Automated Product Inspection in Industry 4.0 Environment

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Abstract. The emergence of Industry 4.0 technologies demands new techniques of measurement which would facilitate seamless integration with other devices in the wireless IoT network. Many of the existing product inspection methods cannot be deployed directly in the IoT environment. Thus, there is a need for innovative inspection techniques in the Industry 4.0 environment. In this context, the proposed inspection technique assumes special significance. Surface irregularities observed in product manufacturing can be due to chatter, vibration, worn-out cutting tools, condition of the machine tools, etc. Evaluation of surface texture helps in predicting a product’s functionality. In this work, an attempt has been made to identify the surface texture images acquired from Shaping, Milling, Electric discharge machining (E.D.M.) and Sand Blasting processes during online inspection. In addition to surface texture identification, the proposed method will also measure surface roughness and component dimensions. Thus, entire product inspection can be done online, and in a single setup. This is also an 100% online inspection method. The main contribution of this proposed research work is that all types of inspection are completed in a single set up, resulting in significant savings.

1. Introduction

Surface texture may be defined as the superposition of roughness, waviness, and error in the form. Surface irregularities having shorter wavelengths are known as roughness. Surface irregularities having medium wavelength are known as waviness and surface irregularities having large wavelength are known as form error. Surface texture evaluation helps in predicting the functionality of a machined component. Many industries such as automobile and machine tool manufacturing normally do the surface inspection of machined components. This is required for ensuring customer satisfaction. During the component inspection, they check not only the surface finish but also the processor texture of the machined surface. This is because the same roughness can be achieved by the different manufacturing processes. Thus, even the component drawing in addition to specifying dimensions will specify both surface finish and texture information. Many researchers have been working on texture evaluation. But as far as the knowledge of the author goes not a single paper exists today which addresses (i) dimensional inspection (ii) surface roughness inspection and (iii) process identification or texture classification. In this work, an attempt has been made to identify the surface textures acquired from Shaping, Milling, Electric discharge machining (EDM) and Sand Blasting processes. Subsequently, both dimensional and surface roughness assessments are done. The findings presented in this article are useful to academicians, practitioners, and researchers.
2. Literature survey

Texture evaluation methods can be classified into statistical, structural, and morphological methods. Statistical methods extract a set of features from a given image [1]. These features are used for classifying a given image by using statistical pattern recognition techniques. The statistical methods can be classified as follows.

- Gray level difference method [2]. In this technique, the probability density function is calculated for the variation in image intensities.
- The spatial grey level dependence method [3]. In this method, joint gray level distribution for two gray levels at distance ‘d’ and angle ‘θ’ is estimated. These are called first and second-order statistics.
- The grey-level run-length method [4, 5]. A set of connected pixels having the same gray value is called an identical run. This method computes the number of identical runs.

2.1 Gray level Cooccurrence Matrix (GLCM)

GLCM was proposed by Haralick et al. [3]. Many researchers have used this method for classifying images [3]. The main problem with this method is to define both ‘d’ and angle ‘θ’. In this work, an attempt has been made to identify the surface textures produced from Shaping, Milling, Electric discharge machining (E.D.M.) and Sand Blasting processes. In this research, the experiment was repeated at different values of ‘d’ and angle ‘θ’. Surface texture classification is useful for determining whether a product becomes successful when it is put into service. Several researchers have been working in the area of classification.

2.2 Structural methods

These methods Haralick et al. [3] try to identify a set of primitives from a given image. The method then tries to define texture as an arrangement of such primitives by different placement rules. A major problem with this method is to define the shape and size of the area where texture features should be collected.

2.3 Multiresolution filtering method

Multiresolution filtering method (e.g., Gabor filtering) is very much similar to the way the human visual system works. Gabor filter work with texture in spatial-frequency domain s [6, 7, 8, 9, 10, 11]. Thus, it is clear from above that not a single paper exists today which addresses (i) dimensional inspection (ii) surface roughness inspection and (iii) process identification or texture classification, in a single setup. With the advent of Industry 4.0, there is a need to design and develop novel techniques, as many of the existing inspection techniques cannot be deployed directly in Industry 4.0 environments [12,13,14]. Also, nowadays, there is a great demand for 100% inspection of machined components. Especially, in automobile and machine tool companies. Thus, it is clear from above that not a single paper exists today which addresses (i) dimensional inspection (ii) surface roughness inspection and (iii) process identification or texture classification, in a single setup. This is very much required in industrial inspection of machined components. In this work, an attempt has been made to identify the surface textures acquired from Shaping, Milling, Electric discharge machining (E.D.M.) and Sand Blasting processes. Subsequently, both dimensional and surface roughness assessments are done. The findings presented in this article are useful to academicians, practitioners, and researchers.
3. Methodology
Research methodology consists of -Experimental set-up, Specimen preparation, Surface texture inspection, Surface roughness inspection and Dimensional inspection.

