Wear 271 (2011) 604–609

Contents lists available at ScienceDirect

Wear

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

The use of surface segmentation methods to characterise laser zone surface structure on hard disc drives

Liam Blunt*, Shaojun Xiao

Centre for Precision Technologies, School of Computing and Engineering, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, United Kingdom

ARTICLE INFO

Article history:
Received 29 March 2010
Received in revised form 16 June 2010
Accepted 17 June 2010
Available online 14 July 2010

Keywords:
Surface topography
Segmentation
Structured surfaces
Hard disc drives
Laser zone texturing
Sobel operator morphological analysis

ABSTRACT

All surfaces, be they at the nano-, micro- or even macroscale are made up of a collection of fundamental features at many different scales which constitute the surface topography. The new generation of so called structured surfaces have features which are organised in deterministic patterns; these include MEMS/NEMS surfaces, micro-fluidic device surfaces and surfaces with repeating features to improve their tribological properties. These types of surface are becoming both technologically and economically critical to high added value manufacturing. The deterministic features on these surfaces include tessellations, rotationally symmetric features and linear features. Surfaces possessing dominant deterministic features are considered to have a defined structure and are termed "structured surfaces" where the features are manufactured on the surface in order to give a specific functional response.

Surfaces with repeating features are of particular importance to tribological applications and have been designed to have specific contact, lubrication and bearing properties. Identification and of the boundaries of such features presents particular problems in terms of measurement and characterisation and much recent research has focussed on "segmenting" measured surface data to allow for efficient characterisation of functional features. The characterisation methodology is based around extracting and characterising individual elements of the surface and secondly characterising their spatial relationships or pattern. The present paper uses the example of a laser zone textured (LZT) surface used in the landing zones of hard disc drives to illustrate the latest developments in this type of surface metrology. These types of surface are used to "scrape out" or relieve pressure the air bearings of read–write head and park the head effectively and without damage. The feature dimensions and spacing are therefore critical and efficient measurement and characterisation is the critical element in assessing the disc and read–write head functionality and life.

1. Introduction

An integral part of all desktop computers, laptop computers, games consoles and some mobile devices is the hard disk drive where programs and data are stored. The hard disk is a metallic or glass disk that is coated with magnetic medium, iron oxide (Fe_3O_3) particles. In hard disk drives used in computers the binary information is written to and read from the disk using a magnetic head referred to as the read–write head. The read–write head passes over the disk surface writing or reading data. Most hard drive systems have multiple rotating platters each with its own read–write head, Fig. 1.

Manufacturers of hard disk drives (HDDs) are striving to constantly increase the storage capacity without increasing physical size or the access time to retrieve data. To achieve this requires a number of approaches; increasing the speed of rotation of the platters from the current rotational speeds of 10,000 or 15,000 rpm. Reducing in the area of individual magnetic domains can also increase capacity. This however means that the read–write heads (sliders) must be smaller, so that they can interact with a smaller area on the disk platter. Also, a smaller slider will have a smaller inertia, improving access times. Additionally reducing the flying height of the slider over the disk improves the data storage capacity [1].

The slider does not contact the platter except at rest, when it is parked on a specially textured area on the hard disc referred to as the landing zone. When in motion the slider is supported on an air bearing, generated and maintained by the rotational speed of the platter. The smaller the slider, the closer to the surface it must fly; HDDs currently in production operate with a clearance of approximately 5–20 nm and typically operate under hydrodynamic lubrication.

* Corresponding author. Tel.: +44 1484 472037; fax: +44 1484 472161.
E-mail address: l.a.blunt@hud.ac.uk (L. Blunt).

0043-1648/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2010.06.014

Fig. 1. Hard disc drive system showing two platters and their associated read write heads.

The landing zone is an area of the platter usually near its inner diameter (ID), where no data is stored. This area is also called the Contact Start/Stop (CSS) zone. Disks are designed such that either a spring or, more recently, rotational inertia in the platters is used to park the heads in the case of unexpected power loss. In this case, the spindle motor temporarily acts as a generator, providing power to the actuator.

Spring tension from the head mounting constantly pushes the heads towards the platter and this is balanced by the air bearing beneath the read write head. In CSS drives the sliders carrying the head sensors are designed to survive a number of landings and takeoffs from the media surface, though wear and tear on these microscopic components eventually cause damage and so called bad sectors.

