Surface Roughness Measurement Based on Image Processing and Image Recognition

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Abstract: - A new method of surface roughness detection based on image processing technique and image recognition algorithm is proposed in this paper. The surface to be detected is placed in a dark box, and two lasers are assembled above the detected surface. When two lasers project two light beams down on the detected surface, one or two lines form at one time, and two curves form at another times. When the detected surface moves at constant speed, the lines or curves moves also on the surface relatively. Take image of the detected surface at same interval, a series of image with lines or curves can be obtained. After both image processing and curve fitting have been done for all the images, surface roughness can be calculated by analyzing the light path of the measurement system. The efficiency of the proposed surface roughness detection techniques were demonstrated by experiment. The measurement results show that roughness less than 0.35mm over an area of 60cm×60cm can be recognized effectively. So the proposed technique is a good candidate among the surface roughness measurement methods.

Key-Words: Surface Roughness; Laser; Image Processing and Recognition; B-spline; Curve Fitting; Geometry Analysis

1 Introduction

In many engineering applications and scientific research works, surface roughness measurement represents an important requirement[1-7]. In order to measure surface roughness, many assessment techniques have been proposed. Traditionally, the commonly used method in industrial field is contact measurement by a profile-meter or a measuring stylus. Although contact measurement is still considered to be the accepted standard for measurement of surface roughness, because of several disadvantages, many non-contact methods have been presented. Recently, there are three main kinds of non-contact detecting methods: image recognition[3], ultrasonic[4,5] and X-ray[1]. In terms of speed and accuracy, image recognition may be one of the most promising methods[3]. G.A.Al-Kind and his co-workers have ever measured surface roughness using image recognition[3]. From the point of view of machine vision, the image recognition based method is practicable. However, the surface roughness is hard to be calculated because it is difficult to analyze the optical path. Moreover, this method depends on illumination. If the direction or illuminance of illumination changes, different measurement result will be obtained even for the same measured surface.

In this paper, a new method for surface roughness measurement is presented based on image processing and recognition technique. Firstly, the measurement system and the measurement principle are introduced. And then it is discussed that the way how to process image and how to calculate the surface roughness with the processed image. Finally, an example of detecting the surface roughness of a floor tile is given. The experiment results are given and discussed at last. The experiments results show that the maximum error of the system is less than 0.35mm over an area of 60cm×60cm. Moreover, this method is compact and easy to be complemented, so it may be a good candidate for the surface roughness measurement.

2 Structure and Principle of Measure -ment System

For the simplicity of introduction, a plane is used to be measured in this paper at first. And then, the process of how to measure the curve surface roughness is introduced. The diagram of the measurement system is shown in Fig.1. A floor tile placed in a dark box is used as a measured surface. Two lasers and a camera are fixed above the measured surface. The axis of the camera lens is perpendicular to the measured surface. When a floor tile is smooth and placed horizontally, it is at the reference position if the distance between floor tile and camera is equal to a set value. Each laser is a point source of light. And each beam of laser light fan out but not radiate in all direction. So one agleam line forms when such a beam of laser light irradiate on plane. And two beams of laser lights projected by the lasers form one line when measured plane is placed in reference position. When the measured plane is not in the reference position, there are two lines. And when the measured surface is not a plane, there are two agleam curves. For example, when a smooth floor tile is placed at the reference position, line MN forms on it, and if a triangular prism is placed on the floor tile, the light S_1C should reach point C will be held up by the triangular prism and can only reach point A. In other words, there is bright dot at A but not at C. In the same way, there are two bright dots at B and D respectively because of laser2. Especially, because BDS_2 is in the light plate of laser2, there is a bright line BD that is parallel to but not the same with MN. Laser1 illuminates at the left side of the triangular prism, and the line can't be shown in the image taken by the camera. This is the reason that two lasers but not one are used.

