Estimation of Surface roughness parameter using Wavelets based feature extraction

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Abstract

Practical use of Computer Vision for surface roughness estimation faces many challenges, as only image is used for evaluation rather than the components. Existing schemes are less suited for real-time machine vision applications due to the great computational burden involved in processing a large image. For example, an operation such as rotation and scaling involves four multiplications and four additions per pixel, which is going to be computationally complex. In this paper, the quantitative measure of surface roughness is estimated in the spatial frequency domain using wavelet transformation (WT) by extracting four features namely total energy (E_t), energy horizontal (E_h), energy vertical (E_v) and energy diagonal (E_d). An exhaustive analysis is done with comparison studies wherever required to make sure that the proposed method of estimating surface finish based on the computer vision processing of image is more consistent. The predicted surface finish values using WT are found to correlate well with the conventional stylus surface finish (R_t) values.

Key words:
Surface roughness, wavelet transform, Machine vision, Feature extraction.

1. Introduction

Surface characterization belongs to a large family known as Texture Analysis and is still considered as a challenging task. When measuring the roughness of a surface, the result can be understood as an image where the grey levels correspond to the surface finish. The deeper a valley, the darker the corresponding pixel, the higher a peak, the brighter the corresponding area in the image. Analysis of these images in order to characterize them is still an open field as there is no single technique that can be used to entirely characterize the roughness parameters [8, 10]. Conventional ways of measuring the surface roughness are Optical (Non-contact) and Stylus technique (Invasive or contact).The main drawback in stylus technique is that it is a contact method and hence can damage the surface, whereas in optical technique, it is not uncommon for the surface components to have roughness less than a nanometer. Alternately, surface roughness [9] can also be analyzed using spectral analysis based using Discrete Fourier Transform (DFT), Power Spectral density (PSD) and Short time Fourier Transform (STFT) but, they produce satisfactory results only when applied to stationary signals. Unfortunately, the roughness profiles in many cases are non-stationary. Hence, use of Wavelet Transform (WT) is explored in this paper to give improved results for non-stationary profiles.

2. Wavelet Transform

Wavelet transform [5, 6] involves representing general functions in terms of simple, fixed building blocks at different scales and positions. Wavelet Transform (WT) provides spatial/ frequency information of an image and helps in analyzing images at different frequency bands.

2.1 Wavelet Transform for 2D signals

In two dimensional cases, the 1D Wavelet transforms are applied along both the horizontal and vertical directions.

$$\phi_{j,k}(x) = 2^{j/2}\phi(2^j x - k) \qquad (1)$$

where $\phi_{j,k}(x)$ is a one dimensional real sequence integrable scaling function defined in (1).Translation factor k determines the position of these 1D functions along the x –axis, scale j determines their width along x and $2^{j/2}$ controls the height and amplitude. This one dimensional scaling function satisfies the conditions:

(i) $\phi_{j,k}(x)$ is orthogonal to its integer translations.

(ii) the set of functions that can be represented as a series expansion of $\phi_{j,k}(x)$ at low scale is contained within those at higher scale. It is inferred that DWT is well localized and permits decomposition in 3 directions – vertical, horizontal and diagonal.

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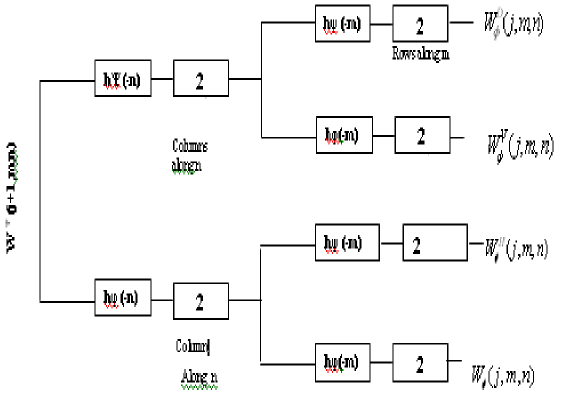

