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MEASUREMENT OF SURFACE PROFILE OF A COMPUTER HARD DISK USING AN OPTICAL FLAT

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RINGKASAN: *Profil permukaan bagi sebuah cakera keras komputer telah diukur dengan menggunakan kepingan optik dan keputusannya dibentangkan. Suatu susunan eksperimen berkos rendah yang dapat memberi maklumat mengenai kerataan cakera tersebut dihuraikan. Corak pinggir di atas cakera tersebut dirakam dan gambar foto diskan ke dalam komputer untuk analisis. Herotan perspektif di dalam imej dibetulkan dengan menggunakan algoritma transformasi. Matriks transformasi dan penskalaan yang digunakan di dalam algoritma tersebut telah ditentukan daripada titik-titik rujukan pada corak grid persegi. Kejituan transformasi disemak dengan mentransformasikan titik-titik grid yang didigitkan daripada imej kembali kepada sistem kordinat pada susunan optik. Daripada keputusan kerja ini ditunjukkan bahawa kepingan optik mampu memberi data kualitatif dan juga kuantitatif yang mengkontorkan profil permukaan cakera tersebut dengan jitu. Masalah-masalah berhubung dengan aplikasi praktik bagi kaedah tersebut turut dibincangkan.*

ABSTRACT: The surface profile of a computer hard disk was measured using an optical flat and the results are presented. A low cost experimental setup is discussed which provides valuable information on the flatness of the disk. The fringe pattern on the disk was photographed and scanned into a computer for analysis. Perspective distortions in the image was corrected using a transformation algorithm. The transformation and scaling matrices used in the algorithm were determined from selected datum points on a square grid pattern. Accuracy of the transformation was checked by transforming digitized grid points in pixel coordinates from the image back to the coordinate system of the optical setup. The optical flat is shown to be capable of providing both qualitative and quantitative data that contour the surface profile of the hard disk accurately. Problems related to the practical application of the technique are discussed.

KEYWORDS: Flatness measurement, optical flat, perspective correction.

INTRODUCTION

An important stage in the quality inspection of computer hard disk is the measurement of surface flatness of the disk. Any deviation from true flatness will cause the clearance of the flying magnetic head to fluctuate rapidly when the disk is rotating at high speeds, hence making the data transferred to or from the disk erroneous or corrupt.

Instruments that are designed and built specifically for measuring hard disk flatness are available commercially. One such instrument is the *Zygo Interferometer.* The costs of these instruments are usually prohibitively high for low volume production, especially in the small and medium scale industry. Other techniques of surface profile measurement such as moirè interferometry (Xie and Atkinson, 1997), holographic contouring (Jones and Wykes, 1989) and ESPI (Vera, 1997) usually have insufficient resolution for measurement of flatness of hard disks and thus are unsuitable for this type of application. The resolution of these techniques, however, may be improved using phase-stepped analysis (Robinson and Williams, 1986) but this normally results in increased cost and complexity of the experimental design. Another limitation of these methods of measurement is that they are not readily applicable to highly polished and, therefore, reflective surfaces. An alternative low-cost method of inspecting the flatness of the disks is by the use of optical flats. Optical flats readily provide qualitative information relating to the surface flatness. However, extraction of quantitative data from the complex fringe map may not be accurate when perspective distortions are present in the imaging system and, therefore, the distortion must be corrected before the analysis.

In the current work an attempt has been made to interpret the fringe pattern on the disk surface and hence to determine the surface profile of the disk. A transformation algorithm that corrects perspective distortions and converts the pixel coordinates in the scanned image to the actual coordinates of the optical setup is presented. This algorithm was tested and verified by transforming digitized points on a square grid pattern. Problems related to the practical application of the technique are discussed.

THEORY OF THE OPTICAL FLAT

The optical flat is made from hardened glass which is polished on one or both surfaces to a high degree of accuracy. A typical optical flat has a degree of flatness of 0.00005mm. When the optical flat is placed onto a reflecting surface a small angle is usually formed between the optical flat and the surface. When illuminated with a monochromatic source the light is partly reflected by the bottom surface of the optical flat and partly by the surface of the specimen as shown in Figure 1.

