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3D TOPOGRAPHY MEASUREMENTS AND CHARACTERIZATIONS OF SOFT, LIVING, FLEXIBLE AND DEFORMABLE SURFACES

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Abstract: *One of the great difficulties to day in quality control and metrological highly fidelity characterisations is the case of soft and easy deformable surfaces like living bodies with history of morphology recorded (originally vegetal, animal, humane, etc) and "memory" materials like papers, human skin, varnishes, leathers, textiles, and others. one of the authors are involved since 1970's with 3d roughness metrology, sensors, scanning components and driving systems, tactile, capacitive pneumatically assisted and optical measurement techniques. Dealing with surface texture characterisations and efforts of theirs standardisations some fundamental results will be presented and analytically evaluated. Dimensional measurements in manufacturing, metrology software and the comparing evaluation, as well as uncertainty, tolerance, testing, calibration and testing methods and total quality management constitutes essential problem. Critical analysis of different methods in domain of 3d texture characterisations is not reported commenting advantages and week points in context of quality control due to limited space in this paper. Some case studies in terms of education will be presented.*
Keywords*: 3D surface texture measurements, production engineering, optical, tactile techniques, quality control, deformable surfaces.*

1. INTRODUCTION

Many functional aspects of engineering surfaces are determined by their morphology: their roughness, shape, organisation of surface motifs, etc. (Kalaidji, 1984). The measurement and characterization of these geometrical aspects is one field of morphological metrology.

Historically, one of the first tribological studies of changes on morphology ordered by government concerned the damages suffered during transportation of gold coins collected as taxes. Two reasons were responsible: diminishing weight and print of the royal symbols reduced the emblem of power and increased facility for any sort of falsification. This problem is still present even if gold is no longer used, having been replaced by paper (cheques & bank notes) or "plastic money" such as credit cards.

The extraordinary development of various techniques (Atomic Force Microscopy, Phase Shifting Interferometry, Confocal Microscopy, and Tactile Topometry) and metrology software have their respective advantages and disadvantages specific applications. They make it possible to characterize in 3D surfaces whose amplitudes extend from 0,05 nm to 5mm and scanning areas in the range of 1 µm to a few mm or event cm. The mechanical principle of the tactile technique is very simple: the vertical movements of a tip, which follows the roughness profile of a surface, are amplified and digitized to extract the usual roughness parameters for a profile (Shotton, 1989, Zahouani et al, 1994). 3D morphology is obtained by collecting parallel scanning profiles with defined steps. The situation is more complex for soft, living, flexible and easily deformable surfaces where essentially the optical techniques are used. Several systems are proposed, involving different physical phenomena: interferential heterodyne microscopy (Le Bosse et al, 1997), defocalisation and confocal microscopy (European Community Report, 1993), roughness diffusion by reflection of monochromatic coherent beams (Blunt, 2004), with various types of processes like phase shearing microscopy (Hilerio, 2004) and projected fringes (Zahouani, 2000). Ranges and resolution limits are depending on techniques, but characterisations of the same surface using various techniques can deliver different values of parameters due to specificity of metrological device (Lopez , 1995).

An appropriate selection of expensive metrological equipment is a difficult task. Moreover, it is only possible to test the comparative capabilities of the metrological topological techniques by a complete analysis of different types of materials: homogeneous or heterogeneous, porous or continuous, structurally or/and topographically anisotropic, (with respect to the quality and the feasibility of determination of the significant morphological parameters. In surface metrology, because the measurement techniques are so diverse and the functionality of the engineering surfaces so variable, the transfer function of the different experimental systems must be accurately analysed to determine the surface morphology and the corresponding roughness parameters. (Lee, et al 1997 and Mathia et al, 1995)

Considering the chain of successive operations leading to the values of the morphological parameters, transfer-function problems can be identified and located mainly in two positions:

i) In the intrinsic working mode of a given system, i.e. in the capability of a system to produce a reliable image of the real surface morphology.

ii) In the processing of the recorded data to deduce signification parameters and image the 3D morphological features.