Fig 1 DWT filter bank

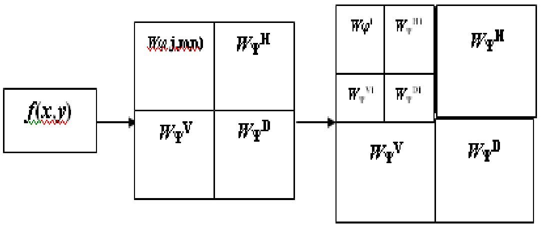

Fig 2 Sub band image Decomposition for wavelet based feature extraction

In Fig 2 , f(x, y) is the highest resolution representation of the image being transformed ,it serves as the input for the first iteration, and for the next iteration the approximation coefficients W $_\varphi$ (j , m, n) is given as input to the filter bank, to obtain the next set of wavelet coefficients[4].

2.2 Fast Wavelet Transform

Both wavelet function ψ (x) and scaling function φ(x) can be expressed as linear combinations of double resolution copies of themselves as follows:

$$\Psi(x) = \sum_n h_\psi(n)\sqrt{2}\ \psi(2x-n) \qquad (2)$$

$$\Phi(x) = \sum_n h_\psi(n)\sqrt{2}\ \Phi(2x-n) \qquad (3)$$

where h_φ and h_ψ are the scaling and wavelet vectors and are the filter coefficients of the Fast Wavelet Transform(FWT) (an iterative computational approach to DWT).

3. Feature Extraction

Energy level in the four sub bands can indicate the prominence of the edges in each wavelet band, which is a measure of texture; hence, this energy is used as a feature vector for texture estimation in this work [8]. The local energy wavelet coefficient in the vertical wavelet band is calculated as

$$E^V = \sum\sum\left(W_\phi^V\right)^2 X(Gaussian\ Kernel) \qquad (4)$$

Similarly E ^{H} , E^D are also computed. Better image representation is achieved by taking the logarithm of the local energy. Hence, the feature set is (log E_1, ^{V}, log E_1 ^{H}, log E_1^D…, log E).

3.1 Daubechies 4 wavelets

In this work (extracting features), the Daubechies 4 wavelet (which belongs to a family of orthogonal wavelets) [5] is used. The Daubechies 4 mother wavelet, its corresponding scaling and wavelet functions and also the decomposition filters used are shown in Fig 3.

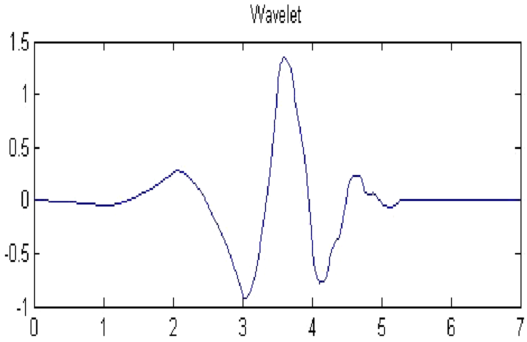

Fig 3 Daubechies 4 wavelet

Daubechies D4 scaling function:

$$a_i = h_0 s_{2i} + h_1 s_{2i+1} + h_2 s_{2i+2} + h_3 s_{2i+3}$$

$$a[i] = h_0 s[2i] + h_1 s[2i+1] + h_2 s[2i+2] + h_3 s[2i+3];$$

Daubechies D4 wavelet function:

$$c_i = g_0 s_{2i} + g_1 s_{2i+1} + g_2 s_{2i+2} + g_3 s_{2i+3}$$

$$c[i] = g_0 s[2i] + g_1 s[2i+1] + g_2 s[2i+2] + g_3 s[2i+3];$$

(5)

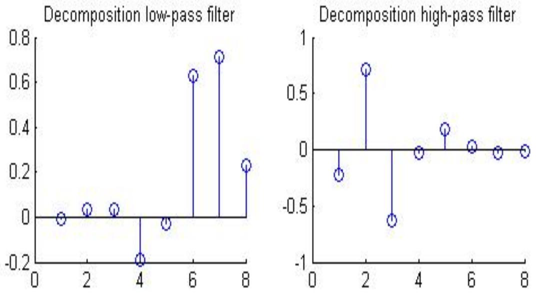

Fig 4 Decomposition of low pass and high-pass filter

4. Experimental set up

The basic experimental set-up consists of a vision system (CCD Camera), PC with image processing hardware and an appropriate lighting arrangement and is shown in Fig 5.