3.1 Experimental set-up.

The experimental set-up (Figure 1) consists of a charge coupled device (CCD) camera, cables, a frame grabber, an advanced Image processing board, and a high-end computer. The workstation uses the Windows operating system. In-house software is developed using C++, for computing the roughness parameters, dimensional inspection, and texture assessment.

3.2 Specimen preparation

Test specimens are made of EDM, Shaping, Milling, and Sand Blasting processes. Table 1 shows the sample specimen details of milled specimens.

![Figure 1. Experimental set-up](image1.jpg)

![Figure 2. Surface images (a) shaped (b) EDM (c) milled and (d) sandblasting processes](image2.jpg)

![Figure 3. Stylus instrument measurement setup](image3.jpg)
Table 1 Milled specimen details

| Speed (rpm) | Depth of Cut (mm) | Feed (mm/min) | StylusRa (μm) |
|-------------|-----------------|--------------|--------------|
| 280         | 0.4             | 12.5         | 1.31         |
| 280         | 0.4             | 31.5         | 1.53         |
| 280         | 0.4             | 80.0         | 3.18         |
| 280         | 0.4             | 100.0        | 3.30         |
| 280         | 0.4             | 200.0        | 2.80         |
| 280         | 0.4             | 250.0        | 3.70         |

3.3 Surface texture inspection

Figure 2 (a) to (d) shows the surface images of shaping, EDM, milling, and sandblasting processes respectively, captured by using a CCD camera connected to the vision system. Table 2 shows the digital image of a milled surface.

3.4 Texture Identification

Texture identification process consists of the following steps.

3.4.1 Grey level co-occurrence matrix (GLCM): Digital images obtained in the previous step are used for computing the co-occurrence matrix. Each entry in the co-occurrence table shows the joint distribution of gray levels i and j, separated at distance ‘d’ and angle ‘θ’. Table 3, shows a sample co-occurrence matrix. Co-occurrence matrix tries to capture texture details from a given image, this it does, by using image intensity values.

Table 2: Digital Image of a Milled surface

| 200 | 138 | 236 | 225 | 180 | 167 | 74  |
|-----|-----|-----|-----|-----|-----|-----|
| 182 | 127 | 235 | 181 | 171 | 137 | 65  |
| 160 | 147 | 232 | 161 | 157 | 122 | 55  |
| 143 | 173 | 201 | 133 | 165 | 100 | 52  |
| 131 | 217 | 164 | 141 | 178 | 105 | 46  |
| 122 | 229 | 190 | 146 | 229 | 128 | 75  |
| 122 | 202 | 213 | 145 | 236 | 132 | 81  |

Table 3: Co-occurrence matrix (GLCM)

| 12 | 15 | 0  | 0  | 0  | 0  | 0  |
|----|----|----|----|----|----|----|
| 20 | 4  | 1  | 0  | 0  | 0  | 0  |
| 0  | 4  | 0  | 0  | 0  | 0  | 0  |
| 12 | 15 | 0  | 0  | 0  | 0  | 0  |
| 12 | 15 | 0  | 0  | 0  | 0  | 0  |
| 12 | 15 | 0  | 0  | 0  | 0  | 0  |
| 12 | 15 | 0  | 0  | 0  | 0  | 0  |

3.4.2. Texture features extraction from GLCM

Texture features are calculated by using following formulae.
Contrast
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} \frac{\left( \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} P(i,j) \right)(i-j)}{n} = 0 \]  
(1)

Correlation
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} \frac{(i \times j) \times P(i,j) - (\mu_x \times \mu_y)}{\sigma_x \times \sigma_y} \]  
(2)

Cluster Prominence
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} (i+j-\mu_x-\mu_y)^2 \times P(i,j) \]  
(3)