Fig.2 illuminates the principle introduced above. There is a rounded hump at the center of the floor tile. When laser shines aslant on it from upper right, the line is curved to right side at the center part. The higher the hump is, the much more the line curves to right side. This means that the distance between every dot near the line MN and the camera (altitude of these dots) can be calculated according to the distance between every dot on projected line and reference line MN. For example, the length of BE can be calculated with the length of CF. Obviously, the length of CF can be read from image according to geometry. When floor tile moves from left side to right side or from right side to left side at constant speed, MN moves also on the surface of floor tile but almost not move in relation to camera, so altitude of most dots on the floor tile surface can be calculated according to the position of agleam curves. With this altitude data of most dots, the altitude of other dots can also be calculated by curve fitting, such as B-spline.

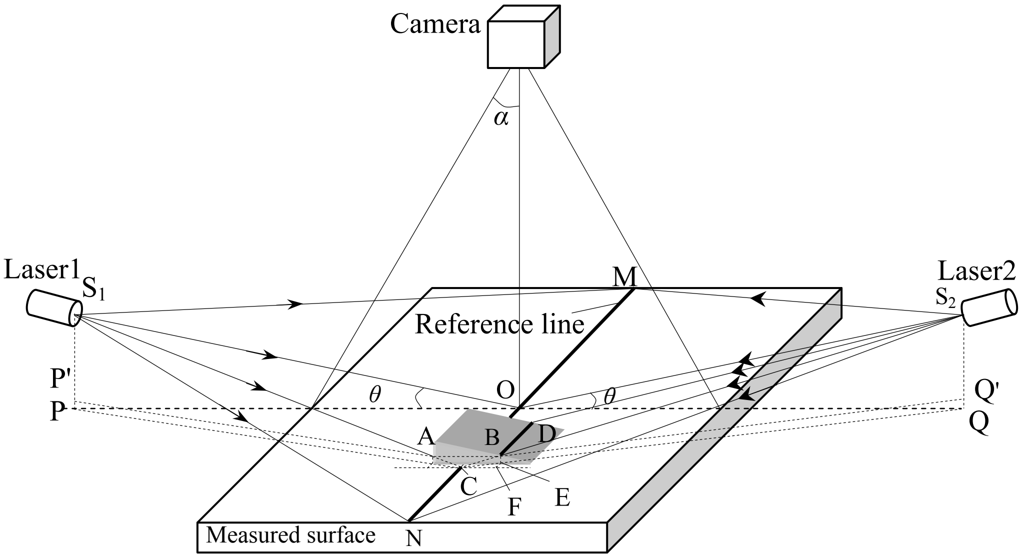

Fig.1 Measurement system and light path

From the measurement theory introduced above, the direct measurement result is discrete data of a surface in relation to a reference plane in a 3-dimentional coordinate. And on the other hand, it is well-known that any surface can be looked as a function in relation to the reference plane in the 3-dimentional coordinate. Generally, the function of the expected measured surface is known. For example, the function of the measured plane in Fig.1 is known in a 3-dimentional coordinate. In fact, it can be regarded as the reference plane. Accordingly, if the measurement result is set as function f_m, and the expected surface is f_e, f_m-f_e is just the roughness of the measured surface. Certainly, both f_m and f_e must be function in relation to the same plane.

3 Roughness Calculation

3.1 Image Processing

Before calculate the roughness of the measured surface, image processing is necessary. There are two

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reasons. The first is that there is always noise in the image, especially that taken in hostile environment, such as high temperature. The second is that the agleam curve is not thin enough that there are several pixels with high value at the section of the curve in the image. In order to decrease the effect of image noise, both image smoothing and threshold treating are necessary. In order to denote point B and D shown in fig.1 with appropriate dots in the image, thinning treating must be done. All the image processing methods used in this paper have been introduced reference [8].

