2nd Order Entropy
an Efective Measure For Real
Time Detection of Defects in Fabrics

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Abstract

It is known that entropic and cohesive processes take place in the production of textile materials (Carvalho Rodrigues, 1989). Inspection of fabrics with machine vision is possible. A measure of the image's entropy is characteristic of the overall, global pattern. Global entropy depends only on the information in the histogram, whereas the local and conditional entropic models take into account the information present in spatial details. Experience revealed that global measurements do not contribute to the detection of detailed geometric features.

In this paper we present the result of computing the entropic information present in spatial details. Such an entropy is a function of pattern dependency. This dependency of patterns can be incorporated by considering sequences of elements to estimate the entropy. In order to arrive at the expression of entropy, a theorem, in part due to Shannon (Shannon, 1949), can be stated. In that sense, different patterns with identical histograms would have the same first order values independent of their contents, but higher orders would not.

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With a set of images it is shown that while the global values for entropy remain constant, the 2nd order values show variation. This variation is sufficient for the measurement of 2nd order entropy to become a serious candidate for real time defect detection in fabrics.

Resumo

É unânime reconhecer que na produção de têxteis são observáveis processos entrópicos a de coesão (Carvalho Rodrigues, 1989). A inspecção de têxteis por métodos de visão por máquina é relevante a promissora. A medida da entropia de 1 ' ordem da imagem é entendida como uma medida global, referente ã informação contida exclusivamente no histograma da imagem. Os modelos de entropia de ordem superior tomam em linha de conta a informação residente em pormenores temporais e espaciais. A equação generalizada de Shannon (Shannon, 1949) permite quantificar cada um destes modelos.

A evidência revela que os resultados de medidas globais não permitem a detecção a identificação capaz de defeitos de têxteis. Neste trabalho, apresenta-se as conclusões referentes à medida da informação presente, quer em imagens sintetizadas pelo computador, quer em imagens de têxteis reais. Estima-se as entropias de 1 ' e 2 ° ordens, comparando de seguida as potencialidades de cada uma delas. Em particular, a entropia espacial de 2' ordem mostra-se sensível à disposição dos padrões. Esta dependência significa que diferentes imagens possuindo o mesmo histograma, os valores das suas entropias, embora sejam os mesmos de I 1 ordem, são manifestamente distintos nos valores de 2' ordem.

1. INTRODUCTION

Fabrics are composed of yarns arranged in space. They reflect and transmit light, and it is in this way that their visual appearance is created. Light seems to be a privileged vehicle for the messages sent by a textile product. Messages carried by light can be organized by a lens to form an image. A computer can calculate the distribution function of the levels of illumination in the image, and from that distribution it can also calculate the image's entropy by using a generalized version of Shannon's formula. When light is considered as the carrier of messages, the image's entropy coincides with the fabric's entropy (Carvalho Rodrigues, 1989).

For any fabric, its entropic measure is therefore one of its intrinsic properties, as much as its geometrical dimensions or its mass

If a fabric having an entropy S(i) is worked upon, an amount of energy E being spent, the resulting textile will have an entropic measure *S(f).* The relation between the initial S(i) and the final entropy *S(f)* depends on whether the work performed was effective. If it induced a more regular, a more ordered state, then S(f) < S(i). If, however, some destruction of order is the result of the process, *S (f) > S(i).*

The difference between the entropy of the two stages in the evolution of the textile, *S(f)-S(i),* when applied to the industrial process, offers a means to measure and judge quantitatively the degree of success of a particular step in the textile process. With the measurement of entropy increments, it would be possible to classify the different steps of the industrial processes for different raw materials in classes of effectiveness in the scale of higher and higher order.

One will show that the second-order entropy is the most significant measure for the spatial distribution of the yarns.

2. q-ORDER ENTROPY

2.1. **Image model**

Let us define some useful terminology and notation. Consider a characteristic function b(x,y), that is 0 for all image points corresponding to the background and 1 for points on the object. Such a two-valued function is called a continuous binary image and it can be obtained by thresholding the gray level image. The continuous characteristic function b(x,y) has a value for each point in the image. In this paper, we shall consider discrete binary images, obtained by suitably tessellating the image plane. The image plane may be tiled with regular squares and the tiles should not overlap, yet together they should cover the whole plane (Peckinpaugh, 1991). Assuming that he image has been digitized one can say bij is the value of the binary image at the tile in the i-th row and the j-th column. Thus, a chess-board will be

bij I If i+j is odd
0 otherwise

where i,j = 0,...,31

Generally speaking, the input image can be defined by

T = L tij]mxm

_ (t(1)...t(m2))T

Where the argument of t() indicates the number of the tile and m2 is the total number of tiles.