Fig 5 Machine vision system for inspecting surface roughness

Illumination of the specification was accomplished by a diffuse, white light source which is situated at an angle of approximately 45° incidence with respect to the specimen surface. The distance between the work piece and camera is approximately 10 cm and it is maintained throughout the experimental study. The specification of the vision system is given in Table A.1.

4.1 Roughness estimation of milled and ground components

Experiments with different operating conditions (i.e., varying speed, feed, and depth of cut) were conducted on milling machine. The machining parameters used for milled surface are given in Table A.2. The specimens are ground using a magnetic chuck grinding with different operating conditions. By varying operating conditions (i.e., feed, depth of cut and speed) different specimens with different surface roughness are obtained. For the present work, the ranges of values chosen for machining parameters are shown in Table A.4.

4.2 Typical machined images

Typical images of the surface texture for milling and grinding and their grey level intensity matrix are given in Fig 6 and 7 respectively. The shift of the histogram towards higher grey levels indicate smoother surface and hence an increased reflectivity.

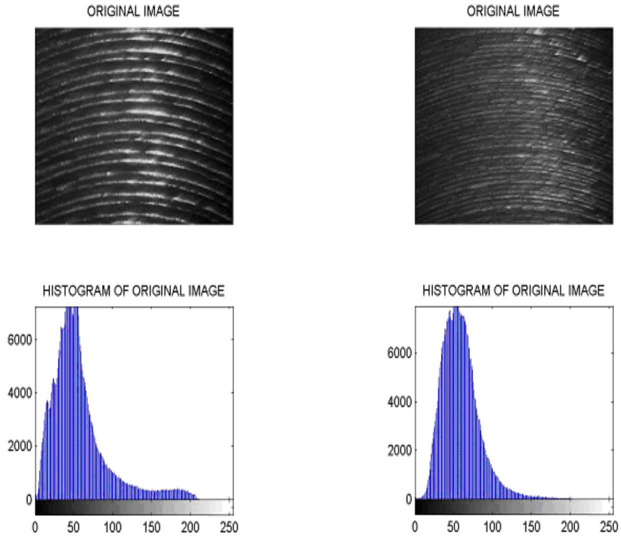

Fig 6 Typical milled images with histogram

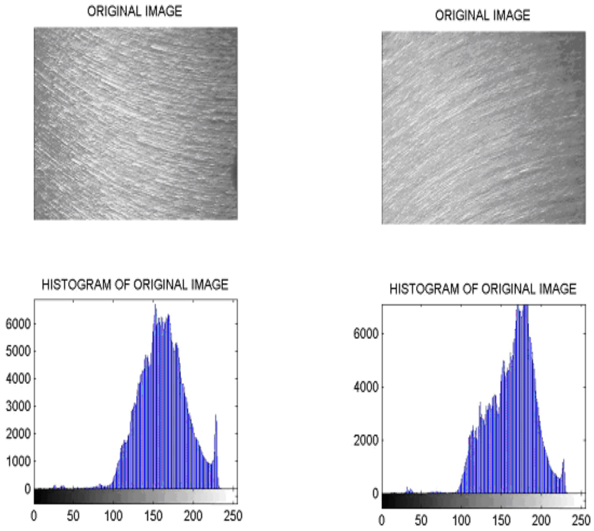

Fig 7 Typical ground images with histogram

Note: In fig 6 and fig 7, x represents the grey levels and y represents the frequency of occurrence.