3.1.1 Image Denoise

Smoothing linear filter is used to smooth image. The general implementation for filtering an $M \times N$ image with a weighted averaging filter of size $m \times n$ (m and n odd) is given by the expression

$$g(x,y)=\frac{\sum_{s=-a}^{a}\sum_{t=-b}^{b}w(s,t)f(x+s,y+t)}{\sum_{s=-a}^{a}\sum_{t=-b}^{b}w(s,t)} \qquad (1)$$

Where $a=(m-1)/2$, $b=(n-1)/2$, $f(x+s, y+t)$ denotes the gray value of the image before filtered at pixel of $(x+s, y+t)$, and $g(x, y)$ the gray value of the filtered image at pixel of (x, y); $w(s, t)$ denotes the weight of pixel of $(x+s, y+t)$. All the $w(s, t)$ forms an $m \times n$ mask. In this paper, after have been taken, all the images are smoothed with the mask shown in Fig.3(a). To generate a complete filtered image, equation (1) must be applied for $x=0,1,\cdots,M-1$ and $y=0,1, \cdots, N-1$. And the image filtered for 3 times with this mask is shown in Fig.3(b). Comparing Fig.3(b) with Fig.2, one can find that there is less noise in Fig.3(b), especially at the right side of the image.

3.1.2 Threshold and Thinning Treating

After has been filtered, image is treated by threshold at first, and then thinning. For threshold, the threshold value must be determined. It is related to the gray value of agleam curve and that of other area. Because the brightness of the dot of the agleam curve on the measured surface is different from each other, different threshold value must be determined for every line. The threshold value can be determined by statistics[8]. For example, for the images taken with the system introduced in section 2, for the first line, the maximum gray value at the agleam curve is about 140, that of other area is about 110, so the threshold value can be set as 125, but for the 1001th line, the gray value of agleam curve ranges from 210 to 255, and that of other area is about 110, so the threshold value can be set as 200, and for this line, if the gray value of the image is great than 200, set it as 1, otherwise, set it as 0. So a binary image is obtained.

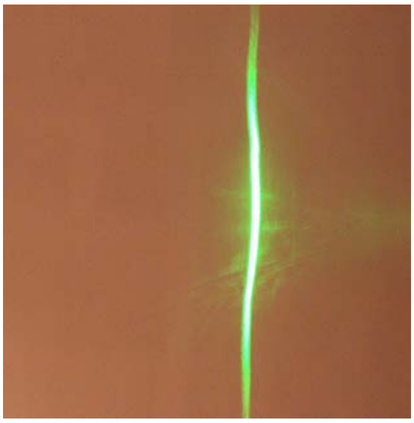
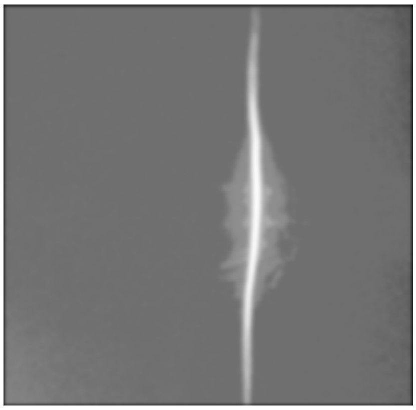


Fig.2 Image of roughened floor tile when laser shine aslant on it

1	1	1	1	1
1	2	2	2	1
1	2	3	2	1
1	2	2	2	1
1	1	1	1	1

(a)



(b)

Fig.3 Mask used to filter image in this paper(a) and the filtered image with it(b)

With the binary image, thinning treating can be done. The aim of thinning treating is that only one pixel whose gray value is 1 exists in the section of the agleam curve. The thinning of set A by a structuring element B, denoted $A \otimes B$, can be defined in terms of the hit-or-miss transform[8]:

$$A \otimes B = A - (A \circledast B) \qquad (2)$$

The commonly used structuring elements are shown if Fig.4(a). For such a set A shown in Fig.4(b), after has been thinning treated by $A \otimes B^{4,5,6,7,8,1,2,3}$, a new set shown in Fig.4(c) would be gotten. For the image shown in Fig.3(b), after has been threshold and thinning treated, such a image shown in Fig.4(c) can be obtained. Certainly, from the point of view of observation, the width of the agleam line has been widened from one pixel to 3 pixels.

