Signal Processing 91 (2011) 2395–2403

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Evaluation of speckle-interferometry descriptors to measuring drying-of-coatings

Eduardo Blotta [a,*], Virginia Ballarín [a], Marcel Brun [a], Héctor Rabal [b]

[a] Lab. de Procesos y Medición de Señales, Facultad de Ingeniería, U.N.M.D.P. Mar del Plata, Argentina
[b] Centro de Investigaciones Ópticas, (CIOp, CONICET-CIC), La Plata, Argentina

ARTICLE INFO

Article history:
Received 2 April 2010
Received in revised form
18 February 2011
Accepted 2 May 2011
Available online 10 May 2011

Keywords:
Speckle interferometry
Co-occurrence matrix
Mathematical morphology
Permutation entropy
Local binary patterns
Drying-of-coatings
Latex paint

ABSTRACT

In the industrial process of painting, paint-drying is an important stage because of its high impact in the final result. Its study is of relevance to improve the properties of the resulting coating. Amalvy's experiments to measure the speed of drying on surfaces, based on techniques of speckle interferometry, have been used as a starting point in the evaluation of other methods, which allow to measure the process with greater accuracy. Haralick's descriptors have been studied in depth, then filters based on mathematical morphology techniques, a natural complexity measure and, finally, local binary patterns. Measures of speed of drying based on gravimetrical information were obtained and used as a gold standard. The comparison of different techniques was based on their ability to predict its values through a linear regression model. Morphological descriptors showed a low dependance with the sampling time, a desired property. Permutation entropy and local binary patterns evinced similar drying curves, showing a remarkable inflection point, coincident with the passage on the constant drying area to a later state, defined by a slower diffusion of the solvent through the dry coat of the surface. More precise descriptors of drying phenomena have been identified in this study.

1. Introduction

Painting has different uses in industry. Besides a surface finish, it provides desired properties to the materials, such as protection against corrosion, adhesiveness, light sensitiveness, electric or magnetic properties, etc. Painting can be applied in many ways, from the most rudimentary techniques with paintbrushes to the use of robots. Drying is the most important step of the painting process, since it determines a great part of the final result. A series of chemical processes occur during this phase that, among other things, create a film, eliminate solvents, etc. It is essential to study drying, either to optimize its drying timing or improve the properties of the resulting coating. The kinetics of drying has been studied, showing that the same can be controlled by solvent diffusion through the paint and surface evaporation [4].

Although the following development refers to the drying of paint, the procedure could be applied to other dynamic speckle experiments.

Initial stages of drying show a constant descending slope corresponding to a behavior similar to solvent in contact with the air, since solvent is found in paint surface and its evaporation is only controlled by environmental factors that surrounds it. The most important factors are temperature, humidity and speed of the air over the painted material. Subsequently, the later stages of drying are controlled by diffusion or capillary flow of solvent towards the surface.

The easiest and most direct method to measure paint-drying, and the one most commonly used, is the gravimetrical one. Such method consists on weighting a

* Corresponding author.
E-mail address: eblotta@fi.mdp.edu.ar (E. Blotta).

0165-1684/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.sigpro.2011.05.002

sample at regular intervals and registering the weight loss due to the solvent evaporation.

The following section makes a brief description of the experiments by Amalvy et al., on measuring the drying of painted surfaces using speckle interferometry techniques.

2. Dynamic speckle

Fig. 1(a) shows a typical speckle image, resulting from the effect that occurs when coherent light is scattered by objects which posses certain degree of physical or biological activity on its surface.

A sequence of images of this type provides variations in the local intensity corresponding to the level of activity found on the surface under observation. Characterization of speckle effect dynamics is commonly complex, due to a variety of physical mechanisms that takes place [14]. However, speckle interferometry techniques have demonstrated to be very capable of identifying dynamic processes that appear on the surface of certain objects.

