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Recognition of Features from Micro Scale Patterned Surfaces

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Abstract

It is recognised that surface feature is the one of the most important factors affecting the functionality and reliability of micro/nano scale patterned surfaces. The information in all surface geometrical patterns is contained in the attributes of the individual pattern features and the structural relationships between these features. To extract this information the individual pattern features need to be identified [1]. A stable syntactic extraction technique of significant surface features from what is termed a structured surface has been developed. Different feature extraction techniques applied for the different types of structured surfaces are illustrated [2-3]. Examples have been selected to demonstrate the feasibility and applicability of the surface pattern analysis techniques. Finally, experimental results will be given and discussed in this paper.

Keywords: Micro patterned surface, segmentation, edge detection

1. Introduction

As the rapid development in the microtechnology, especially for Mico Electro Mechanical Systems (MEMS) proceeds micro scale patterned surfaces now play an important role in many industrial fields. It is therefore vital that techniques are available which can accurately, reliably and cost-effectively characterise these micro scale patterned surfaces.

Broadly speaking, pattern recognition is a technology that concerns the description or classification of measurements. The three main approaches to pattern analysis are identified by Schalkoff as: Statistical, Syntactic and Neural Pattern Analysis [4]. The structure of a typical pattern recognition system consists a sensor (in this study, the Talysurf CCI system), a feature extraction mechanism (algorithm), and a classification or description algorithm (depending on the approach). The structure is shown in Figure 1.

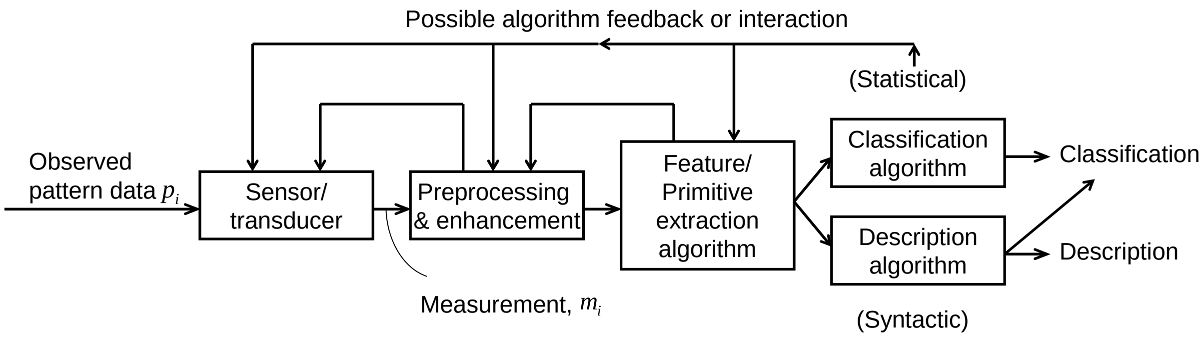


Fig. 1. Typical pattern recognition system structures

2. Experimental investigations

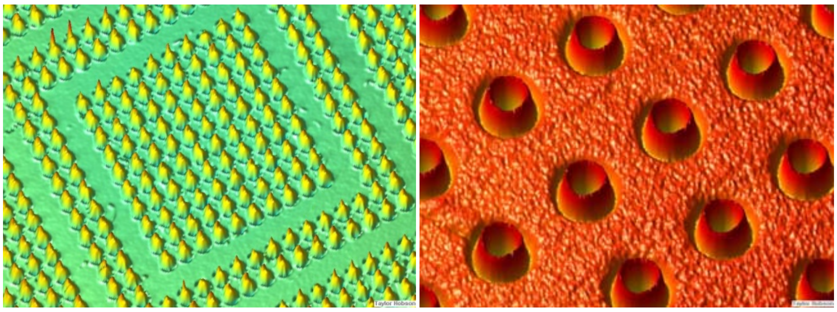
In this work a white light interferometer (Taylor Hobson CCI System) has been used in a clean room environment to measure a range of structured surfaces. For instance, a 50×

objective lens allows this machine to measure a sample area of approximately $300 \times 300\mu m$ (imaged onto a CCD array of 1024×1024 pixels) with a working distance of 3.4mm between lens and measured surfaces, and a measurement time of one to two minutes. Lower magnifications can be used to enable larger areas to be examined but this will increase the minimum achievable lateral resolution. The major specifications of the Taylor Hobson CCI System are summarised in table 1.

Table 1. Specifications of the Taylor Hobson CCI System

Talysurf CCI 3000	Specifications
Vertical resolution	0.01nm
Maximum lateral resolution	0.36µm
Vertical range	100µm
Maximum measurement area	7.2x7.2mm^2
Data points	1024x1024 pixel array
Root mean square repeatability	3pm
Typical measurement time	10–20 seconds

Typical measurement results are show below in Figure 2.



(a) (b)

Fig. 2. (a) micro chip pin surface (b) laser etched landing zone of hard disk surface

3. Analysis of experimental data

The classification of 3-D geometrical objects from visual data is an important pattern recognition task. This task includes feature selection, dimensionality reduction (3-D information is mapped onto a 2-D image), and the use of qualitative and structural descriptors.