3.2 Roughness Calculation

3.2.1 Image Resolution

Before calculate the roughness of measured surface, let's discuss the image resolution to make clear that how long one pixel means. As shown if Fig.1, both the optic angle α and resolution $r\times c$ (r means the pixel number in lateral direction, and c means that in longitudinal direction) of the camera are well known, and the distance h between camera and reference position is also known, so the size of the area related to one pixel is $s\times s$. s is determined by

$$s=2h\tan(\alpha)/r \tag{3}$$

Where $\tan(\alpha)$ means tangent of angle α. For the measurement system shown in Fig.1, h=1.7m, the resolution of camera is 2048×1536, and it's optic angle is 20°. So s is about 0.57mm.

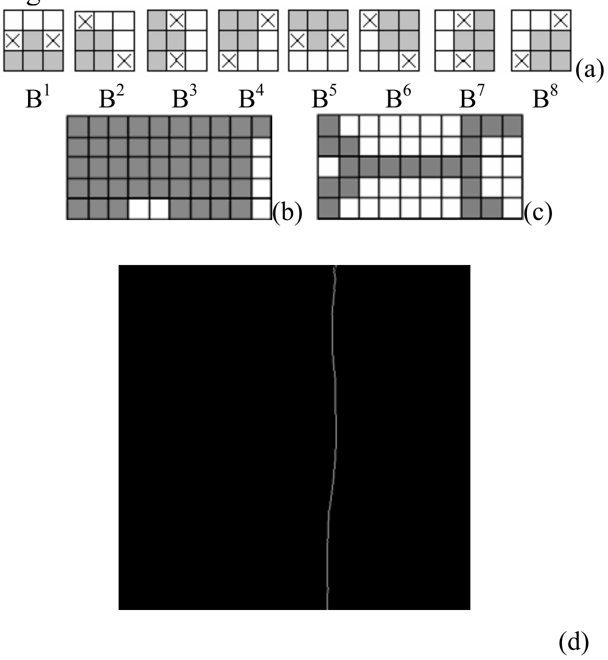


Fig.4 Sequence of rotated structuring elements used for thinning(a), Set A(b) and the result (c) after convergence, image has been threshold and thinning treated(d).

3.2.2 Roughness Calculation

As shown in Fig.1, laser light projected by the laser 2 fans out as a plane, and the angle between this plane and the measured plane is θ. Light S_2C should reach dot C has been held up at B. So after the cross section in the horizontal direction at dot B has been intercepted, section view shown in Fig.5 can be gotten. Where l means the distance between dot Q and B, Δd denotes the altitude of dot B. From Fig.5, one can find that the image of BQ is the same of $B'Q'$. Such equations are easy to be obtained according to geometry:

$$(h-\Delta d)\tan\beta = \Delta d/\tan\theta \tag{4}$$

$$\frac{(h-\Delta d)\tan\beta}{B'Q'} = \frac{h-\Delta d}{h} \tag{5}$$

Where $B'Q'=sn$, n denotes pixel number between dot B' and Q', which can be read from the processed image; s is determined by equation (3). Then

$$\Delta d = \frac{hsn\tan\theta}{h+sn\tan\theta} \tag{6}$$

Because θ is commonly less than 15°, sn less than several centimeters, $sn\tan\theta << h$, equation (6) can be simplified as

$$\Delta d=sn\tan(\theta) \tag{7}$$

Obviously, the calculation difficulty is very low when equation (7) is used to calculate surface roughness. According to equation (3), because n must be an integer, Δd may be discrete value. If θ=15°, the value of Δd may be n*0.1527mm (n=0,1,2,···). In other words, the measurement resolution of the system used in this paper is 0.1527mm/2=0.0764mm.