Around 1995 IBM developed a technology where the landing zone on the disk was textured by a precision laser process (*Laser Zone Texturing,* LZT) producing an array of smooth micro-/nanometre-scale "bumps" in a landing zone [2], this vastly improved stiction (the tendency for the heads to stick to the platter surface) and wear performance and acted to "scrape out" or relieve pressure the air bearing prior to parking. This technology is still in wide used predominantly in desktop and enterprise (3.5 inch) drives. CSS technology can be prone to increased stiction due to environmental constraints, e.g. as a consequence of increased humidity. Excessive stiction can cause physical damage to the platter and read–write head or spindle motor.

In order to give consistent parking performance the size, geometry and density of the LZT "bumps" are critical. Consequently manufacturers measure these features as a quality determinant. This process is carried out by manual inspection of surface topography maps and is very time consuming. This paper seeks to show how surface segmentation techniques have provided an automatic technique for characterisation of LZT bumps. In fact the technology is now available as a software upgrade on optical interferometers provided by Ametek Taylor Hobson, UK.

1.1. Advances in surface metrology

In traditional surface manufacturing processes, such as grinding, milling, polishing and honing, the organisation of the surface features resulting from the micro-scale manufacturing processes such as chip removal is stochastic in nature and can be efficiently characterised by conventional roughness parameters such as Ra, Rq Sa and Sz [3]. Even in turned surfaces that have a fundamental periodic component there is still a large stochastic element in the surface due to material shear mechanisms at the tool workpiece interface, ploughing and smearing at the tool workpiece interface. However, surfaces whose features are organised as a deterministic pattern such as MEMS, micro-fluidics, and micro-optics are becoming both technologically and economically critical to high value added manufacturing. The deterministic patterns on these surfaces include tessellations, rotationally symmetric patterns and linear patterns. Surfaces with a dominant deterministic feature pattern are termed "structured surfaces". All structured surfaces are specifically designed to meet a highly defined functional requirement such as the specific optical response of a Fresnel lens [3,5].

To identify features on a surface, an automatic method is required to segment the surface into regions of interest followed by techniques to identify the basic geometric elements within these regions and then analyse their departure from nominal as a function of their spatial arrangement. Conventional statistically based roughness parameters are of little use for these structured features as they are essentially designed to measure statistical properties if stochastic surfaces generated by conventional machining processes. In the present paper, laser zone texturing (LZT) on hard disc drives is used as an example to illustrate the difficulties encountered and advances that have been achieved in analysing structured surfaces.

1.2. Structured surfaces

Initially it is useful to classify structured surfaces into two classes each class based on their generic geometric form [3–5]

- *Class 1*: Structured steps these include; surfaces that have steps, edges and facets such as MEMS and micro-fluidic devices.
- *Class 2*: Structured patterns these include; surfaces having a tessellated pattern, that is, a repeated structure over the surface such as structured abrasives or micro lens arrays.

For class 1 type surfaces, the analysis is based on the detection of geometrical feature edges using edge detection filters such as Sobel filtering [6]. Following edge detection change tree filtering [4] is applied to the "edge data" and thus a series of closed contours can be established bounding significant features (Fig. 2).

The edge map including closed contours can then be "overlaid" on the original data and steps planes and significant features can be easily segmented and separated. Within the segmented data, datums can be established and geometrical relationships established across the surface such as planer height, flatness and squareness [5].

Class 2 type structured surfaces are made up of repeat structures such as laser machined pockets on landing zones of hard disc drives. Characterisation of these types of surface entails analysis of the departure from the nominal geometry of the basic repeat unit and analysis of the distribution and spacing of the repeat units.

The key of feature of segmentation analysis lies in the selection of the operator for extracting the feature boundary. When comparing typical examples of classes 1 and 2 structured surfaces, it is easy to find that the main difference between them is the spatial character of the feature boundary. For the class 1 type, the boundary is fairly consistent with a step, and so it can be defined by the difference of adjacent measured points using a first order spatial derivative operator such as a Sobel filter [5,7]. For the class 2 type of features, higher order spatial derivative operators should be considered. Furthermore, the operator should have a symmetry consistent with the geometry of the feature boundary for example using higher order operators such as the Laplace of Gaussian (LoG) operator. An example of the use of the Laplace of Gaussian (LoG) operator when applied to LZT surfaces is the subject of the present paper.