TABLE 1

Operator P-45° specifications

Notation

t(i,j) -Brightness of the tile situated at line i, column j, for the whole image.
c(i,j) - Number of times the brightness j follows the brightness i, according to P.

c(i,j) = {0}
For i from *2 to k do*
For j *from 2 to k doi*
It *[(t(i,j) is black) And (t(i-1,j-1) is black)] c(1,1) ++;*
If [(t(i,j) is black) And (t(i-1j-1) is white)] c(1,2) ++;
It *[(t(i,j) is white) And (t(i-1j-1) is black)] c(2,1) ++;*
If f(t(ij) is white) And (t(i-1j-1) is white)] c(2,2) ++; I

End For j
End For í
Interface

I

Operator P-45 (tile-image, bc)
Input: tile-image, binary made of tiles image including dimensions.
Output: bc, a 2X2 integer matrix of co-occurrence.
Computes the co-occurrence matrix from the binary image made of tiles.

2.2. **Spatial quantitative characterizations**

This section describes quantitative statistical measures of patterns of yarns seen in fabrics. These measures may be used to distinguish two given images, the regular and the other one with defect.

Consider first the statistical properties of the configuration (i.e., images) presented at a particular time step of the inspection process. According to the image model, in a configuration generated by a random sequence all kq blocks of length q must occur with equal probabilities. Deviations from randomness imply unequal probabilities for different subsequences. With probabilities pi(x) for the kq blocks of site values in a block of length q, one may define the spatial entropy.

$$S(q) = -(1/q).\sum_{i=1}^{kq} [p_i(x).\log_k p_i(x)]$$

In the spatial entropy each block is weighted with its probability, so that the result depends explicitly on the size of blocks. For blocks of length 1, the measure entropy S(1) is related to the densities pi of sites with each of the k possible values i. S(2) is related to the densities of blocks of length 2 (or clusters of length 2), and so on. In general, the measured entropy gives the average information content per site allowing for co-occurrences in blocks of sites up to length q. Mote that entropy may be considered to have units of (k-ary) bits per unit distance. Table 2 specifies the algorithm.

2.3. **Second-order entropy**

The c-binary matrix is the relative frequency with which two tiles, separated by the block distance (ox,Ay) occur within the defined neighborhood one with brightness i and the other with brightness j, according to an a priori specified site operator P

TABLE 2

q **order entropy specifications**

Notation

c(i,j) - integer, value of quantity to be measured. q -integer, indicates the order of entropy. s(q) - float, measure of q-order entropy. p(i,j)-float, probability of value c(i,j). sum-summation of every c(i,j).

```
c(i,j) = {0}
For i from 1 to n do
For j from 1 to n do
        p(i,j) = c(i,j)/sum;
        S(Q) = s(9) -'le(P(Q)*logz(P(Q)))
End For j
End For i
```

Interface

q order entropy (tc,sq)
Input: tc, a two dimensional integer table including dimensions.
Output: sq, a float for q order entropic measure.
Computes the entropy of q-order from the two dimensional table.

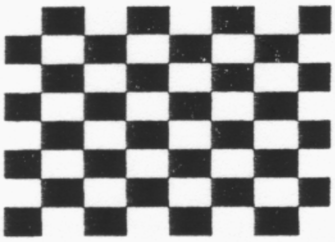
(see Table 1). Since the c matrix depends on P, let P be a site operator «one site to the right and one site below, then we obtain the following 2x2 matrix c,

$$c = [c_{ij}]_{2x2}$$

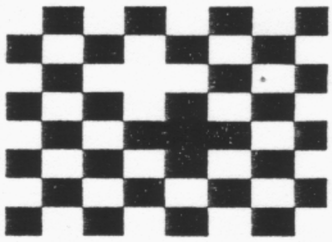
Where cij represents the number of times, within the whole image, that a tile with brightness j follows a tile with brightness i at a -45° orientation (Gonzalez, 1977). In this way, the P-operator is appropriate for detection bands of constant brightness running at -45°. Table 3 shows how important the 2nd order entropy is. Pictures 1, 2, 3, 4 present the same first order entropy and different 2nd order entropies.