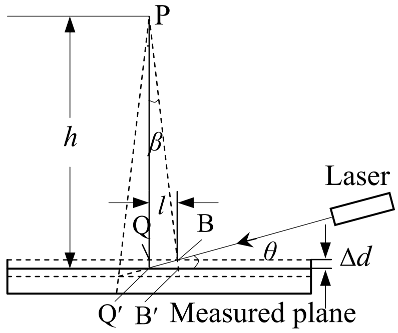


Fig.5 Cross-section view of light path

3.2.3 Curve Fitting

For commonly used camera, 0.2 second or more is needed to take one image, so not every dot on the measured surface can be measured directly, and some measures must be taken to calculate them indirectly. For this aim, Fig.6 gives the idea. When measured surface moves from left side to right side at constant speed, a series images with an agleam curve can be obtained. Put these image together, such a figure shown in Fig.6 can be gotten. Then, for the dots denoted with "●" and "○", their coordinate is known, and their altitudes have been calculated with equation (6) or (7). In other words, they are also known. And for the dot denoted with "Δ", it can be calculated indirectly by curve fitting such as least square, B-spline interpolation, and so on. For every curve fitting method, it can be done with different data. In other words, it can be done in different direction. For example, the altitude of dot denoted with "Δ" can be calculated both with dots denoted with "●" on line AB and with that denoted with "○". Generally, less the distance between the dot to be interpolated and the samples is, more precise the interpolation value is. So the direction in AB should be considered firstly if curve fitting only be carried out in one direction. Otherwise, curve fitting can be carried out at first in different direction, and then take the weighted arithmetic average value of the curve fitting results as the altitude of the dot denoted with "Δ".

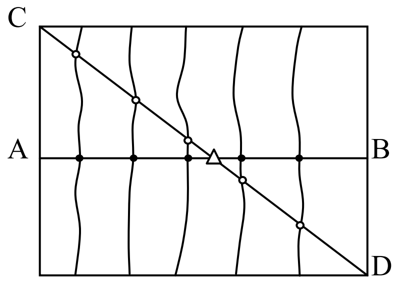


Fig.6 Direction of curve fitting

4 Measurement Example and Result Analysis

4.1 Measurement Example and Result

In order to exemplify our surface roughness method, such a measurement system shown in Fig.1 is designed and built up. Two triangular prisms with size of 40cm×20cm×2cm is placed on a floor tile, shown in Fig.7(a). Floor tile moves from left side to right side at constant speed of 0.1m/s(meter per second). Images are taken at 0.5-second interval. So the mean interval between two adjacent images is 0.05 meter. After every image has been denoised, treated through threshold and thinning, there are 8 curves on the triangular prisms. In order to exemplify the effect of interpolation, at the medium of two adjacent curves, a new curve is calculated by interpolation. For this new curve, it's coordinate is determined by equation (8):

$$x=(x_i+x_{i+1})/2 \qquad (8\text{-a})$$

$$y=y_i=y_{i+1} \qquad (8\text{-b})$$

For example, for the dot denoted with "Δ" in Fig.6, it's coordinate value in x-direction is the mean of that of the dots denoted with "●" adjacent to it, and it's coordinate value in y-direction is just the same of dot A and B. The measurement results are shown in Fig.7(b). In order to compare the measurement results with the idea results in figure, the cross -sections of measurement results and idea results of two triangular prisms are taken and shown in Fig.7(c). The dots denoted with "*" and "○" represent the measurement results of two triangular prism respectively. And two real lines represent the corresponding idea results respectively. From Fig.7(c), one can find that maximum measurement errors exist at the fourth row signed with ring. By comparing all the measurement results with the corresponding idea results, the maximum error can be gotten. Comparing result shows that the maximum is only 0.31mm, less than 0.35mm.

