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Machine Vision and Image Processing in Industrial inspection and quality control

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Abstract : *This paper presents a new approach for surface roughness measurement and defect detection using Machine vision and image processing. It has an advantage over traditional method where the surface geometry is not touched and line to line scanning is not required. In this system, a CCD camera is used to grab the image of the roughness sample using optical set up along with image processing software and hardware. This paper explains how 3D parameters can be measured to provide greater insight into surface finish. It also includes two cases in which 3D parameters measurements are essential in the design and development of high performance surfaces. Experimental results demonstrated good correlation between the received signal parameters and the root mean square surface roughness. A range of roughness up to 10μm was detected, with a resolution of 0.01μm.*

***Key words** – Profilometers, Conic kernel*

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I. Introduction

Machine Vision has been used in food industry for the past two decades to assure the quality of the products. Machine vision has been successfully implemented for applications ranging from simple inspection to complex robot guidance. Vision based inspection systems reduce human interaction with the examined goods, categorize generally faster than human beings, and tend to be more reliable in their product classification. Food industries use vision based inspection systems for testing the quality of products such as meat, fruits and vegetables, bakery products etc [1-2]. Huda M. Jawad et al [1] developed measuring object dimensions and its distances based on Image processing. Dipti Nileshaswar [2] developed the device for measuring the dimensions of mechanical component using image processing techniques, Measurement.. He introduced automated process for measuring the dimensions of mechanical component. The proposed method includes image pre-processing techniques, edge detection technique, hough transform technique for circle detection and stereo vision concept is used for hole depth measurement of mechanical component. Bin Li [3] developed geometric dimension measurement system of shaft parts based on machine vision. Tonghai Wu [4] developed Bearing defect inspection system based on machine vision. Yunfan Wang et al [5] developed rotational speed measurement through digital imaging and image processing. M Ricci et al [6] developed Magnetic imaging and machine vision NDT for the on-line inspection of stainless steel strips. En Hong eta al [7] developed Non-contact inspection of internal threads of machined parts.

The measurement of surface roughness is important in areas of optics such as mirrors used in laser gyro systems, diamond turned optics, contact lenses, optical disks, soft lenses, contact lenses, polygon scanners and optical fibers. Surface roughness characterization is also of much interest in the magnetic storage area where the roughness of magnetic tape, floppy disks, hard disks, and magnetic heads is very important. There are two basic methods to measure the roughness of a surface (i) optical method (ii) mechanical method. Mechanical methods are based on the principle of profilometers. These are very expensive and unstable devices. The main disadvantage of these devices is the contact with the surface, which could scratch the surface and the device could give inaccurate readings of the roughness measurement. The other method is optical based, non-contact and is superior in many ways like very fast and complete scanning and processing The present technique is based on optical phenomena principles, which are used to measure roughness. Realization of these methods is inexpensive and does not require any high precision and sophisticated mechanical and optical components. The use of a computer allows fast and easy measurements. Due to its simplicity, this technique can also be used to measure roughness in continuous production processes.

II. Theory

The recognition, location, and description of 3D objects from natural light images are often difficult to obtain. In this paper we put forward an approach based on 3D analytical geometry. First we start with two-dimensional analytic geometry to recognize symmetric objects like cone, cylinders, spheres, ellipsoids etc. After obtaining a set of ten coefficients from the explicit representation of quadrics, a series of 2D curves are obtained from the intersection of planes at various orientations with surfaces. It is observed that only two planes are sufficient to generate a unique set of curves distinguishing each object from the other.

Conic Kernel

There are several equivalent coordinates to represent 3D orientation. They differ in the number and form of orientation variables. For example, a 2D polar angle and an implicit elevations angle (between the polar radius and z-coordinate) are used together to describe 3D orientation in the cylindrical coordinates, while three directional angles, (i.e. three angles between three Cartesian coordinate[3-4]. For orientation analysis, we believe that the orientation variables should be as small as possible to alleviate the complexity of indexing and visualization. Thus, we choose the spherical coordinates in which only two angles (azimuth and elevation) are needed to represent 3D representation.

The input data for plane analysis and measurement can be either the local image derivatives space (i.e. a space coordinated by partial derivatives of images with respect to different axes). They are the same for filtering purpose. For simplicity, we use the same representation $I(x,y,z)$ for both kinds of input data. Here we assume that $I(x,y,z)$ is correctly obtained for every (x,y,z). Thus, the error in obtaining image derivatives or spectrum is not considered. For orientation analysis we start by computing a local spherical mapping on the input data through artesian coordinate to polar coordinate by following steps

$$I(x, y.z) \rightarrow (r, \theta, \phi),$$

$$\text{when } r = \sqrt{x \quad + y^2 + z^2} \quad , \theta = \arctan (y/x), \;\; \phi = \arctan (z/ x^2 + y^2)$$

