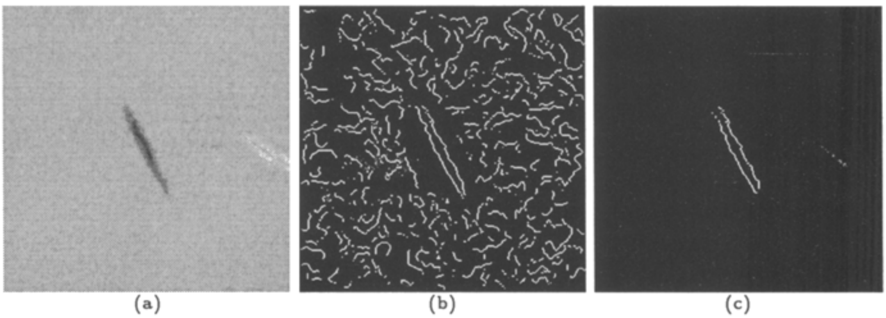


Fig. 1. (a)Original image of a cut on a piece of leather. (b)Output obtained using the Lipstchitz exponent decay across scales. Most of the textured background has been filtered but several structures need to be removed. (c)Output obtained using the Lipstchitz exponents and the coherence values of module maxima. The latter information enhances defective regions which exhibit much stronger directionality.

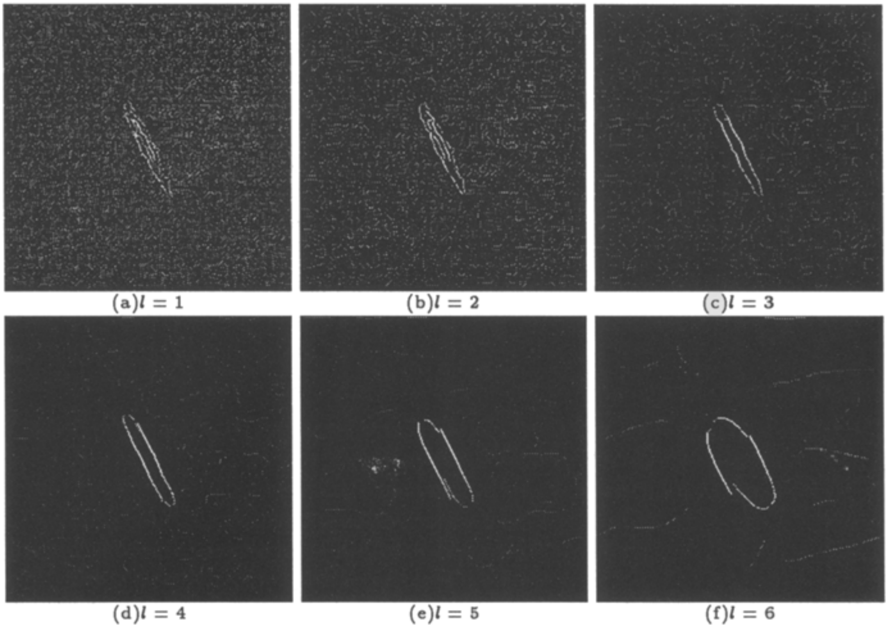


Fig. 2. (a)-(f) Module maxima of the wavelet transform at scales $l = 1, ..., 6$ respectively. At coarser resolutions only the strongest structures are maintained but their location becomes worse. Moreover, the defect is not separated from the background yet.

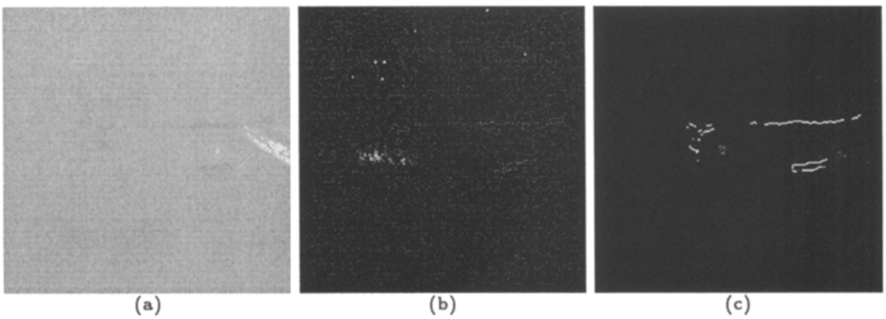
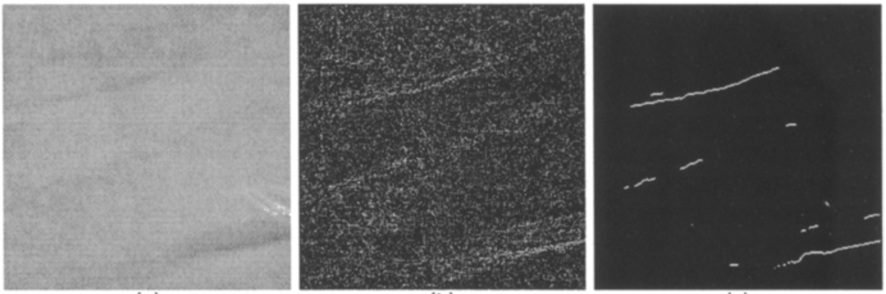
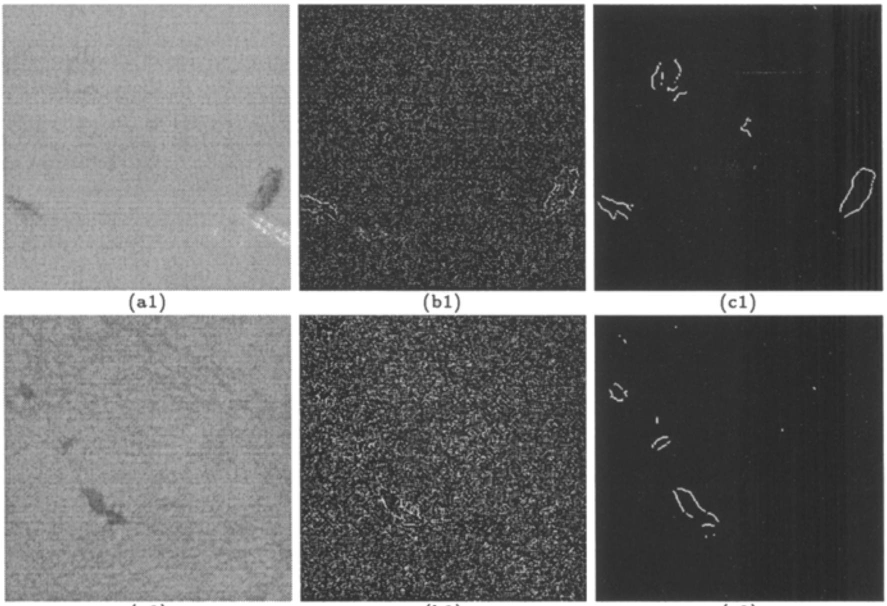


Fig. 3. (a)Scar defect image. (b)Modulus maxima at level 1. (c)Estimated defects.



(a) (b) (c)

Fig. 4. (a)Fold defect image. (b)Modulus maxima at level 1. (c)Estimated defects.



(a1) (b1) (c1)

(a2) (b2) (c2)

Fig. 5. (a1-a2) Gored defect images. (b1-b2) Modulus maxima at level 1. (c1-c2) Estimated defects.