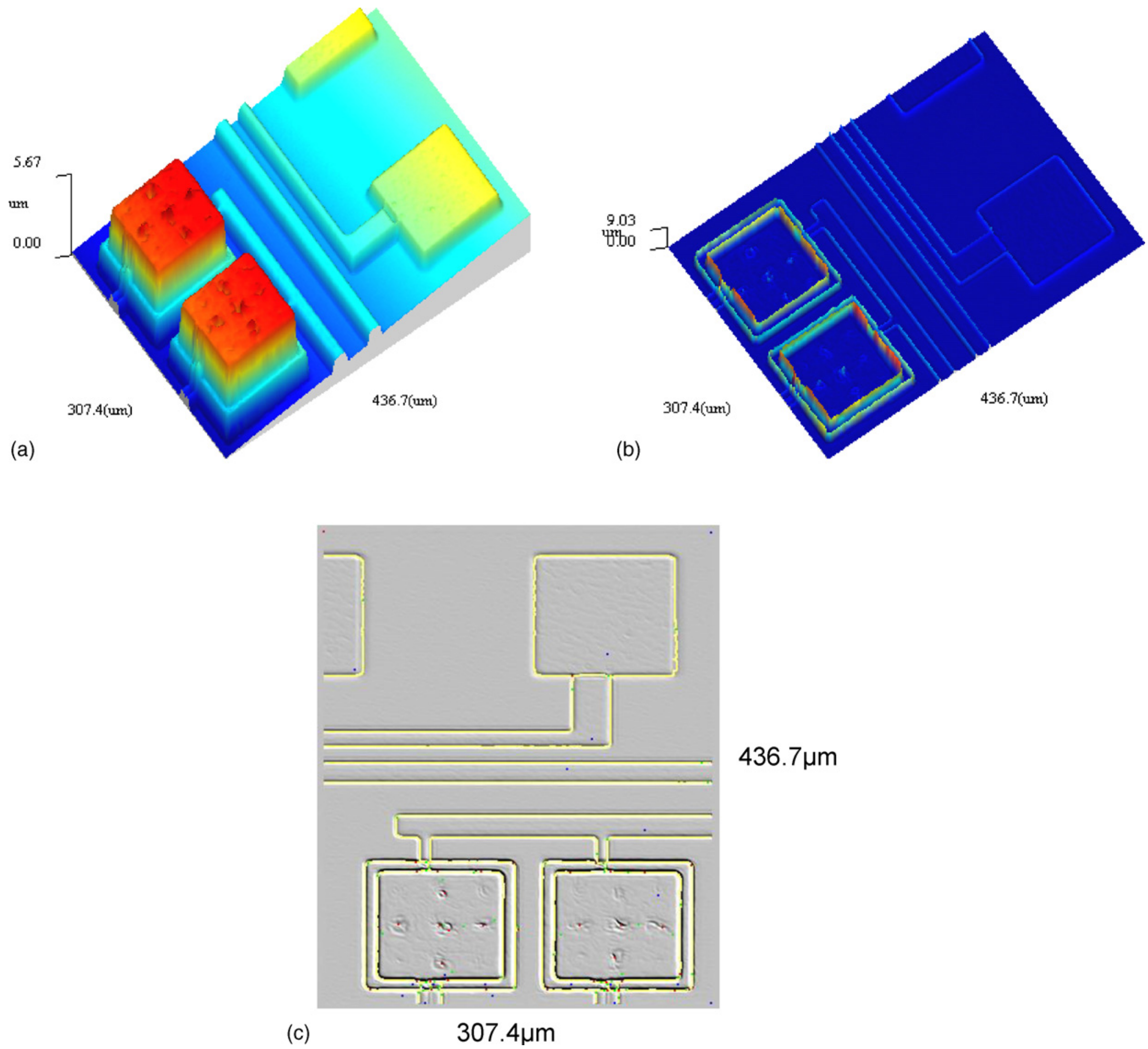

Fig. 2. MEMS device (a) original data, (b) edge filtered surface, (c) enclosed contours overlaid on original data.