2. PRINCIPLE OF USED METROLOGICAL OPTICAL DEVICE

The optical setup of the CHR is based on a quasi-confocal configuration with extended z-axis field. Field extension is obtained by spectral coding of the z-axis.

Unlike conventional microscopy, which images, simultaneously, all the points in the field of view, confocal microscopy images only one object point at a time. The field of view must be reconstructed by (x,y) scanning. Confocal microscopy may be derived from conventional microscopy by double spatial filtering. The first filter ensures that, at a given instant, a single point of the field is illuminated; the second one ensures that light returned from the object may reach the detector only if it originates from this point. This configuration is depicted in Fig 1a, where the point source S is imaged by the objective lens L on the object point M. Retro-diffused light passes back through objective lens L and is then directed towards the detector by a plate beam splitter. The diaphragm P, located at the image of M given by L, plays an essential role in this configuration as it stops light coming from all points except M, in particular points located on the optical axis, above or below M (fig.1b). When (x,y) scanning is added to the confocal configuration, one obtains the image of a plane located at a precise distance from the objective L, with no interference from points lying outside this plane. This property is called "optical sectioning" and it constitutes the principle advantage of confocal microscopy. An additional advantage resides in the excellent lateral resolution, about 30% better than that obtained with conventional microscopy. The microtopography of a sample consists on measuring the altitude (z coordinate) of each point of the surface on the sample. This may be achieved by dynamic focusing, in other terms, by moving some mechanical part along the z axis. Non-temporal coding of the measurement space is an alternative approach which eliminates the need for moving parts. In the CHR measurement space is coded spectrally using the axial chromatism of the objective lens. For conventional optical systems, axial chromatism is considered as an aberration and optical engineers work hard to compensate it.

Chromatism results from dispersion (the variation of the refractive index as a function of wavelength) of the lenses used in optical systems. When the optical characteristics of an objective lens depend on wavelength, the image of a point source emitting white light is generally a continuum of monochromatic image points distributed along the optical axis (fig.2).

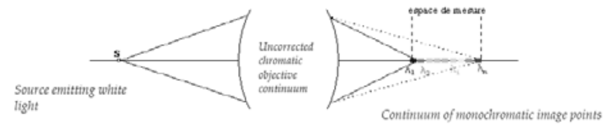

Fig. 2. Principle of chromatic coding

Practically, a white light source is imaged by an objective lens with extended axial chromatism on a series of monochromatic point images in the measurement space. When the measured sample intercepts the measurement space at point M, a single of the monochromatic point images is focalized at M. Due to the confocal configuration, only the wavelength λ_M will pass through the spatial filter with high efficiency, all other wavelengths will be out of focus.

Suppose now that the object is constituted of a several transparent or semi-transparent thin layers. Each interface between adjacent layers reflects light at a different wavelength, and the spectrum of the detected light is composed of a series of spectral peaks. In other terms, all the interfaces may be detected and their positions measured simultaneously. The next step is decoding of the collected light in order to extract the information about the z-coordinate of the point M. This may be realized by spectral analysis. After its passage through the diaphragm, the light beam is directed towards a diffraction grating which deviates each wavelength at a different direction. If a line CCD intercepts the light coming out of the diffraction grating, the position of the intensity maximum on the CCD signal is directly correlated with the position (Z-coordinate) of point M.

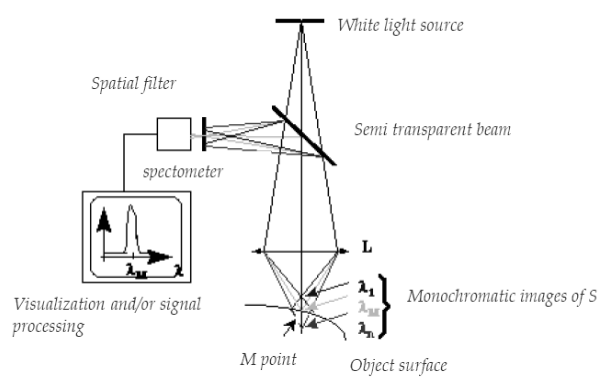

Fig.3. Layout of confocal microscopy with extended z-axis field

The characteristics of the CHR sensor are determined by the principle of measurement:

- The principle of confocal imaging yields an excellent spatial resolution regardless of ambient illumination,
- The chromatic coding ensures that measurement is insensitive to reflectivity variations in the sample and allows working with all types of materials, transparent and opaque, specular or diffusing, soft or hard, with no need to treat the sample prior to measurement.
- The use of a white light source and not of a coherent source (laser) eliminates completely all the difficulties associated with speckle.