Histogram equalization is a technique which consists of adjusting the grey scale of the image so that the grey level histogram of the input image is mapped onto a uniform histogram. Let the variable r represents a random variable which indicates the grey level of an image. We can assume that r is continuous and lies within the closed interval $[0:1]$ with $r=0$ representing black and $r=1$ representing white. For any r in the specified interval let us consider a transformation of the form.

$$s = T(r) \quad \textbf{(1)}$$

Let the original and transformed grey levels be characterized by their probability density functions $p_r(r)$ and $p_s(s)$ respectively. Then from elementary probability theory, if $p_r(r)$ and $p_s(s)$ are known then the probability density function of the transformed grey level is given by:

$$p_s(s)=\left[p_r(r)\frac{dr}{ds}\right]_{r-T^{-1}(s)} \quad \textbf{(2)}$$

If the transformation is given by:

$$s=T(r)=\int_0^r P_r(w)dw \quad \textbf{(3)}$$

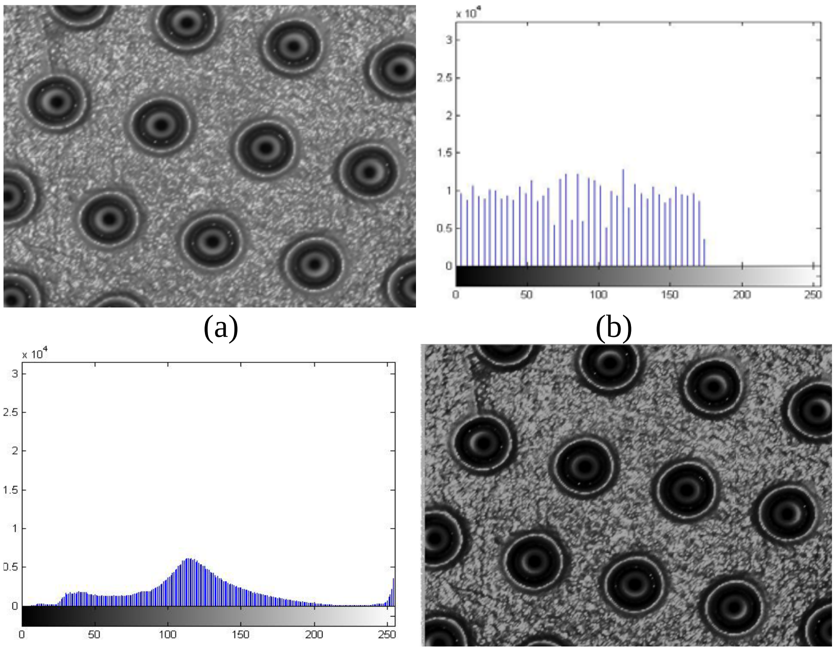
Then substituting $\frac{dr}{ds}=\frac{1}{p_r(r)}$ in Eq. 2 we obtain $p_s(s)=1$. Thus it is possible to obtain a uniformly distributed histogram of an image by the transformation described by Eq. 3.

An algorithm to implement histogram equalization for a grey level image is given below. For every pixel in the image then the grey level value is a variable i, $hist[i]=hist[i]+1$ when $i=0$ to $L-1$ for a L level image. From the histogram array, one can get a cumulative frequency of histogram $hist_{cf}[i]=hist_{cf}[i-1]+hist[i]$. The generated equalized histogram is given as

$$eqhist[i]=\frac{\left[L*hist_{cf}[i]-N^2\right]}{N^2} \quad \textbf{(4)}$$

Where, L is the number of grey levels present in the image, N^2 is number of pixels in the $N\times N$ image, $[x]$ is the truncation of x to the nearest integer. Replacing the grey value i by $eqhist[i]$ for each i, then $eqhist$ contains the new mapping of grey values.

Considering Figure 3 the histogram of the original image is non-uniform due to many surface undulations, the histogram of the equalized image has more or less a uniform density function.



(a) (b)

(d) (d)

Fig. 3. (a) Original image of hard disk surface (b) histogram of the image (c) equalized histogram (d) enhanced image of hard disk surface

A number of edge detectors have been developed by various researchers. Edge detection by gradient operations works fairly well with images that have sharp intensity transitions and low noise. The most important operators are the Robert operator, Sobel operator, Prewitt operator, Canny operator and Krisch operator. In this study, the Sobel operator is selected [3]. The Sobel operator is a 3×3 neighborhood based gradient operator. The convolution masks for the Sobel operator are defined by the two kernels shown in Figure 4. The two masks are separately applied on the input image to yield two gradient components G_x and G_y in the horizontal and vertical orientations respectively.

