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An evaluation of surface roughness parameters measurement using vision-based data

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Abstract

This paper presents a methodology for using machine vision data to acquire reliable surface roughness parameter measurement. Stylus-based measurements were acquired and compared to vision-based measurements using standard and non-standard roughness parameters. Two light reflection models namely Intensity-Topography Compatible (ITC) model and Light-Diffuse model were adopted and applied to interpret acquired vision data and to enable suitable computation of roughness parameters. Results showed that the ITC model gives more superior results compared to the Light-Diffuse model with remarkable close values to those acquired by the traditional stylus-based data of all roughness parameters but the Skewness parameter (R_{sk}). In the case of the Skewness parameter (R_{sk}), however, it was shown to provide highly different values from those acquired by stylus technique. The overall acquired results indicate that vision systems are a valid source of data to obtain both amplitude and spacing roughness parameters with confidence using the proposed methodology. It is expected that these results would encourage further developments in the area to achieve commercial 3D vision-based roughness measurement systems for industrial use.

Keywords: Vision-based topography; Image texture; Roughness parameters; Surface measurement; Surface texture

1. Introduction

Surface roughness measurement presents an important task in many engineering applications [1]. Every surface has some form of texture that takes the form of peaks and valleys. These peaks and valleys vary in height and spacing and have properties inherent in the way the surface was produced or utilised.

The development of non-contact-based roughness measurement techniques for engineering surfaces has received much attention. However, stylus-based equipment is still dominating this measurement task [2]. Stylus techniques have great inherent limitation as they were originally intended to acquire 2D surface topography. Therefore, 3D surface roughness data can only be obtained from stylus equipment by executing multiple scans of the surface. However, this task is a very time consuming. As a result most research efforts have focused on 2D roughness measurements for industrial use, and very few articles in the literature have comprehensively handled 3D surface roughness measurements.

In recent years, the modelling and prediction problems of surface roughness of a work-piece by computer vision have received increasing attention [3–7]. However, most of the published work focuses with surface roughness assessment in turning operations. This is due to the relaxed requirements for data processing, where only one line across an image could be sufficient to evaluate the surface texture.

Although it has been shown that the surface roughness may be characterized by a surface image, obtaining practical surface roughness values using instruments based

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on computer vision technology is still difficult [8]. The main problem is how to acquire reliable measurements of the actual surface roughness of work-pieces.

Lee et al. [9] proposed a method to assess surface roughness using texture features of image data. Their results demonstrated the validity of the proposed approach to achieve accurate R_a measurements, although it was not stated how much R_a acquired values may vary with light or material change.

Bradly and Wong [10] developed a method to monitor surface texture of the work-piece for the purpose of on-line tool condition assessment in milling operations. Their method utilises spatial and frequency domains. Kumar et al. [11] introduced a surface roughness parameter for image data using regression analysis. Li et al. [12] used the distribution pattern from a laser-scattering image to characterize the topography of surface finish. Tasan et al. [13] proposed a wear measurement technique based on the comparison of local surface heights gained from image data.

The aim of this paper is to evaluate the suitability of using vision-based data to acquire acceptable surface roughness parameter measurements, and thus may open the way to establish vision-based 3D surface roughness measurement systems for practical use in engineering applications.

2. Surface roughness measurements

A single parameter of the surface roughness could not indicate a change in the manufacturing process [1]. Therefore, many parameters and methods were developed over the years to enable improved ways of surface roughness evaluation.

In order to separate the elements of roughness and waviness from a raw signal of a surface profile, cut-off filters are used [14].

As the data is filtered with a cut-off, sampling is achieved by breaking the data into equal sample lengths. These sample lengths are chosen in such a way that a good statistical analysis can be made of the surface. Acquired data array, F, that represents the full evaluation length, are usually divided into five sub-arrays of equal number of samples to enable better statistical analysis. These sub-arrays are commonly referred to as the sampling length. Mathematically, the sampling length arrays, f_i, are obtained as follows:

$$f_i(m) = F\left(m + i\frac{N}{5} - \frac{N}{5}\right), \tag{1}$$

where N presents the total number of elements in the evaluation length array, F, i is the sampling length data array number having an integer value in the range of 1–5, and m presents the element number within each of the sampling length data arrays thus m has an integer value of 1,2,3,…,N/5.

Reference mean lines are commonly implemented in the computation of surface roughness parameters. The most common line used as a reference line is the least-squares mean line in which the areas of the profile above and below this line are equal and the sum of the squares of the deviations of the profile from this line is minimized. Therefore, if F presents the filtered data array of the full evaluation length and C presents the mean line then the departure data array G and sub-arrays g_i from the mean line are computed by

$$G(n) = F(n) - C \quad \text{for} \quad n = 1, 2, 3, \ldots, N$$

and

$$g_i(m) = f_i(m) - C \quad \text{for} \quad i = 1\text{–}5 \quad \text{and} \quad m = 1, 2, 3, \ldots, N/5.$$

The adopted surface roughness evaluation parameters used to achieve the goal of this work are listed in Table 1.

3. Equipment setup

A Surtronic 3P stylus-based surface roughness measuring machine manufactured by Taylor Hobson (UK) was used. The machine was calibrated using reference surface roughness specimen (Type 112 1107) having an Ra value of 6.07 μm. Table 2 summarizes the results using the Surtronic built-in capability of measurements which where obtained using 50 traces along 5 different positions on the specimen surface. These results demonstrate the machine accuracy and the close repeatability of measurements, as obtained results showed to be less than 0.5% difference for all repeated measurements.

In order to enable further analysis of surface profiles the Surtronic 3P was successfully interfaced to a PC using its analogue signal output which is originally meant to be used with a plotter. Hence, a National Instrument PCI-6013 data acquisition card and SCB-68 connector block were used to enable the A/D conversion. National Instrument (VI Logger 2) software was used to acquire the signal data.

To acquire vision data, a Pulnix (TM 300) CCD camera equipped with a 25 mm 1:1.4 F Cosmicar television lens was used. The camera was interfaced to the PC using a Data Translation frame grabber card type DT-3152 and employing a related image-grabbing software. The images are digitized in a resolution of 768 × 576 pixels with 256 available grey levels.

Fig. 1 shows a block diagram of the employed equipment.

4. Image data implementation for surface roughness measurements

Although image data inherit roughness properties from light, valid interpretation models of image data to enable roughness measurements are still required to be developed. Two models are therefore adopted and investigated in this work to assess their feasibility in engineering roughness measurement.