This metrological device has been created so that several types of optical brushes can be used. There are different resolutions, depths of field, and working distances between the optical brush and the object. Different types of optical sensors are available, with measurement range from 0-20 μm to 1 mm, the resolution from 10nm to 1nm and working distance from 0.6mm to 12mm.

3. CASE STUDIES

In terms of morphologies two grand groups can be distinguished; random and mono and multi directionally oriented, highly or less anisotropic surfaces. The following examples of cellular solids, porous, woven or not-woven will show the miscellany forms of soft, easily deformable surfaces. Following illustrations are showing divers morphologies of surfaces for which tactile conventional techniques can not be used. The list of those rarely and with great difficulty measured surfaces is infinitely long, can start with blood vessels, dragonfly's wing, meet, ketchup, contact lenses, leafs, flowers, snowflakes etc Numerical values of different parameters are not given in order to respect seize of the paper, but authors can deliver them.

Diversity of living materials is extraordinary rich in form and morphology depending on a great number of parameters; nature, medium and condition of growth and evidently on age. (Thompson, D.W.)

3.1. Wood and flowers

Case of wood surfaces finishes with sand paper is also difficult case of metrology especially in piece of furniture manufacturing where all surfaces should have identical tactile and optical properties. In this case again optical technique is most suitable.

3.2. Quality control of papers and printing

The parameters of surface's' topography are within so range of numbers and in some cases like banknotes, passports, very height quality printed books, etc are usually confidential.

A flexo print is achieved by creating a mirrored master of the required image as a 3D relief in a rubber or polymer material. A measured amount of ink is deposited upon the surface of the printing plate (or printing cylinder) using an anilox roll. The print surface then rotates, contacting the print material which transfers the ink. Topography measurements can help in process of paper production and quality of printing, ink optimization and time and cost reduction.[13]

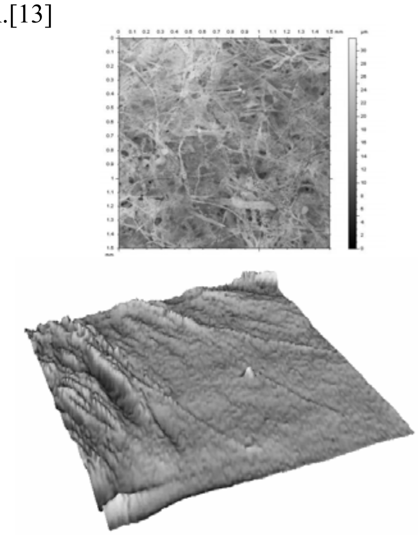

Fig .4. Wood morphology (Above) and Laury flower (Below)

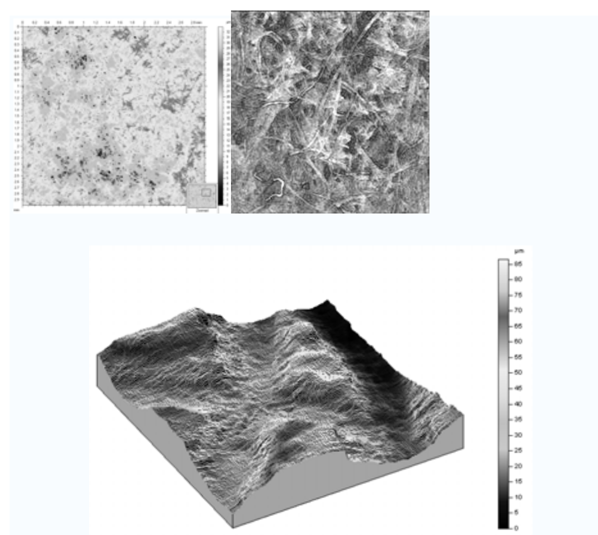

Fig.5. 3D morphology image of paper and specific print on banknote paper (left)