5. Experimental results

5.1Estimation of R_t for milled and ground surfaces

In this section, the estimated value of surface roughness R_t using the wavelet transform (both for milling and grinding operation) is presented. For comparison study, the results obtained using Fourier transform [7] is also presented. The results obtained are validated by plotting the correlation graph between stylus measured (conventional method) R_t and vision measured (proposed) R_t. The correlation graph using FT and WT techniques for milled components is shown in Fig 8a and 8b respectively [3]. Similar plots obtained for ground components are shown in Fig 9a and 9b respectively. Also, the comparison plot of estimated roughness values using vision approach and stylus approach both for milled and ground components using FT and WT are presented in Fig 10a and 10b and Fig 11a and 11b respectively. The results obtained indicate the superiority of the wavelet transform method over other schemes.

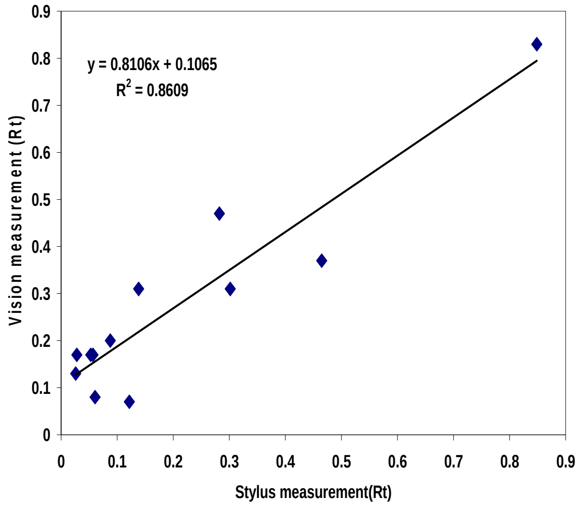

Fig 8a Correlation between predicted roughness values using vision approach and stylus approach for FT features (Milling)

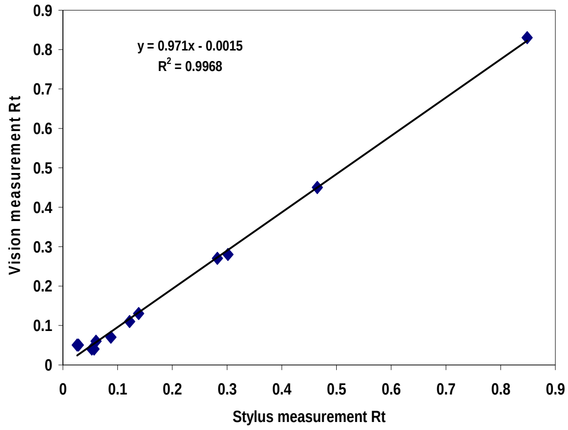

Fig 8b Correlation between predicted roughness values using vision approach and stylus approach for WT (Milling)

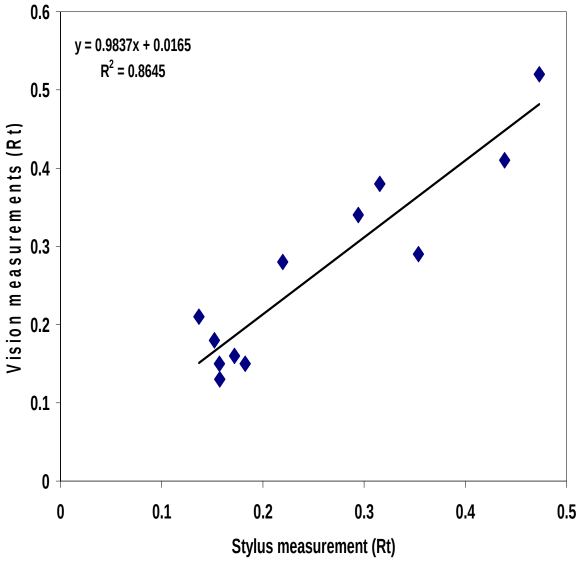

Fig 9a Correlation between predicted roughness values using vision approach and stylus approach for FT features (Grinding)

