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Application of digital image magnification for surface roughness evaluation using machine vision

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Abstract

In this work, a machine vision system has been utilized to capture the images and then the quantification of the surface roughness of machined surfaces (ground, milled and shaped) is done by the application of regression analysis. Subsequently, original images have been magnified using Cubic Convolution interpolation technique and improved (edge enhancement) through Linear Edge Crispening algorithm. Based on the surface image features, a parameter called G_a has been estimated using regression analysis, for the original images and for the magnified quality improved images. Finally, a comparison has been carried to establish correlation between magnification index, G_a and surface roughness.

Keywords: Cubic convolution; Regression analysis; Magnification factor; Grey level average

1. Introduction

With growing demand of industrial automation in manufacturing, machine vision plays an important role in quality inspection and process monitoring. Surface roughness inspection is one of the essential quality control processes that are carried out to ensure that manufactured parts conform to specified standards. This kind of inspection is normally done through the use of stylus type instruments, which correlate the motion of a diamond-tipped stylus to the roughness of the surface under investigation. The major disadvantage of using a stylus instrument for such measurements is that it requires direct physical contact, which limits the measuring speed. In addition, the instrument readings are based on a limited number of line samplings, which may not represent the real characteristics of the surface. This kind of deviation may cause serious errors in the surface quality assessment especially when the surface profile is periodic. Because of these drawbacks, contact type instruments are not suitable for high-speed automated inspection. Previous researchers using machine vision techniques for surface texture assessment have covered several calculated parameters, with stylus profilometer measurements of average roughness (area) performed on the same surface. Luk et al. [1] utilized statistical parameters, derived from the grey level intensity histogram such as the range and the mean value of the distribution and correlated them with the R_a value determined from the stylus method. Al-Kindi et al. [2] implemented a technique utilizing a roughness parameter based on both the spacing between grey level peaks and the number of grey level peaks per unit length of a scanned line in the grey level image to estimate the surface roughness. Du-Ming Tsai et al. [3] employed a two-dimensional Fourier transform of a cast surface in both the grey level image and binary image to estimate the surface roughness of castings (for surfaces with $R_a > 10$ μm). Jason et al. [4] first scan the scattering pattern from the surface, the analog and digital electronics measure the light intensity incident on each detector, then compute both the reflected and total incident intensity which are then used to compute the surface roughness (for surfaces with $R_a > 20$ μm). Bradley et al. [5] employed a fiber optics sensor for surface roughness measurement. In their work, changes in the surface topography are manifested as phase

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changes of the incident and reflected light on the surface. Hisayoshi Sato et al. [6] worked on the estimation of surface roughness using a scanning electron microscope. They showed that the profile of a surface could be obtained by processing back scattered electron signals which are in proportion to the surface inclination along the electron beam scanning, which meant that the profile of the surface roughness can be derived by integrating the intensity of the back scattered electron signal. Bjuggern et al. [7] developed a total integrated infrared scatterometer to perform the rms roughness measurements of engineering surfaces. Hasegawa et al. [8] employed fractal characteristics of the ARMA model in an approach to model a machined surface profiles. Carneiro et al. [9] measured the surface roughness using scanning probe microscopy, which includes more than 20 three-dimensional roughness parameters to characterize the surface topography. After capturing the images of surfaces using machine vision systems manufactured by various processes including shaping, milling, grinding, etc. Ramamoorthy et al. [10,11] have utilized the grey level intensity histograms, etc. for establishing new optical parameters for roughness evaluation. Ramamoorthy et al. [12] have also used stereometry techniques to get the three-dimensional depth profiles of such surfaces and successfully estimated the surface area and volume of the components.

Most state of the art digital image magnification techniques suffer from the limitation that they do not introduce any new information to the original image. This lack of information, more precisely the absence of high spatial frequency components is responsible for the perceptible degradation of magnified images, which are reflected, in blurred edges. Interpolation methods are usually employed in magnification of digital images. One of the best interpolation schemes namely cubic convolution developed by Keys [13] approximates the ideal sinc function by truncating it and this non-ideal interpolation cuts some high frequencies, which are present in the original image, leading to band limiting effects on the high resolution image. Although the cubic spline method generates a better high-resolution version of an image, computationally it is much more cumbersome compared to cubic convolution. Edge blurring is even more severe with other magnification techniques. There have been several attempts in the past for improvements to achieve image magnification. Hewlett Packard [14] has reported an approach in this regard which is patented by them. Most of these methods use edge information at the low resolution of the original image to be interpolated. Allebach and Wong [15] use a sub-pixel edge estimation technique to generate a high resolution edge map from the low resolution image, and then use the high resolution edge map to guide the interpolation of the low resolution image to the final high resolution version. Jensen and Anastassiou [16] present an approach for resolution enhancement based on a new edge fitting operator. A small neighborhood of 3×3 about each pixel in the low-resolution image is first mapped to a best fit continuous space step edge. The bi-level approximation serves as a local template on which the higher resolution sampling grid can then be superimposed (where disputed values in regions of local window overlap are averaged to smooth errors). The result is an image of increased resolution with noticeably sharper edges. Biancardi et al. [17] estimate the phases and frequencies of absent waveforms of absent frequencies from the original low resolution image and then synthesize them in the high resolution image. This technique, like the one by Allebach and Wong, takes advantage of sub-pixel edge estimation from the low-resolution image to direct the subsequent polynomial interpolation step.

There are limitations even in the widely accepted mechanical stylus methods such as evaluation of roughness, waviness and form error. Various electrical filters, cut off ratios and magnification are used during evaluation. Here in this work an attempt is made to digitally magnify the surface image. To test the quantification parameters evaluated using this method, a comparative study has been presented with the mechanical stylus parameters with complete analysis. It has been finally established that this digital magnification followed by qualitative evaluation of surface images could be very well used for engineering surfaces such as shaped, milled and ground surfaces.

2. Experimental procedure

The experiments were carried out by preparing flat specimens made by different machining processes, such as grinding, milling and shaping. Surfaces with different textures were obtained by controlling the machining parameters of these processes. The vision system consisted of a CCD camera, image processing software, a computer, an image processing board and a video monitor. The images of the surface of the work piece to be measured were captured by the camera and the frame grabber card digitized the image and stored it in the frame buffer. The digitized image was stored as an array of 512×480 with 8 bit pixels brightness resolution. Each pixel had a definite illumination intensity value. The grey scale analysis technique has been normally used for processing and analyzing the image. The digital image was transferred to a display subsystem. Here, the image data was converted to a standard television format and was displayed on a television monitor.

3. Magnification of digital images

Magnification of digital images is basically a problem of brightness interpolation in the input image which is also a low resolution image. It starts with the geometric transformation of the input pixels which are mapped to a new position in the output image. A geometric transform is a vector function $\mathbf{T}$ that maps the pixel (x,y) to a new position