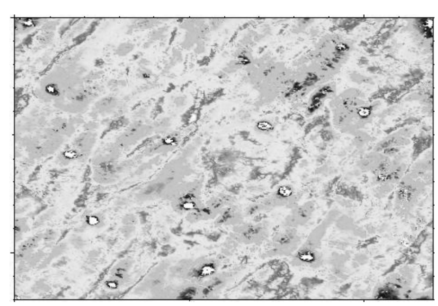

Fig. 6. Papers filter morphology showing micro pores (white areas)

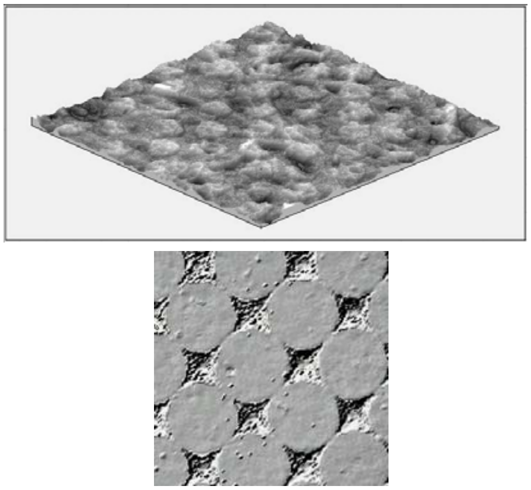

Fig.7 Ink dots morphology's images offering quality control for flexography

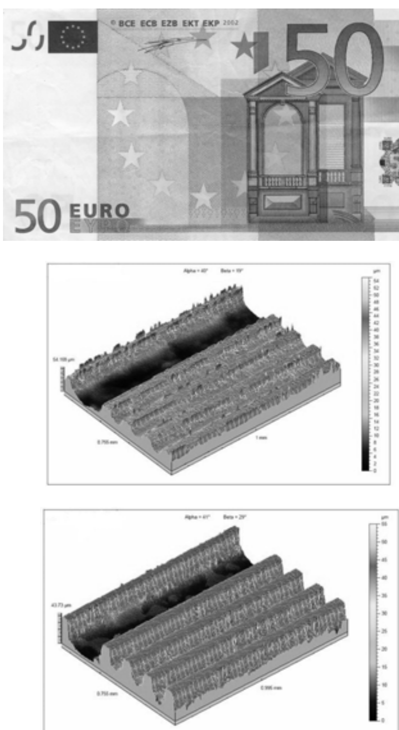

Fig.8. Ink mark on € banknotes offering fast tactile detection

3.3. Textile

There is many sorts of textiles, but two large variants can be distinguished; woven and non-woven materials. Tactile and pneumatics sensor are totally inappropriate techniques. Only few optical techniques can be applied.

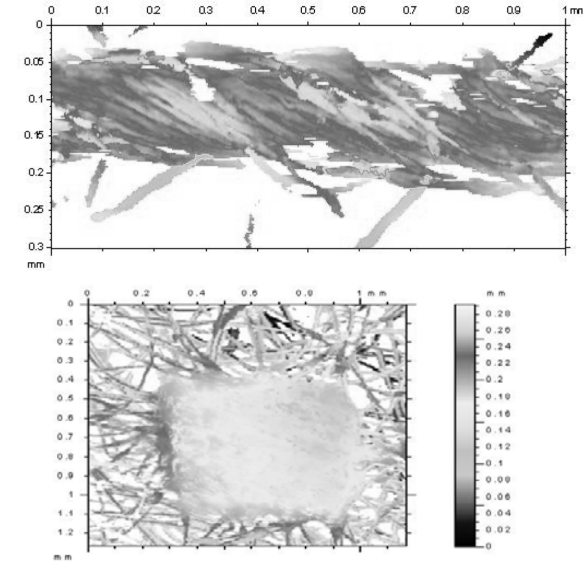

Fig.7 Morphology and 3D size measurement of flocking of non woven textile sheet materials

3.4. Human skin

For cosmetics applications, to optimise various sort of skin creams formulations, for cicatrization kinetics study the replica's analysis offers highly potential of information.