2. Results and discussion

A number of HDD's from various manufacturers were measured using a non-contact technique. In the present study the measurement is carried out using a Taylor Hobson optical phase shifting white light *C*oherence *C*orrelation *I*nterferometer (CCI) utilising a specially designed rotary specimen mounting stage. Zoomed areas measured using a 50X objective of a typical HDD are shown in Fig. 3. For the purposes of the present study the LZT zones with the measurands shown in Table 1 are required to be automatically assessed. In practice all the HDD surfaces require non-contact measurement with in-process measurement systems being an essential element. Additionally industrial manufacturers require that the whole LZT zone needs to the measured and assessed within 10 s.

Table 1
Typical required measurands of HDD laser textured zones.

Distance between the centres of two bumps in the same row
Distance between the two rows of bumps
Maximum height of the highest bump
Average height of all bumps
Average diameter of all bumps

The LZT bumps as shown in Fig. 4, indicate that the form of the boundary resembles an inverted "Mexican hat". In order to "filter" the geometrical data for the laser bump a high order operator is applied in order to accentuate the geometrical boundaries of the LZT features. In this case it was considered that the bumps could be described by the Laplace of Gaussian (LoG) operator [6].

The LoG is the combination of the Laplacian operator and a smooth Gaussian filter. The definition of the Laplace operator is

$$L(x, y) = \nabla^2 f = \left(\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}\right) = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) f(x, y) \qquad (1)$$

For processing the practical measurement, a discrete convolution kernel can be used to approximate the second derivatives in the definition of the above Laplace operator.

$$\frac{\partial^2 f}{\partial x^2} \rightarrow \begin{bmatrix} -1 & 2 & -1 \end{bmatrix} \quad \text{and} \quad L(x, y) \rightarrow \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \qquad (2)$$

where the one-dimensional approximation of Laplacian is obtained by the three-point finite difference method as $\frac{\partial^2 f}{\partial x^2} \approx (2f(x, y) - f(x - \Delta_x, y) - f(x + \Delta_x, y))/\Delta_x^2$, and the two-dimensional approx-