A pseudo-image (see Fig. 1(b)), known as temporal history speckle pattern (THSP) [12], can be obtained by gathering a selected column of the dynamic speckle image sequence. Such image shows a temporal variation of the gray levels of the speckle line, along the horizontal axis. Applying a texture analysis of these pseudo-images it is possible to characterize the temporal evolution of underlying phenomena related to such speckles. The literature reports the usage of different methods to measure the activity, such as co-occurrence [1], spectral [18] or morphological [5–7] statistics.

3. Material and methods

The following sub-sections briefly describe the diverse descriptors employed in this work.

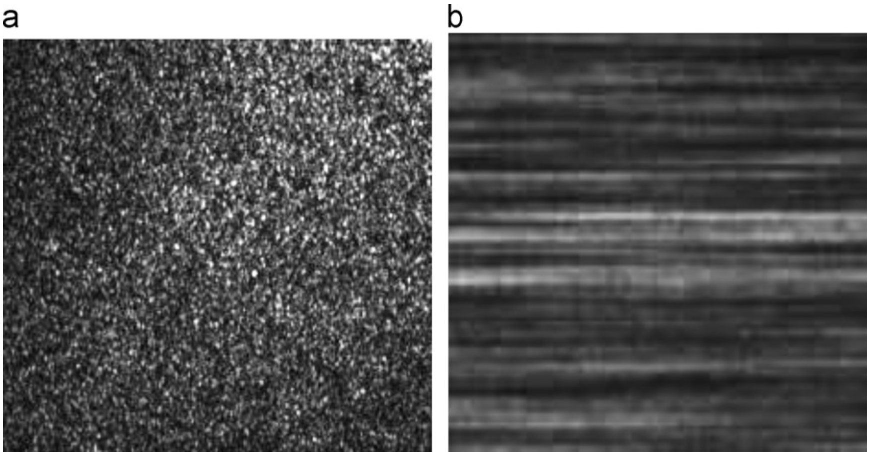

Fig. 1. (a) Typical frame of a speckle pattern and (b) typical THSP image.

Table 1
The 14 Haralick's texture descriptors.

Descriptor	Equation
Energy	$f_1=\sum_i\sum_j c_{ij}^2$
Contrast	$f_2=\sum_i\sum_j(i-j)^2c_{ij}$
Correlation	$f_3=\sum_i\sum_j(i-m)(j-m)c_{ij}$
Variance	$f_4=\sum_i\sum_j(i-m)^2c_{ij}$
Inverse difference moment	$f_5=\sum_i\sum_j\frac{1}{1+(i-j)^2}c_{ij}$
Sum average	$f_6=\sum_{i=2}^{2N_g} ip_{x+i}(i)$
Sum variance	$f_7=\sum_{i=2}^{2N_g}(i-f8)^2p_{x+i}(i)$
Sum entropy	$f_8=-\sum_{i=2}^{2N_g} c_{x+y}(i)log(c_{x+y}c_{ij})$
Entropy	$f_9=-\sum_i\sum_j c_{ij}log(c_{ij})$
Difference variance	$f_{10}=\sum_{i=2}^{2N_g}(i-f_{11})^2p_{x+i}(i)$
Difference entropy	$f_{11}=-\sum_{i=2}^{2N_g} c_{x-y}(i)log(c_{x-y}c_{ij})$
Information measures of correlation[a]	$f_{12}=\frac{f_9-HXY1}{\max\{HX,HY\}}, f_{13}=\sqrt{(1-e^{[-2.0(HXY2-f_9)]})}$
Maximal correlation coefficient	f_{14}=(2 largest eigenvalue of $\sum_k\frac{c(i,k)c(j,k)}{c_x(i)c_y(k)}$

[a] $HXY1=-\sum_i\sum_j c(i,j)log(c_x(i)c_y(j))$, $HXY2=-\sum_i\sum_j c_x(i)c_y(i)log(c_x(i)c_y(j))$ and HX, HY are the entropies of c_x and c_y, respectively.