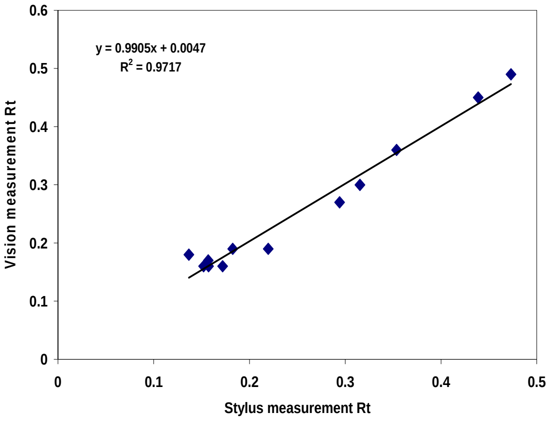

Fig 9b Correlation between predicted roughness values using vision approach and stylus approach for WT (grinding)

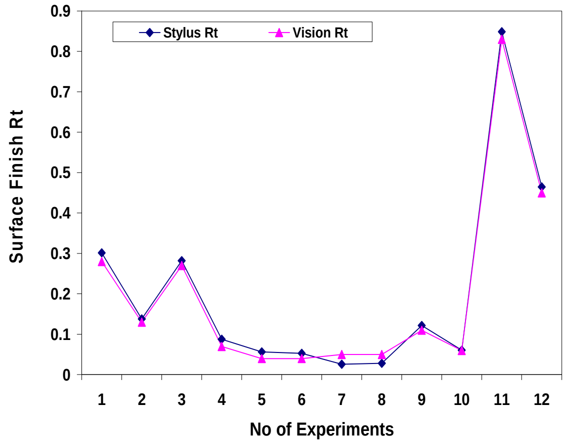

Fig 10b Comparison between predicted roughness values using vision approach and stylus approach for WT (Milling)

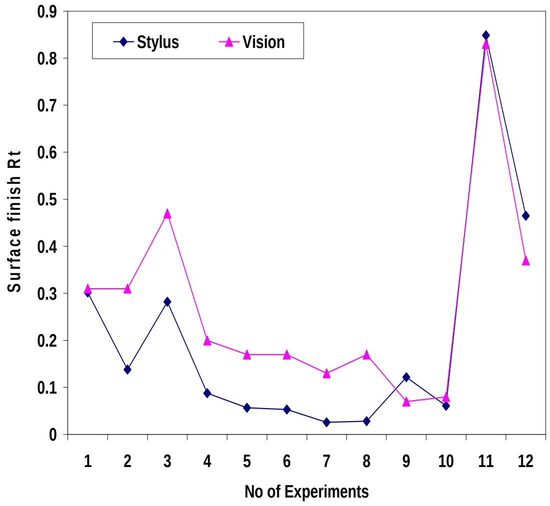

Fig 10a Comparison between predicted roughness values using vision approach and stylus approach for FT features (milling)

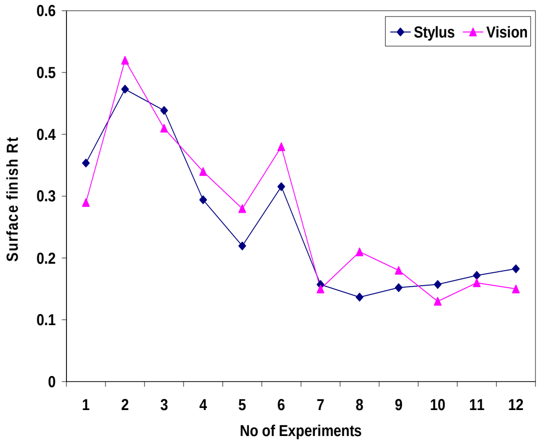

Fig 11a Comparison between predicted roughness values using vision approach and stylus approach for FT features (grinding)