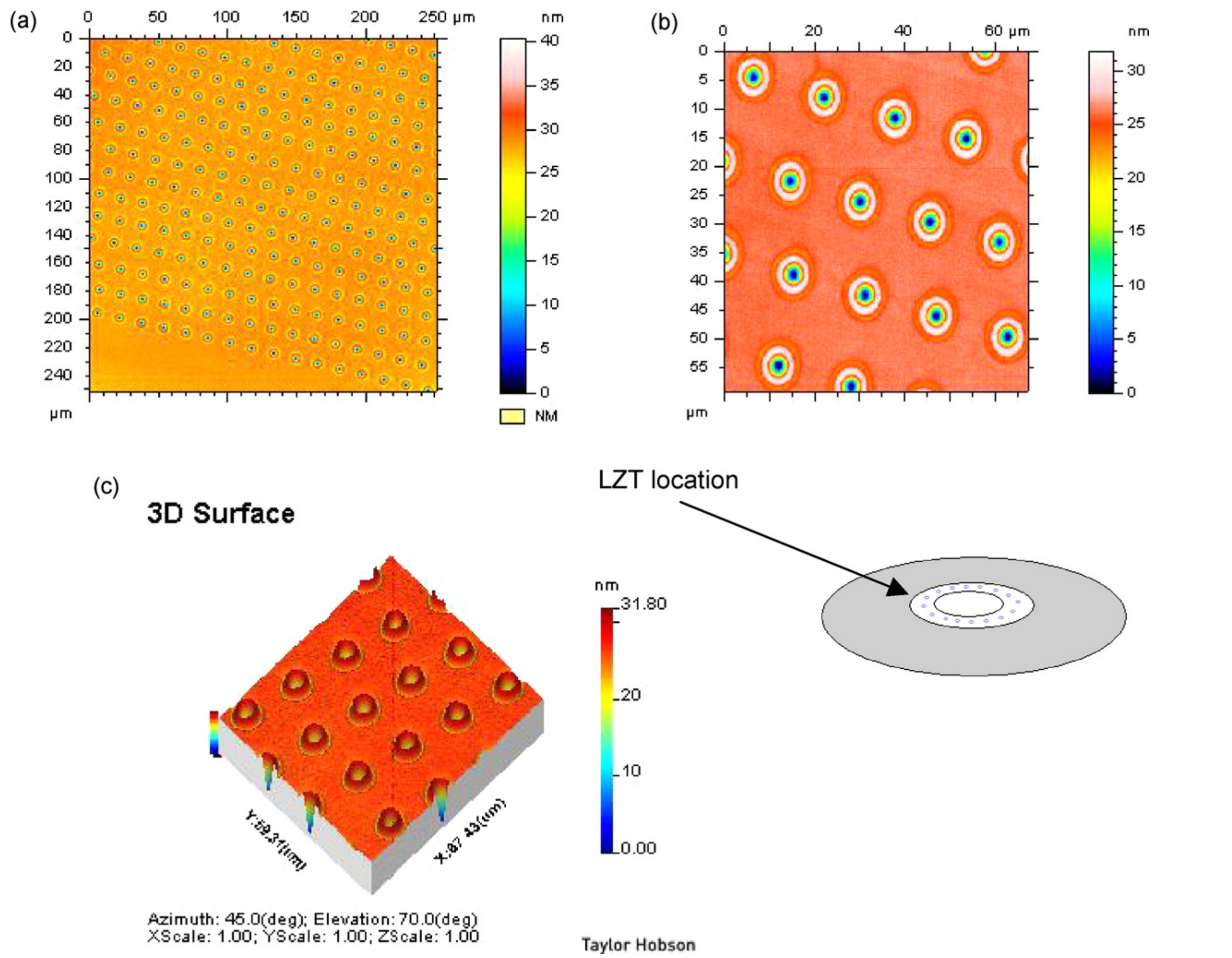

Fig. 3. Zoomed areas of the laser textured zone (LZT) (a) a patch of measured HDD surface, (b) zoomed LZT pattern, (c) axonometric view of LZT patch showing form of laser ablated bump.

imation with five-points is obtained as

$$\begin{aligned} L(x,y) &= \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \approx \frac{2f(x,y) - f(x-\Delta_x,y) - f(x+\Delta_x,y)}{\Delta_x^2} \\ &\quad + \frac{2f(x,y) - f(x,y-\Delta_y) - f(x,y+\Delta_y)}{\Delta_y^2} \\ &= \frac{4f(x,y) - f(x-\Delta,y) - f(x+\Delta,y) - f(x,y-\Delta) - f(x,y+\Delta)}{\Delta^2} \\ &\quad \text{with } \Delta_x = \Delta_y = \Delta \end{aligned}$$

In the case of LoG operator, the Gaussian function $f(x,y) = G(x,y) = (1/2\pi\sigma^2)e^{-x^2+y^2/2\sigma^2}$ will act as the pre-processing smooth filter and the Laplacian operator as the edge detector by evaluating the local gradient divergence. The Laplacian of Gaussian on the x direction is obtained as

$$\frac{\partial^2 G}{\partial x^2} = \frac{1}{2\pi\sigma^2}\frac{x^2-\sigma^2}{\sigma^4}e^{-\frac{x^2+y^2}{2\sigma^2}}$$

The combined LoG function in both x and y directions and with standard deviation σ has the form:

$$LoG(x,y) = \frac{\partial^2 G}{\partial x^2} + \frac{\partial^2 G}{\partial y^2} = -\frac{1}{\pi\sigma^4}\left[1 - \frac{x^2+y^2}{2\sigma^2}\right]e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad (3)$$

The form of the discrete 40*40 kernel that approximates the above function (for a $\sigma = 6.8$) is shown in Fig. 4b.

Following application of the operator to the LZT surface data in a pseudo filtering process, the boundary of the filtered LZT bump can be considered as a high ridge around the bump which is generated by the LoG filter, Fig. 4c. The segmentation of the LZT bumps is achieved by the subsequent application of a morphological surface network analysis which isolates dominant topographical features [8]. In this case it is important that the border of the LZT bumps are clearly delineated and in the present study the high ridge around the filtered bump is defined as the geometrical border of the bumps. The morphological analysis has been presented previously and when applied in this case delineates the high ridge as a bounding contour. This contour is then overlaid on the original data and this corresponds to the LZT boundary (Fig. 5).

Having obtained the average basic repeat unit and the tessellation pattern, further statistical analysis is then relatively straightforward. Given successful segmentation various “properties” can be determined for example the form deviations of each measured tessellate from its associated model tessellate, together with various local attributes, the maximum height of the tessellate etc. as outlined in Table 1.