Dissimilarity
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} P(i,j)|i-j| \]  
(4)

Energy
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} [P^2(i,j)] \]  
(5)

Entropy
\[ -\sum_{i=0}^{L-1} \sum_{j=0}^{L-1} P(i,j) \times \log(P(i,j)) \]  
(6)

Homogeneity
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} \frac{P(i,j)}{1 + |i-j|} \]  
(7)

Maximum Probability
\[ \max(P_{ij}) \]  
(8)

Sum entropy
\[ -\sum_{i=0}^{N-2} P_{xy}(i) \log(P_{xy}(i)) \]  
(9)

Difference Variance
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} (i-\mu)^2 \times P(i,j) \]  
(10)

Difference entropy
\[ -\sum_{i=0}^{L-1} P_{xy}(i) \log(P_{xy}(i)) \]  
(11)

Inverse difference moment normalized
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} \frac{P_{ij}}{1 + (i-j)^2} \]  
(12)

Inverse difference normalized
\[ \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} \frac{P_{ij}}{(1 + |i-j|)^2} \]  
(13)

Sample texture features of EDM, shaped, milled and sandblasted surface images are shown in Table 4, 5, 6, and 7 respectively.
3.4.3. Feature set reduction: To improve computational efficiency, only those features that are required for classification are selected by using the singular value decomposition method is used. So that all redundant features are eliminated.

3.4.4. Method of texture classification: After selecting a set of required features from the set of available features, the K- nearest neighbour classification scheme is used for classifying images. Out of the total number of samples, one sample (t1) is taken out for classification. The method computes the Euclidean distance between the test sample (t1) and the training sample (t2). The method then assigns the test sample to that class, where the Euclidean distance is minimum. Table 8 shows the results of the classification experiment (Confusion matrix). 15 samples, belonging to different classes, were used in the classification experiment. From Table 8 it is clear the classification rate is 100% in case of EDM (E), milling (M), shaping (S) and sand blasting specimen images. However, in the case of Ground (G) specimens, out of 15 specimen images, 12 were classified correctly as belonged to the class of Ground specimens. But, 2 specimens were classified as Sand Blasting (SB) and one was classified as EDM (E) specimen.

Table 4 Texture features values of EDM surface

| Feature No. | E1   | E2   | E3   | E4   | E5   | E6   | E7   | E8   | E9   | E10  | E11  | E12  | E13  | E14  | E15  |
|-------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| F1          | 0.75 | 0.74 | 0.68 | 0.63 | 0.64 | 0.68 | 0.62 | 0.78 | 0.67 | 0.70 | 0.64 | 0.79 | 0.79 | 0.69 | 0.68 |
| F2          | 0.70 | 0.76 | 1.09 | 1.40 | 1.20 | 1.15 | 1.57 | 0.57 | 1.19 | 1.04 | 1.38 | 0.54 | 0.54 | 1.07 | 1.12 |
| F3          | 0.75 | 0.74 | 0.68 | 0.63 | 0.64 | 0.68 | 0.62 | 0.78 | 0.67 | 0.70 | 0.64 | 0.79 | 0.79 | 0.69 | 0.68 |
| F4          | 2.10 | 2.13 | 2.28 | 2.48 | 2.46 | 2.39 | 2.54 | 2.02 | 2.47 | 2.33 | 2.47 | 1.88 | 1.88 | 2.26 | 2.34 |
| F5          | 0.50 | 0.49 | 0.40 | 0.29 | 0.36 | 0.48 | 0.29 | 0.63 | 0.48 | 0.51 | 0.36 | 0.57 | 0.57 | 0.40 | 0.44 |
| F6          | 17.0 | 17.0 | 18.0 | 20.0 | 20.0 | 19.0 | 20.0 | 17.0 | 20.0 | 19.0 | 19.0 | 15.0 | 15.0 | 17.0 | 19.0 |
| F7          | 5.52 | 5.52 | 5.61 | 5.88 | 5.95 | 5.74 | 5.91 | 5.47 | 5.93 | 5.67 | 5.78 | 5.14 | 5.14 | 5.50 | 5.68 |
| F8          | 1.62 | 1.64 | 1.67 | 1.75 | 1.76 | 1.76 | 1.79 | 1.63 | 1.82 | 1.74 | 1.77 | 1.50 | 1.50 | 1.66 | 1.72 |
| F9          | 0.91 | 0.93 | 1.05 | 1.15 | 1.08 | 1.08 | 1.20 | 0.84 | 1.10 | 1.05 | 1.15 | 0.82 | 0.82 | 1.06 | 1.07 |
| F10         | 3.35 | 3.81 | 5.93 | 4.49 | 4.43 | 7.86 | 4.70 | 6.24 | 8.07 | 8.05 | 5.97 | 4.34 | 4.34 | 5.22 | 6.82 |
| F11         | 18.0 | 21.0 | 35.0 | 28.0 | 28.0 | 49.0 | 30.0 | 38.0 | 52.0 | 51.0 | 36.0 | 23.0 | 23.0 | 30.0 | 43.0 |
| F12         | 0.99 | 0.99 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 | 0.98 | 0.98 |