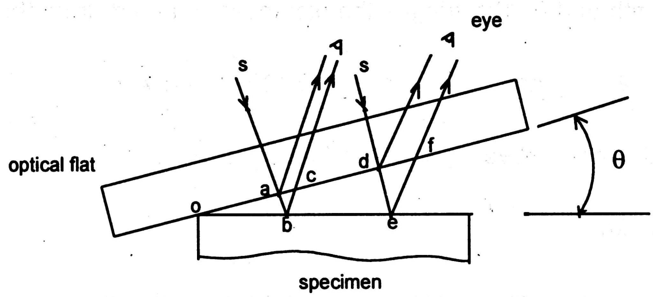


Figure 1. *Incident and reflected rays on the optical flat*

For the light rays reflected from points a and b shown in Figure 1 the difference in the optical path lengths between them is abc. If the distance abc equals half the wavelength of the light used, i.e. $\lambda/2$, destructive interference occurs and points b appears dark. If the angle θ is constant across the width of the specimen a dark fringe can be seen on the specimen surface where the optical path length difference is $\lambda/2$. At the second point shown, that is point e, if the distance def equals $3\lambda/2$ a dark fringe again appears. Exactly in between points a and e the difference in the path lengths of the rays will be λ and therefore constructive interference occurs. Hence, this region appears bright. The surface will therefore be covered with dark and bright fringes, the dark fringe appearing whenever the difference in path lengths of the interfering rays of light is an odd number of half wavelength, i.e. when

$$\Delta \text{ path length} = (2n - 1)\ \lambda/2 \tag{1}$$

where n = 1, 2, 3 .... .

Since the path length difference and hence the position of the fringe depends on the angle between the optical flat and the specimen surface, the fringes thus contour the shape of the surface. Therefore, by analyzing the fringe pattern it is possible to determine the surface profile of the specimen.

The difference in height between successive fringes, measured from the optical flat, can be determined as follows. In Figure 1 since angle θ is small, therefore, for the first fringe,

distance $\quad ab \approx bc = 1/2\ (\lambda/2)$

and for the second fringe,

$de \approx ef = 1/2\ (3\lambda/2)$

Similarly, for the nth and (n-1)th fringes the distances d_1 and d_2 from the optical flat are

$d_1 = 1/2\ (2n-1)\ \lambda/2$ and $d_2 = 1/2\ [2(n-1)\ -1]\ \lambda/2$

Therefore, the distance between adjacent fringes is

$\Delta d = d_1 - d_2 = \lambda/2.$

For the n-th fringe the distance from the optical flat is, therefore,

$$d = (2n - 1)\ \lambda/4 \qquad (1)$$

EXPERIMENTAL PROCEDURE

A schematic of the experimental layout is shown in Figure 2. The hard disk was placed on a clean sheet of glass on the bench to act as a flat datum. A 100mm diameter optical flat was placed onto the disk and the whole arrangement was illuminated with sodium light of wavelength 0.585µm. The fringe pattern on the disk was photographed and scanned into a computer for analysis. This elaborate technique could have been avoided if an image processing system is available whereby the image can be captured directly into the computer, though this may add cost to the experimental design. However, acquiring the image is a small part of the analysis and is considered insignificant in the current work.

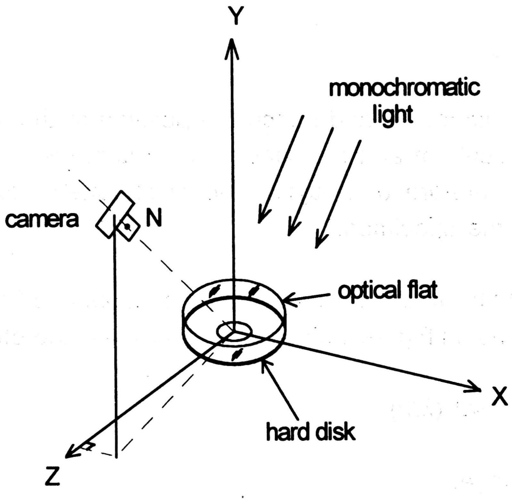
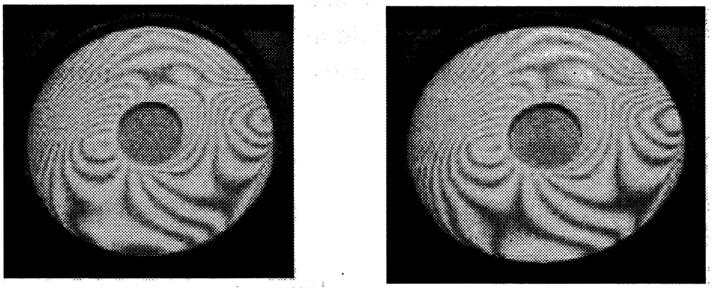


Figure 2. *Schematic of the experimental setup*

Four fringe patterns were obtained to compare visually the general form of the fringes. These fringe patterns were obtained by rotating the optical flat by 90° each time relative to the disk. Since the fringe patterns were similar only the first was used in the analysis. The fringe patterns for the 0° and 180° positions are shown in Figures 3(a)-(b).