TABLE 3
Entropies of synthetic images

	Tiling image			
Image	(bit/tile) SS	64x64 (bit/tile) S2	(bit/tile) S	128x128 (bit/tile) S2
chessboard -	0.9167	-Ì 0.8789	0.9286	0.7606
change 1	0.9167	0.8669	0.9286	-_ 0.7501
columns j	0.9167	0.7718	0.9286	0.6686
two-halves	0.9167	- 0.6000	0.9286	0.5581

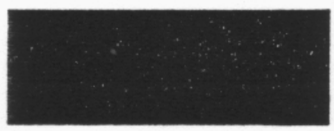


Picture 1. Chessboard



Picture 2. Change 1

Picture 3. Columns



Picture 4. Two-halves

3. EXPERIMENTAL SETUP

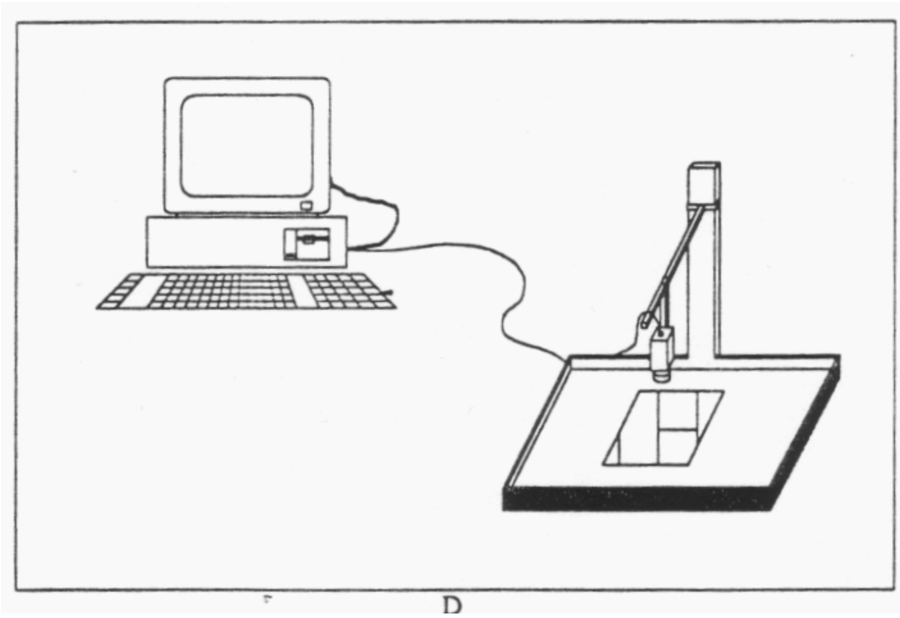
3.1. **Image processing**

The plug-in board for interfacing the video to the PC was the PC-OEIL Image Processing board. The frame grabber provides the capability for image acquisition, storage and display. The pipeline processor allows high speed 8 bit image processing on a 512x512 element-sized image. A 25 MHz 80386 PC-based system was used as the computer. A PC-based menu-driven software was designed to perform measurement on the tiled image that could be either acquired from the camera on-line, digitized from videotape or retrieved from disk. Using a library of 'C' routines plus some routines provided °ith the PC-OEIL, the basic testing procedures were implemented.

3.2. **Camera unit**

The camera unit used for acquiring data was a general purpose 1/2" B/W CCD camera. For the lens system, an f-number of 1.4-16 and a gain range setting from x1/2 to x15 was used. The object was illuminated with 4 flourescent lamps at a distance of 2 meters. The experiments were conducted with photographic equipment including a stand and a light box. For gathering the

Figure 1



Experimental setup. Computer, camera and photographic equipment.

ligth three objectives were chosen. First, 50 mm focal length plus 40mm extension tube for close-ups. Second, 25 mm focal length plus 20 mm extension tube for the same purposes. Finally, a fixed 8.5 mm focal length. The minimum focusing distance that the system can provide is about 8 cm. Figure I shows the equipment set up.