In order to have fine orientation resolution we use conic kernels with small angular support to sample the orientation space locally these kernels are radial-angular separable. A conic kernel cantered at (θ_i, ϕ_j) reads

$$k(\theta,\phi)(r,\theta,\phi) = \frac{G_o^{\theta i, \phi j}(\theta,\phi)}{N_{R_{min} R_{max}}^{(\theta_i, \phi_j)}(r)}$$

Where $N_{R\max, R\min}^{\theta i, \phi j}(r)$ is a compensation function along the radial direction. First we focus on the angular part of the kernel, which is a 2D Gassuian function [4-5] in $(\theta,\phi)-$space

$$G^{(\theta_i, \phi_j)}(\theta,\phi) = \frac{1}{2\pi\sigma^2} \exp\left(\frac{-(\mu(\theta,\theta_i))^2 + (\phi - \phi_j)^2}{2\sigma^2} \right.$$

As the azimuth angle θ is periodic, we define $a\mu(.)$ to represent the minimal circular difference between θ and θ_i $(\theta, \theta_i \in [0^o, 360^o])$,

$$\mu(\theta,\theta_i) = \min(|\theta - \theta_i|, |\theta - \theta_i - 360^o|, |\theta - \theta_i + 360^o|)$$

Conic Kernel response to 3D planes

In the 3D coordinate systems, a plane passing through the origin (0,0,0) with a unit normal vector $N = (n_1, n_2, n_3)^T$ reads $xn_1 + yn_2 + zn_3 = 0$

In order to represents a plane with (θ, ϕ), we convert the Cartesian coordinates into spherical coordinates

$$(x,y,z) \rightarrow (r, \theta, \phi) \text{ and } (n_1, n_2, n_3) \rightarrow (1, \theta_n, \phi_n).$$

After dropping out (r) we obtain an equation with variable θ and ϕ

$$\cos(\phi)\cos(\phi_n)\cos(\theta - \theta_n) + \sin(\phi)\sin(\phi_n) = 0$$

After horizontal and vertical planes with normal parallel to the co-ordinate axes, their corresponding representations in the (θ, ϕ)- space are straight lines. In 3d analysis, we usually encounter titled planes which turn into harmonic curves with different amplitudes and phases in the (θ, ϕ) - space . The normal vector of each plane i.e. θ_n, ϕ_n is related to the extreme point θ_m, ϕ_m on corresponding curve as follows

$\theta_n = \theta_m + 180^0$

$\phi_n = 90^0 - \phi_m$

The titled phases parameters (u, v) can then be estimated using θ_n and ϕ

$u = \cos(\theta_n)\cot(\phi_n)$

$v = \sin(\theta_n)\cot(\phi_n)$

Further, each harmonic curve has two zero- crossing points on the θ axis with a distance of 180^0 and θ_m lies exactly in the middle of two zero-crossing points[12-13].

The extra geometry constraint is very useful in determining the number of points. Further, each harmonic curve has two zero-crossing points on the θ axis with a distance of 180^0 and θ_m lies exactly in the middle of these two zero-crossing points. This extra geometry constraint is very useful in determining the number of planes automatically as well as in obtaining reasonable initial values of plane parameters. In practice, we obtain a set of points in the $(\theta, \phi)-$ space. Extracting the parameters θ_n, ϕ_n form these points is then a standard fitting problem. For a simple curve, least square estimation is applicable.

III. Description of the method

The system for image acquisition is developed around National instruments image Acquisition Card, PCI 1408, installed on the Pentium III. This card can acquire the monochrome images with a maximum transfer rate of 132 M bytes/sec on 32 bit wide bus. Image grabbing window is configured to acquire the image size 640 x 480 and pixel depth of 8 bits. The image is transferred from the camera to the computer at frame rate 30 frames per second. To achieve optimum results the roughness standard under study was illuminated from two different angles. The image was recorded by Pulnix TMC-76 CCD camera and image acquisition system. The image was stored in the two dimensional array. Discrete wavelet transform is used to analyze the acquired image. The two-dimensional wavelet transform decomposes the image in horizontal, vertical, and diagonal components at different level of intensities containing texture information content. The processing is made through Labview software and Matlab. Standard roughness sample is analyzed by using image processing and Symlet wavelet transform.

Determination of the Exterior Orientation Elements

The bundle adjustment is based on the collinear condition, which refers to the perspective center of a camera, the points on the photograph, and the points in the object space being aligned in the bundle of rays. Rotation elements and the perspective centre position of camera at the moment of exposure (X0, Y0, Z0) resulted from the least square method. In this paper, the exterior orientation elements of digital images acquired by the CCD camera are not calibration data, so the interior and the exterior orientation elements were resulted from the bundle adjustment using the additional parameters of principal displacement and focal length. For reliability evaluation of resulting exterior orientation elements, space coordinates of check points in each object space are computed by the bundle adjustment. The accuracy of the computed positions is evaluated from residual errors and computed positions by the bundle adjustment. Object coordinated were generated by applying the space intersection theory, where conjugate points are resulted by matching, and exterior orientation elements are obtained by the calibration process of systematic error.