(a) (b)

Figure 3. *Fringe patterns on the optical flat for (a) original position and (b) after rotating through 180°*

As can be seen from Figure 3 the fringe patterns are almost identical, indicating that rotation of the optical flat has minimal effect on the fringes. However, both images suffer from perspective distortions due to the elliptical shape of the disk in the image. The distortion was due to the inclined camera position as shown in Figure 2. In addition, the scanned images exist in pixel coordinates. The fringes on the image, therefore, must be transferred back to its actual position on the disk in the axes system of the experimental setup before the analysis could be carried out. In order to perform this transformation an algorithm was developed and coded into a C program. The transformation algorithm, which was verified using a square grid of size 100mm by 100mm, consists of the following steps:

1. Project selected datum points on the grid pattern through the camera lens nodal point N to intersect the film plane in the camera (Figure 4(a)). The distance of the film plane from the nodal point is arbitrary selected and appropriate scaling performed later.

2. Rotate bench axes through α and β in such a way that the new z-axis is now in-line with the camera viewing direction (Figure 4(b)). Apply rotation matrix to the four selected datum points.

3. Translate origin of the bench axes O to the origin of the film plane O'.

4. Rotate film plane through 180° in order to upright the transformed datum points.

5. Compare the transformed datum points with corresponding datum points digitized from the image and determine the scaling factor and rotation angle. The rotation angle is used for correcting the orientation of the image.

6. Perform the reverse of the transformations in (1) to (5) for all the digitized points on the scanned image. This will transform all the digitized points on the image in pixel coordinates back to the actual axes system of the optical setup.

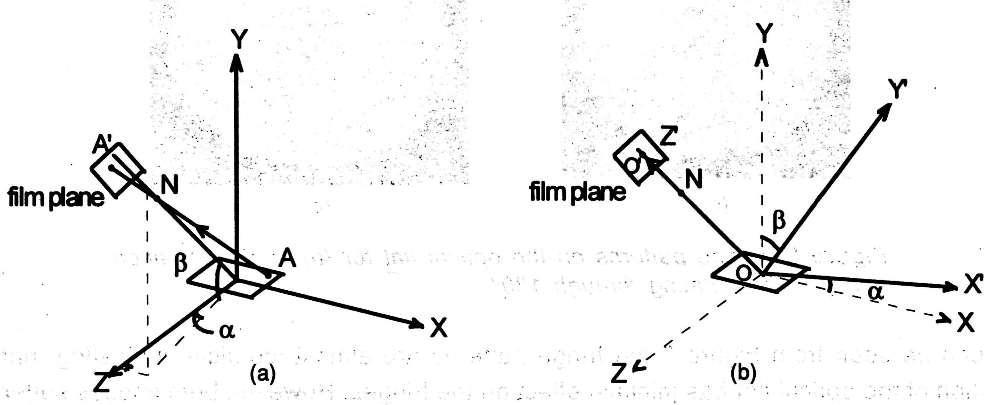


Figure 4(a). *Projection of datum points onto film plane. (b) Rotation of bench axes to get z-axis in-line with viewing direction.*

RESULTS AND DISCUSSION

A photograph of the square grid pattern on which the accuracy of the transformation was checked is shown in Figure 5. The datum points are labeled A, B, C and D. A total of 121 grid points were digitized in pixel coordinates and transformed back onto the grid pattern in the actual bench axes system using the program developed. Plots of the digitized and transformed grid points are shown in Figures 6(a)-(b).

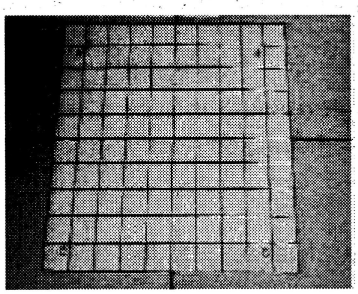


Figure 5. *Scanned image of the square grid pattern (datum points are labeled A, B, C, D)*

In Figure 6(a) the digitized coordinates are in pixel values since the digitizing was done on the scanned image. After the transformation these points were plotted onto the grid pattern in the actual axes system of the optical setup shown in Figure 2. The results of the transformation is shown in Figure 6(b). From Figures 6(a)-(b) we can see that the transformation can be carried out with a good degree of accuracy.