4. RESULTS

The pratical problems encountered in handing the tessellation process are those of required memory and CPU time. Our experiments dealt with the memory problem by limiting the number of intensity levels in data to two (binary). It is found that lowering

TABLE 4Entropies of fabrics (the letter d indicates defect)

Textile	Tiling image			
	64x64		128x128	
	(bit/tile) S	(bit/tile) S2	(bit/tile) S	(bit/tile) S2
15xsize				
Cotton mm 27	0.9374	0.8088	0.9469	0.7023
Cotton mm 27, d	0.9296	0.8231	0.9392	0.7146
5xsize				
French canvas	0.9425	0.8730	0.9503	0.7526
French canvas, d	0.9336	0.8832	0.9423	0.7617
4xsize				
French canvas	0.9513	0.8939	0.9577	0.7859
French canvas, d	0.9486	0.9021	0.9550	0.7894
1/2xsize				
French canvas	0.9713	0.7460	0.9728	0.7707
French canvas, d	0.9710	0.7492	0.7709	0.7709

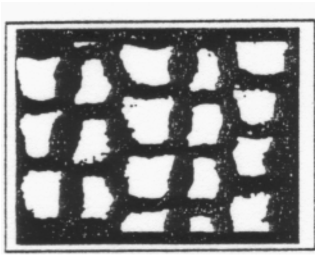
TABLE 5

Variation of fabric's entropy
after the defect has been inspected

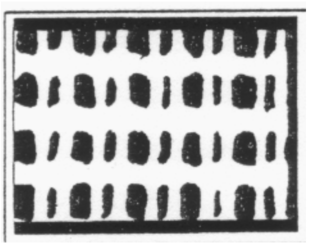
Textile	Tiling image 64x64 (10^{-3})		Tiling image 128x128 (10^{-3})	
	S	S2	S	S2
x15 Cotton mm 27	11.7	13.7	11.6	15.6
x5 French canvas	9.5	12.7	8.8	12.3
x4 French canvas	2.9	10.1	2.8	5.5
x1/2 French canvas	0.3	5.8	0.1	0.3

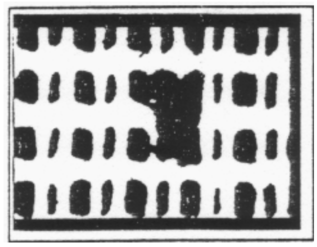
the number to two levels is reasonable for this particular appli cation. The time required to compute the co-occurrence matrix for all neighborhoods in the input image depends on the size of the tile and the length of the displacement vector. The measu rements (see Table 4) have been made in 64x64 and 128x128, which means 8x8 pixel/tile and 4x4 pixel/tile, taking displacements Ax=l., Ay =1.

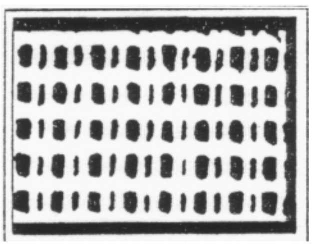
According to Table 5, the french canvas x4 magnification has shown very good performance with both 64x64 or 128x128 tessellations. All the analyzed situations indicate that the variation of 2nd order measure is at least doubled.

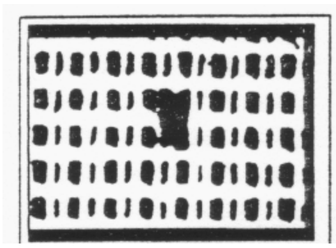

Picture 5. a) x15 Cotton Hm 27

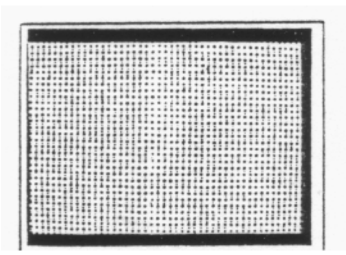

Picture 5.b) x15 Cotton Hm 27, defect

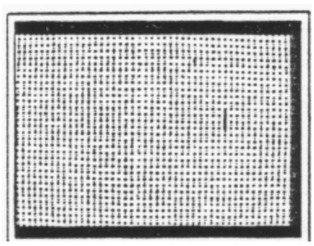

Picture 6.a) x5 French Canvas


Picture 6.b) x5 French Canvas, defect


Picture 7.a) x4 French Canvas


Picture 7.b) x4 French Canvas, defect


Picture 8.a) x1/2 French Canvas


Picture 8. b) x1/2 French Canvas, defect

CONCLUSIONS

The entropic measures of fabrics that are presented are directly related to the information contained in a binary block of length q. A monotonic decreasing function of q is defined for entropic measurements of the yarns in the image.

The first-order entropy takes into account the presence (or absence) of yarns through a histogram operation. The intent of the second-order entropy is to provide us with an effective measure for spatial distribution of the yarns along a specific direction in terms of missing regularity of arrangement of the yarns.

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