Table 5 Sample texture features obtained from shaped surface

| Feature No. | S1   | S2   | S3   | S4   | S5   | S6   | S7   | S8   | S9   | S10  | S11  | S12  | S13  | S14  | S15  |
|-------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| F1          | 0.72 | 0.72 | 0.72 | 0.70 | 0.73 | 0.72 | 0.71 | 0.75 | 0.75 | 0.73 | 0.67 | 0.78 | 0.72 | 0.72 | 0.75 |
| F2          | 0.86 | 1.02 | 1.08 | 0.84 | 0.84 | 1.01 | 1.21 | 0.75 | 0.77 | 1.03 | 1.30 | 0.64 | 0.86 | 1.15 | 0.85 |
| F3          | 0.72 | 0.72 | 0.72 | 0.70 | 0.73 | 0.72 | 0.71 | 0.75 | 0.75 | 0.73 | 0.67 | 0.78 | 0.72 | 0.72 | 0.75 |
| F4          | 2.76 | 2.53 | 2.46 | 2.68 | 2.70 | 2.57 | 2.62 | 2.45 | 2.58 | 2.50 | 2.74 | 2.29 | 2.77 | 2.46 | 2.26 |
| F5          | 0.80 | 0.68 | 0.67 | 0.75 | 0.78 | 0.73 | 0.69 | 0.77 | 0.80 | 0.74 | 0.70 | 0.78 | 0.78 | 0.69 | 0.67 |
| F6          | 57.0 | 47.0 | 44.0 | 52.0 | 54.0 | 48.0 | 48.0 | 46.0 | 51.0 | 47.0 | 53.0 | 43.0 | 56.0 | 45.0 | 40.0 |
| F7          | 9.21 | 8.40 | 8.11 | 8.90 | 9.03 | 8.42 | 8.44 | 8.33 | 8.81 | 8.28 | 8.82 | 8.02 | 9.21 | 8.12 | 7.76 |
| F8          | 2.22 | 1.94 | 1.89 | 2.14 | 2.17 | 2.00 | 2.01 | 1.99 | 2.12 | 1.96 | 2.09 | 1.88 | 2.21 | 1.91 | 1.77 |
| F9          | 0.98 | 1.05 | 1.06 | 0.96 | 0.97 | 1.04 | 1.10 | 0.93 | 0.94 | 1.04 | 1.14 | 0.88 | 0.98 | 1.08 | 0.97 |
| F10         | 15.0 | 7.0  | 12.0 | 10.0 | 11.0 | 15.0 | 15.0 | 14.0 | 15.0 | 20.0 | 12.0 | 15.0 | 12.0 | 18.0 | 11.0 |
| F11         | 157  | 65   | 85   | 98   | 120  | 118  | 119  | 108  | 138  | 157  | 124  | 107  | 132  | 131  | 73   |
| F12         | 0.99 | 0.99 | 0.98 | 0.99 | 0.99 | 0.98 | 0.98 | 0.98 | 0.99 | 0.98 | 0.99 | 0.99 | 0.99 | 0.98 | 0.99 |
### Table 6 Texture features values of milled surface