In the case of the LZT bumps shown above the following parameters are indicative of those used by manufacturers to evaluate the pattern and deviation of the LZT tessellated structure. Typical values form a range of HDD’s are shown below.

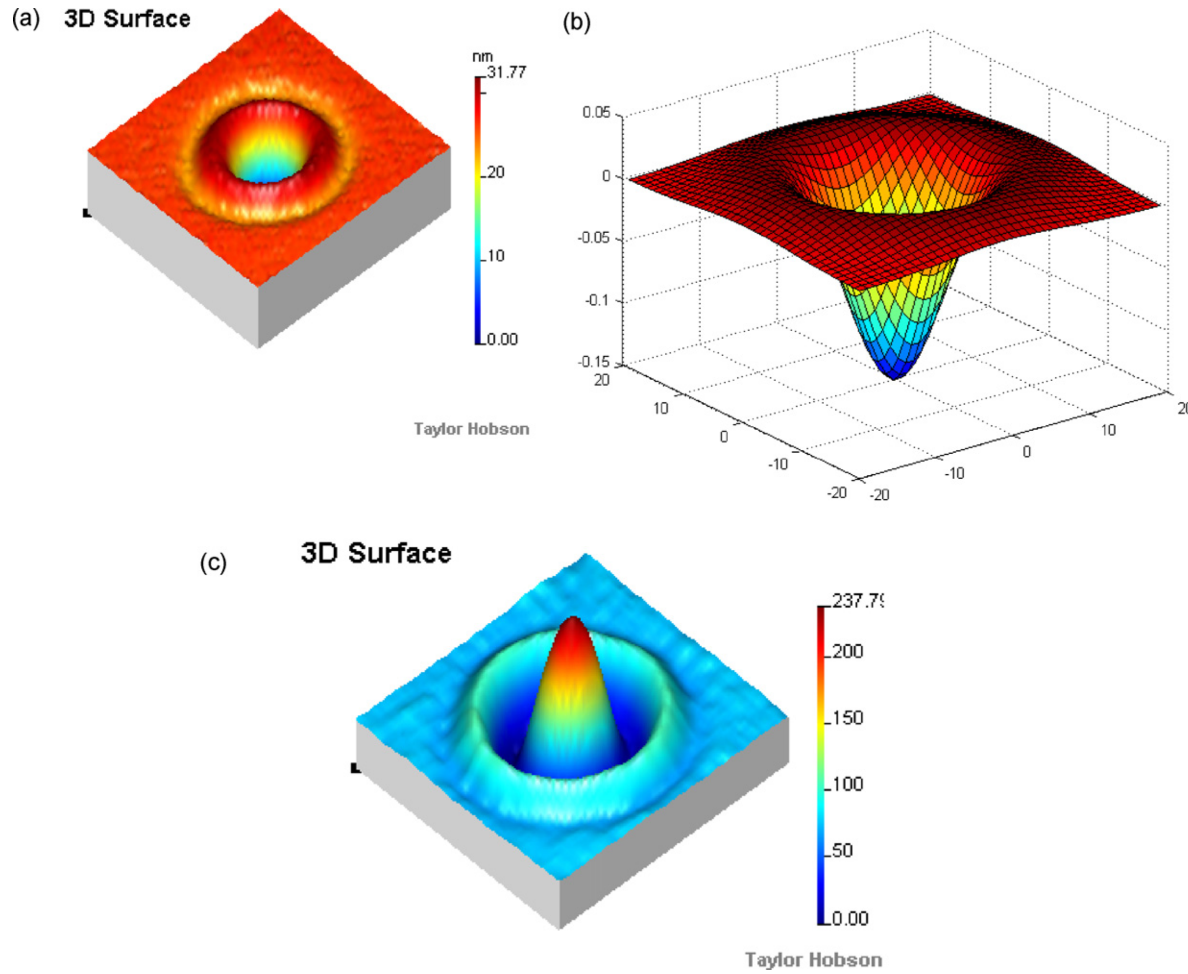

Fig. 4. (a) A single LZT bump, (b) 40*40 LoG operator kernel, (c) LoG filtered LZT bump.