-1	-2	-1
0	0	0
1	2	1

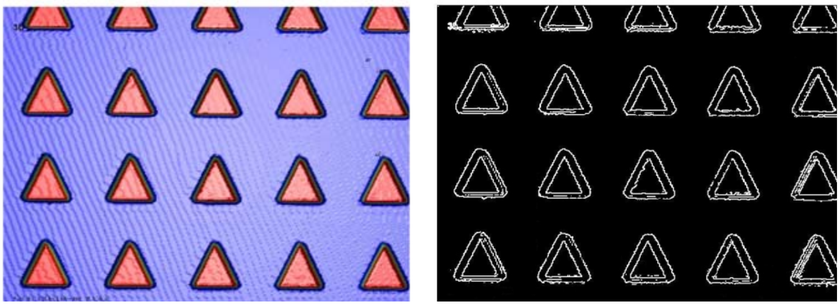
(a)

-1	0	1
-2	0	2
-1	0	1

(b)

Fig. 4 Sobel masks to compute (a) gradient Gx, (b) gradient Gy

The result of an edge image of an etched Si structure generated by Sobel operator is shown in Figure 5.



(a) (b)

Fig. 5 Detection of an etched Si microstructure using Sobel edge detector

For other types of feature extraction task, for example, a chip pin surface, active contours can be used, and this is the case in the present study. Active contours or snakes are a completely different approach to feature extraction compared to the Sobel operator. An active contour is a set of points that aims to enclose a target feature i.e. the feature to be extracted. An analogy would be using a balloon to find a sharp point. An initial contour is placed outside the target feature, and is then evolved so as to enclose it. Active contours are express as an energy minimization process. The target feature is a minimum of a suitably formulated energy function. This energy function includes more than just edge information [5].

To achieve this goal, an external energy is explicitly defined that can move the zero level curves toward the object boundaries. Let I be an image, and g be the edge indicator function defined by

$$g = \frac{1}{1 + |\nabla G_\sigma * I|^2} \tag{5}$$

Where G_σ is the Gaussian kernel with standard deviation σ. An external energy for a function $\Phi(x, y)$ is defined as below,

$$\varepsilon_{g,\lambda,\upsilon}(\Phi) = \lambda L_g(\Phi) + \upsilon A_g(\Phi) \tag{6}$$

Where $\lambda \succ 0$ and υ are constants, and the terms $L_{g(\Phi)}$ and $A_{g(\Phi)}$ are defined by

$$L_g(\Phi) = \int_\Omega g\delta(\Phi)|\nabla\Phi| dxdy \tag{7}$$

and

$$A_g(\Phi) = \int_\Omega gH(-\Phi)dxdy \quad \textbf{(8)}$$

Respectively, where δ is a Dirac function, H is a Heaviside function.

Now, the following total energy function is defined

$$\varepsilon(\Phi) = \mu P(\Phi) + \varepsilon_{g,\lambda,\upsilon}(\Phi) \quad \textbf{(9)}$$

The external energy $\varepsilon_{g,\lambda,\upsilon}$ drives the zero level set toward the object boundaries, while the internal energy $\mu P(\Phi)$ penalizes the deviation of Φ from a signed distance function during its evolution. An example of feature extraction results are shown in Figure 6.

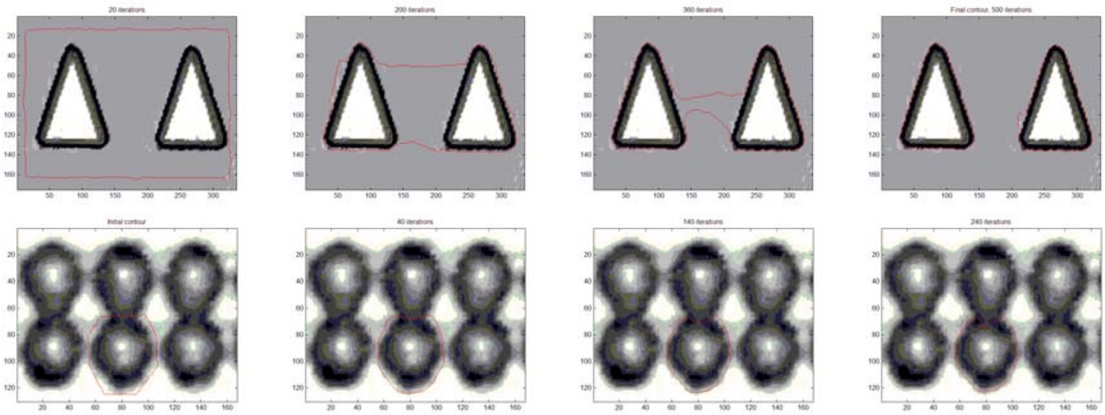


Fig. 6. Feature extraction of an etched Si microstructure and micro chip pin surface based on active contours

4. Conclusions

In this paper, a framework of pattern recognition is introduced. The basic principles involved in the preprocessing of the Histogram equalization and image enhancement have been presented. Edge detection algorithms based on Sobel operator and Active contours have also been introduced. The measured data and the experimental results based on different techniques are given to illustrate the techniques. Sobel edge detection operator has a good performance on low-level surface feature extraction. Active contour is a flexible technique with sufficient accuracy for surface feature extraction, and incorporate higher-level information.

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