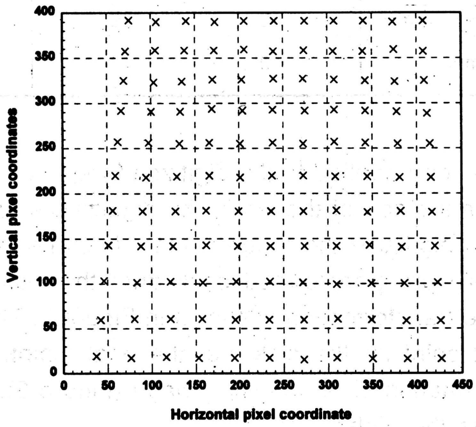


Figure 6 (a)

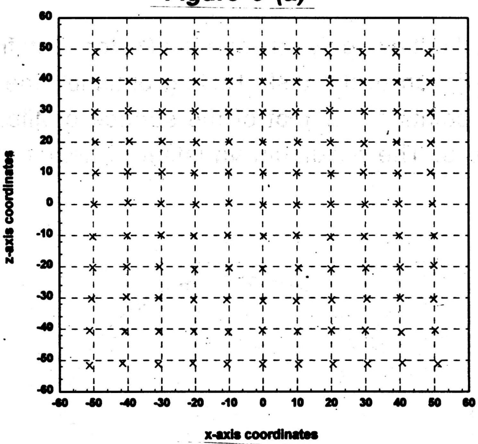


Figure 6 (b)

Figure 6. *Plot of digitized points (a) before transformation and (b) after transformation*

An error analysis was carried out to determine the accuracy of this transformation. The results of the analysis (shown in Table 1) indicate that more than 60% of the digitized points can be transformed within a positional error of 0.5mm and up to 85% of the points were transferred within a positional error of 1.0mm. This result verify the correct operation of the transformation algorithm and its ability to correct perspective distortions.

Table 1

Error range	Number of points x-direction	Number of points y-direction	Percentage x	Percentage y
error ≤ 0.5mm	79	74	65	61
0.5mm < error ≤ 1.0mm	32	29	27	24
error ≥ 1.0mm	10	18	8	15

The transformation was then applied to the digitized fringe centers on the image of the optical flat. At the present stage of the work, the digitizing was done manually though an automatic method of digitizing the fringe centers is currently being developed. The digitized fringe centers were transformed back onto the disk surface. A plot of the digitized points after the transformation is shown in Figure 7. The fringe orders and the location of the highest point on the disk, i.e. the peak point, were determined after examining the fringe formation in the original image (Figure 3). The point marked P in Figure 7 is identified as the highest point.

The analysis was carried out by applying equation (1) for each fringe in Figure 7 in order to obtain the height variation of the disk. Having obtained the x-, y- and z-coordinate values at the digitized points a 3-D plot of the surface profile was obtained. The 3-D plot is shown in Figure 8. The maximum variation in height was found to be 3.8μm.

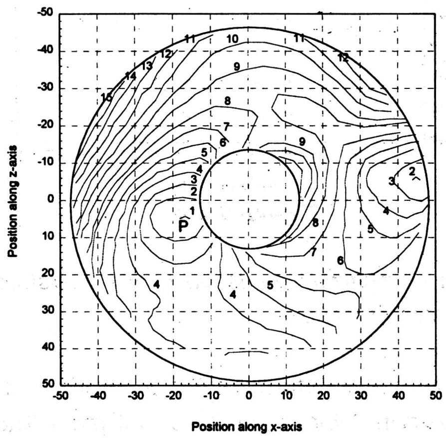


Figure 7. *Plot of digitized fringe centers (after transformation)*

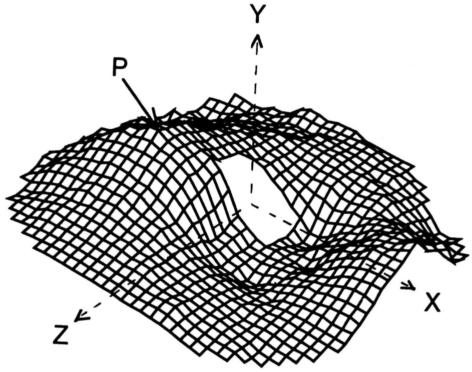


Figure 8. *3-D plot of surface profile of hard disk*

CONCLUSION

In this paper it is shown how a simple optical flat can be used to determine the surface flatness of a high precision product such as a computer hard disk. A transformation algorithm that can accurately locate the fringe centers on the object from a photograph of the fringe map has been developed. The algorithm is used for correcting perspective distortion in the image caused by the viewing system. Although in the current work the analysis was carried out on scanned images, the speed of the analysis can be improved by digitizing the image directly into an image processing system using a high resolution camera. Instead of using a manual method of digitizing and locating the fringe centers, an automated technique of tracking fringes centers may be used for rapid analysis of the fringe map. Work is currently in progress to achieve this. One main disadvantage of the technique is that it is necessary to place the optical flat directly onto the surface of the hard disk, thus requiring care to avoid scratching of the surface under study.

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