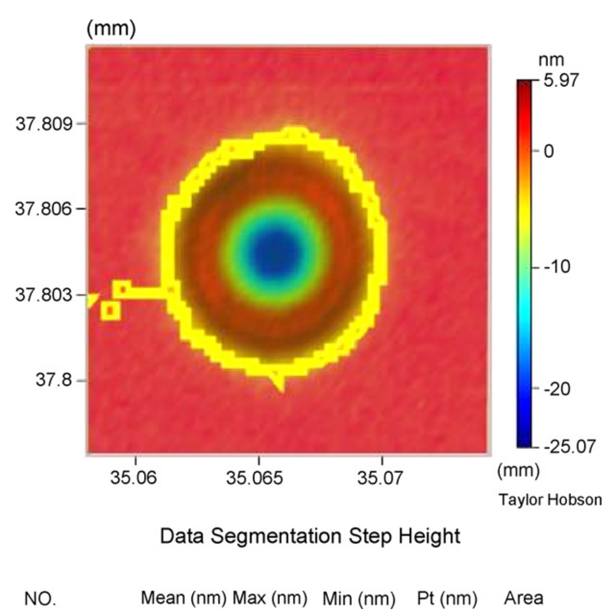

Fig. 5. Extraction of the LZT bump from the HDD surface using a continuous contour technique.

• Distance between the centres of two bumps in the same row	~15–20 μm
• Distance between two rows of bumps	~15–20 μm
• Maximum height of the highest bump	~5–10 nm
• Average height of all bumps	~5–10 nm
• Average diameter of all bumps	~7–12 μm

It should be pointed out that changes in the texture occur during service due to wear during multiple landing events and changes of tribological properties between the head and disc consequently ensue. The segmentation technique outlined has now been adopted is a quality assurance tool by a leading HDD manufacturer [9], however it would be an equally useful tool to monitor topographical changes in the landing zone as a function of length of use.

3. Conclusions

Structured surfaces are becoming increasingly technologically important in many high added value engineering components such as micro lens arrays, by their very nature it is the structured geometry which is critical the function of the part and traditional surface characterisation parameters are of little use in describing the surface structure geometry. Segmentation analysis offers the possibility of effective characterisation of structured surface geometry but requires effective filtering technologies to define the surface structure boundaries and thereby facilitate the segmentation. For characterisation of LZT zones on hard disc drives, segmentation analysis has provided a fast tool for automatic on line process measurement. A LoG filtering technique was used to effectively accentuated the tessellate geometry and segmentation was accomplished by using morphological techniques to define the tessellate boundary based on continuous contours of bounding ridge features.

Acknowledgement

The authors would like to thank Ametek Taylor Hobson Ltd. for their financial support for this work.

References

[1] Seagate Cheetah 15K.5 Product Data sheet.
[2] P. Baumgart, D.J. Krajnovich, T.A. Nguyen, A.G. Tam, A new laser texturing technique for high performance magnetic disk drive, Transactions Magnetics, IEEE 31 (6 Part 1) (1995) 2946–2951.
[3] X. Jiang, P. Scott, D. Whitehouse, L. Blunt, Paradigm shifts in surface metrology. Part I “the current shift”, The Proceedings of Royal Society 463 (2007) 2049–2069.
[4] X. Jiang, P. Scott, D. Whitehouse, Freeform surface characterisation – a fresh strategy, CIRP Annals 56/1 (2007) 278–282.
[5] X. Jiang, P. Scott, D. Whitehouse, L. Blunt, Paradigm shifts in surface metrology. Part II “the current shift”, The Proceedings of Royal Society 463 (2085) (2007) 2049–2071.
[6] R. Fisher, S. Perkins, A. Walker, E. Wolfart, Laplacian of Gaussian, The Hypermedia Image Processing Reference, 2003. http://homepages.inf.ed.ac.uk/rbf/HIPR2/log.htm.
[7] L. Blunt, S. Xiao, X. Jiang, P. Scott, Geometrical Characterisation of MST and Microfluidic Devices Using Novel Surface Metrology Techniques, Proc. EUSPEN Conf. Montpellier France, May, 2005, pp. 97–100.
[8] L. Blunt, X. Jiang, P. Scott, A New Approach to Surface Metrology – Structured Surfaces, Proc Int. Conf. EUSPEN Bremen, May, 2007, pp. 254–258.
[9] Private communication Taylor Hobson Ltd.