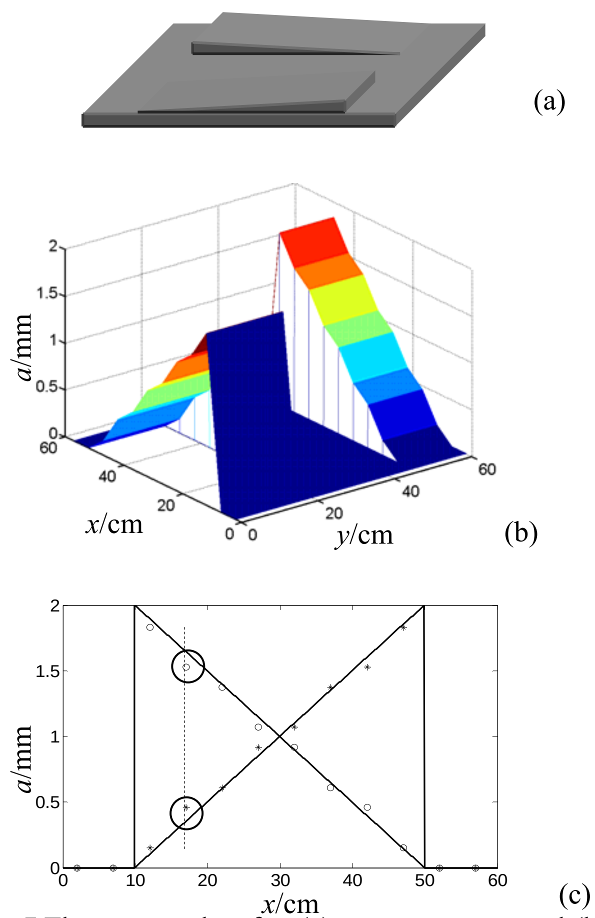


Fig.7 The measured surface(a), measurement result(b) and the cross-section of the measurement result(c-d)

4.2 Analysis of Measurement Result

In section 3.2.2, it is analyzed that the measurement resolution is just 0.0764mm. But the measurement result shows that the maximum measurement error is 0.31mm. It is about 4 times of the measurement resolution. Where does the additional error come from? Followings may be the major causes:

(1) The lasers are not ideal. From both Fig. 2 and Fig.3 (b), it is easy to find that the width of

the agleam curve is greater that 1.5 cm. Because of the nonuniformity of the laser-light density distribution, the agleam dot in the cross-section of Fig.4(d) may be not just the dot denoted with “B” in Fig.5.

(2) The lens disorders the light reflected form measurement surface to camera. Fig.1 shows that the disorder of lens to light has not been considered in this paper. In fact, because of the nonuniformity of the lens thickness, the light reflected form measured surface to camera is not line. In other words, there is always distortion in the image taken by camera. This will introduce measurement error to a certain extent.

Accordingly, although high precision for surface roughness measurement can be obtained using the method presented in this paper, there are measures to improve it. This method may be a good candidate for surface roughness measurement.

5 Conclusion

This paper presented a new method of surface roughness measurement. For this method, only simple geometry is involved. And the introduction of measurement theory and measurement system shows that this method is easy to be comprehended and carried out. Additionally, both a camera linked with a computer and two lasers which can project fan -shaped light are just needed to complete the surface roughness non-contact measurement. So the cost of this method is low. The measurement results of two triangular prism show that the maximum error is less than 0.35mm over a 60cm×60cm area. This precision is acceptable in many industrial fields, such as road roughness measurement and plate roughness measurement of floor tile. So this method may be a good candidate of surface roughness measurement. Certainly, there are measures can be take to improve this method. The first is that choosing better laser which can project fan-shape light. And when the light projected by this laser irradiate on a plane, the width of the agleam curve is narrower than that shown in Fig.2. The second is taking the effect of lens of camera on the image into account. Additionally, taking more appropriate image processing techniques to process the images taken for surface roughness measurement may be also one good measure to improve measurement precision.

Although a plane is used as a measured surface in this paper, the altitude of all the dots on the measured surface, even a curve surface, can be measured as dots on a plane. The difference between surface roughness measurement of plane and that of curve surface is the idea surface which is known. Subtract the idea surface from that the measurement results means, the surface roughness of the measured surface can be obtained. So this method may be used to measure roughness of any surface.

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