IV. Errors in measurement

As with any optical technique, a number of error sources degrade the accuracy of measurement. When combining together multiple topography maps, limiting the sources of these errors becomes especially important because the errors magnify as multiple measurements are introduced. Therefore we need to consider the error sources by this process. Following are the errors which may influence the uncertainty in measurement: 1. Objective distortion and aberrations. 2. Magnifications. 3. Pixel aspect ratio. 4. Error of the measurement technique. 5. Detector/array non linearity. 6. Vibrations. 7. Errors due to defocus. 8. System noise. 9. Measurement uncertainty in roughness measurement.

In roughness measurement a profile of the surface of a given work piece is measured by sampling. Thus the measured is represented by a vector of data. Consequently these data are accompanied by a covariance matrix, in order to have the complete information of the measurement process. Due to the uniformity of the measurement process, each data point of the input data vector is expected to be measured with same measurement uncertainty. Thus all entries in the diagonal of the covariance matrix are the same. If there is no knowledge about the correlation of the measured input data, then, the covariances have to be set to zero. In this case the covariance matrix of the measured input data s simply a constant diagonal matrix. However, even in this very simple case it will be shown that the covariance matrix of the filtered data is a full matrix with no zero entries. This is due to the fact that the filtration process always causes a correlation between the data points.

IV. Comparison and Analysis

Surface roughness from the reference plane and the reference surface to all points in the sample area were computed with the proposed method in this paper. In order to evaluate measurement-processing capability of the proposed system resultant values of a ccd camera were compared with the resultant values of surface roughness obtained by using standard contact type perthometer model 6SP6. Sample areas of digital images acquired by camera evaluated the same areas as did perthometer model 6SP6. Also, the three – dimensional position of each sample area was computed by applying the space intersection theory, where conjugate points resulting from matching are used for all pixels in the sample area images. Surface roughness is computed with application of mentioned reference plane and reference surface equation using the resulting three – dimensional positions information.

V. Results and Discussions

Three- dimension measurement techniques and parameters are well understood and widely adopted for characterizing surface finish and performance. Nevertheless, in many application two- dimensional (2D) parameters are the only parameters specified for controlling surface quality. In most cases, average roughness (Ra) is the parameter specified. This paper explores why 2D parameters continue to be used and, what is more important, it describe how 3D parameters can be measured to provide greater insight into surface finish and performance It also include

two cases in which 3D parameters have helped in the design and development of high performance surfaces. The roughness standards are made of hardened stainless steel of dimensions 40 mm x 20 mm x 10 mm. They have irregularly profile which repeated every 4 mm in longitudinal direction of the specimen. Normal to the measuring direction of the specimen, the grooves on the measuring faces are constant in the form of profile The nominal values of the set 3 roughness standards in µm are:

Ra: 0, 2 0, 5 1, 5 Rz: 1, 5 3 8, 5

The standards deviation calculated from 12 measurements is” 6% of Ra and Rz.

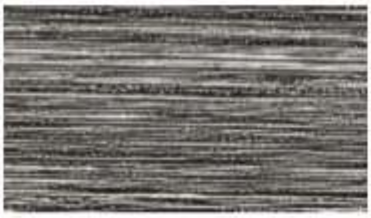

Fig. 1(a) Original image

Fig. 1(b) 3D Profilometry showing the structure

Fig. 2.a Phase structure of the surface

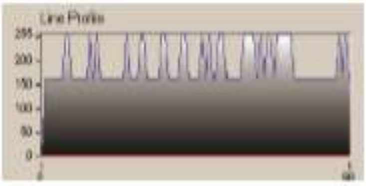

Fig 2.b Line profile

Fig3. 3 dimensional profiles after phase mapped

VI. Conclusion

Important measuring tasks in dimensional metrology have been identified in the non-contact optical systems. For this subject, solutions have been presented, which make use of optical techniques. Initial results are quite satisfactory and show the 3D-orientation measurement. More comparable calibration of this method against standard method is in progress. The results obtained by image processing system are compared with the results obtained using Perthometer (S6P). It is seen that repeatability in our scheme is comparable with the standard method 1. Standard surface roughness from the reference plane and surface can be measured accurately with less than r0.1μm errors, after applying the filtering scheme. 2. A primary window operating roughness measurement system can be constructed by using a digital camera and Labview in Window environment for real time processing. Results of this study may be applied to industrial measurement of high precision demanded by the close range photogrammetric.

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