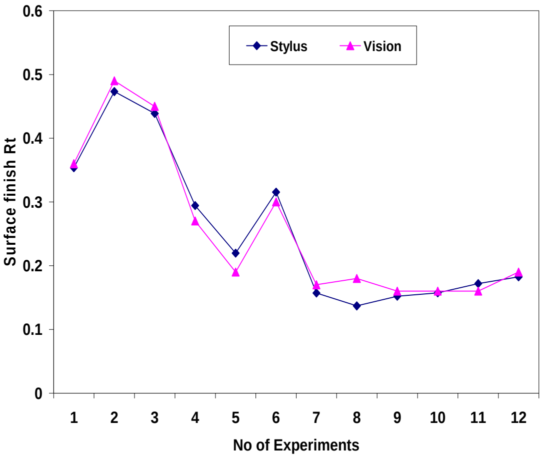

Fig 11b Comparison between predicted roughness values using vision approach and stylus approach for WT (Grinding)

6. Conclusions

In this work, the surface roughness parameter R_t is estimated for milled and ground components. The texture features (using which R_t is estimated) were extracted using WT and improved results were obtained compared to conventional schemes. Future direction of work could be focused on implementing these algorithms on dedicated hardware units such as FPGA's so as to suit the work for real time implementation.

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Biographies

S.Ramapriya received the M..Sc Mathematics from Madras University, Chennai in 1994. She received the M.phil degree from Ramanujan Institute of Advanced Studies in Mathematics, Chennai, in 1995. Presently, she is working as a Senior Lecturer, Department of mathematics in Easwari Engineering College, Chennai, India. Her research interest includes wavelets in image processing, Machine vision, time series analysis, and special functions.

Dr.S.K.Srivatsa received the B.E from Jadavpur University in 1968. He received the M.E and PhD degree from IISC Bangalore in 1972 and 1976 respectively. He retired as a professor of Electronics and communication Engineering, Anna University in 2005. Since then, he is a senior Professor in St.Joseph Engineering college, Chennai, India,. He has produced 19 PhD's and he is the author of well over 300 publications in reputed Journals and Conference Proceedings. He is a Life Fellow/Life member in about two dozen professional societies. He is the recipient of about a dozen awards. His areas of interest include Logic design, graph algorithms, networks, image processing and robotics.

APPENDIX

A1 Specification of Vision system

Sl. No.	Features	Specifications
1	CCD Camera	TK-C1380U
2	Resolution	768(H) x 568(V)
3	Modes of Electronic shutter	9 Modes
4	AES range linear	1/60 through 1/10000 second
5	Magnification	4x to 100x

A2. Machining parameters

Tool	speed (m/sec)	feed (mm/min)	depth of cut (mm)	cutter diameter (mm)
Carbide	32-2000	40-1250	0.1-1.6	25

Specification of Milling Operation

a. Type of machine
Bharat Fritz Verner Special type
Milling machine
Longitudinal - 630 mm
Cross feed - 250 mm
Height - 450 mm
b. Tool specification
Triangular insert TPAN 1603 PDR
175P
Tool Diameter φ 25 mm
Work piece size
100 mm x 50 mm

The composition of work piece is shown in Table A.3

A.3 Composition of Work piece Materials

Material	Grade	C	Si	Mn	Co
EN8	SAE 1038	0.35%	0.10%	0.6%	0.06%

A.4 Machining parameters for grinding

Tool	Speed (rpm)	Feed (m/min)	Depth of cut (μm)	Wheel diameter (mm)
Silicon Carbide	1500-4000	5-25	5-80	250

A.5 Specifications of the surface grinding machine

Table size	1700 x 300 mm
Working surface of table	600 x 200 mm
Maximum height admitted between table and grinding wheel	450 mm
Maximum longitudinal traverse of table	550 mm
Maximum cross table traverse	240 mm
Maximum vertical head traverse	400 mm
Table speed	5 to 20 m/min
Cross traverse speed	0 to 5 m/min
Spindle speeds	1500 to 3000 rpm
H.P of wheel head motor	2