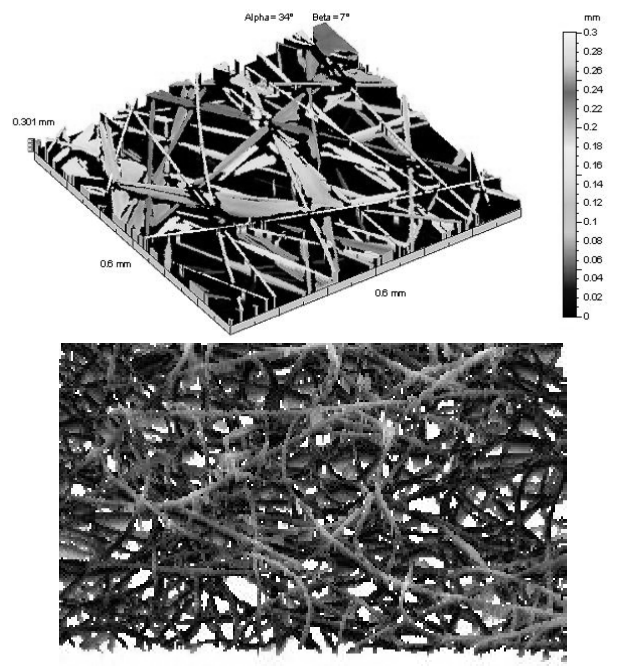

Fig. 8 Fibres build material morphology of non-woven materials

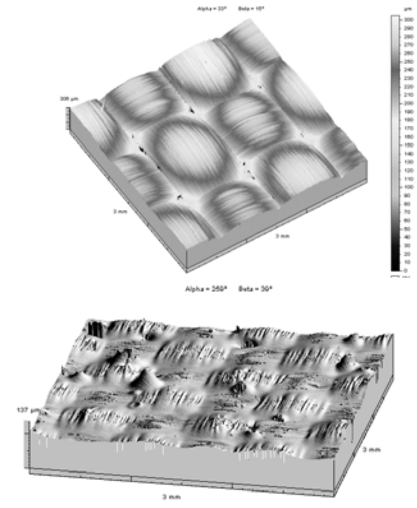

Fig. 9 Woven material protected with relatively thin soft film again required optical technique, like for air bags.

4. CONCLUSIONS AND PERSPECTIVES

For quality control quantitative optical non-destructive measurements can help in identification of functional parameters, but not only. That way the measurements can be reduced and relationship between final function of observed or produced surfaces can be achieved. Time reduction of control and thanks to comparative images analysis's, the homogeneity of surface morphology can be followed. In many cases modern counterfeiting can be rapidly identified.

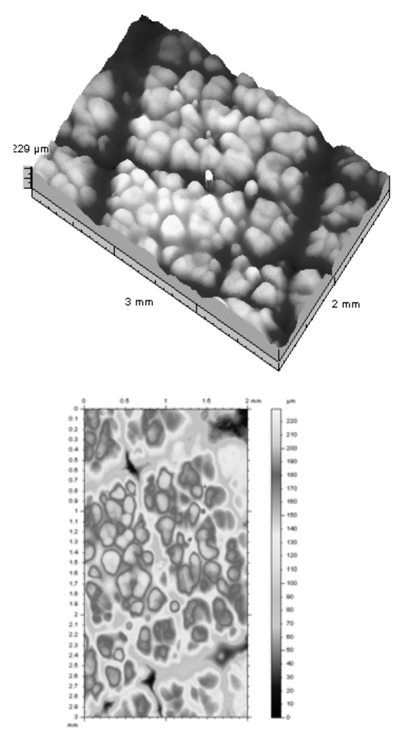

Fig.10 Replicas morphology of human skin

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