| Feature No. | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | M13 | M14 | M15 |
|-------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|
| F1          | 0.83 | 0.68 | 0.62 | 0.70 | 0.86 | 0.72 | 0.62 | 0.76 | 0.90 | 0.68 | 0.68 | 0.83 | 0.83 | 0.65 | 0.81 |
| F2          | 0.36 | 0.82 | 1.27 | 0.87 | 0.31 | 0.68 | 1.12 | 0.58 | 0.21 | 0.81 | 0.84 | 0.37 | 0.34 | 0.95 | 0.40 |
| F3          | 0.83 | 0.68 | 0.62 | 0.70 | 0.86 | 0.72 | 0.62 | 0.76 | 0.90 | 0.68 | 0.68 | 0.83 | 0.83 | 0.65 | 0.81 |
| F4          | 1.63 | 2.30 | 2.56 | 2.28 | 1.43 | 2.02 | 2.40 | 1.82 | 1.03 | 2.21 | 2.21 | 1.48 | 1.31 | 2.29 | 1.58 |
| F5          | 0.49 | 0.39 | 0.30 | 0.39 | 0.47 | 0.30 | 0.22 | 0.25 | 0.36 | 0.31 | 0.28 | 0.36 | 0.21 | 0.30 | 0.37 |
| F6          | 31.5 | 29.9 | 27.2 | 28.2 | 31.1 | 27.6 | 24.6 | 25.7 | 27.8 | 24.6 | 22.1 | 22.7 | 23.7 | 20.6 | 18.8 |
| F7          | 6.89 | 7.00 | 6.79 | 6.81 | 6.70 | 6.65 | 6.45 | 6.34 | 6.12 | 6.42 | 6.14 | 5.91 | 5.88 | 5.98 | 5.53 |
| F8          | 1.37 | 1.70 | 1.79 | 1.68 | 1.20 | 1.51 | 1.66 | 1.36 | 0.89 | 1.61 | 1.60 | 1.22 | 1.06 | 1.64 | 1.29 |
| F9          | 0.67 | 0.89 | 1.09 | 0.97 | 0.64 | 0.86 | 0.99 | 0.83 | 0.51 | 0.90 | 0.93 | 0.69 | 0.65 | 0.93 | 0.69 |
| F10         | 0.51 | 0.86 | 1.89 | 2.22 | 0.70 | 0.47 | 1.03 | 0.67 | 0.28 | 0.79 | 0.62 | 0.41 | 0.09 | 1.55 | 0.22 |
| F11         | 3.17 | 9.27 | 15.1 | 13.6 | 2.48 | 4.64 | 8.34 | 3.89 | 1.21 | 6.82 | 6.61 | 3.32 | 1.27 | 9.82 | 2.68 |
| F12         | 0.99 | 0.99 | 0.98 | 0.99 | 1.00 | 0.99 | 0.98 | 0.99 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |

### Table 7 Texture features values of a sandblasted surface

| Feature No. | SB1 | SB2 | SB3 | SB4 | SB5 | SB6 | SB7 | SB8 | SB9 | SB10 | SB11 | SB12 | SB13 | SB14 | SB15 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|
| F1          | 0.85 | 0.81 | 0.82 | 0.87 | 0.88 | 0.77 | 0.81 | 0.87 | 0.80 | 0.77 | 0.82 | 0.88 | 0.82 | 0.78 | 0.88 |
| F2          | 0.29 | 0.41 | 0.38 | 0.26 | 0.26 | 0.48 | 0.41 | 0.28 | 0.42 | 0.50 | 0.38 | 0.23 | 0.37 | 0.51 | 0.24 |
| F3          | 0.85 | 0.81 | 0.82 | 0.87 | 0.88 | 0.77 | 0.81 | 0.87 | 0.80 | 0.77 | 0.82 | 0.88 | 0.82 | 0.78 | 0.88 |
| F4          | 1.66 | 1.86 | 1.85 | 1.51 | 1.58 | 2.04 | 1.77 | 1.48 | 1.98 | 2.17 | 1.70 | 1.33 | 1.81 | 2.13 | 1.37 |
| F5          | 0.64 | 0.59 | 0.61 | 0.63 | 0.67 | 0.59 | 0.50 | 0.55 | 0.64 | 0.67 | 0.51 | 0.56 | 0.60 | 0.64 | 0.55 |
| F6          | 7.44 | 8.36 | 7.31 | 8.52 | 7.99 | 8.21 | 8.33 | 9.56 | 8.18 | 9.00 | 9.05 | 9.61 | 7.09 | 7.68 | 8.11 |
| F7          | 3.93 | 4.16 | 3.96 | 4.05 | 3.97 | 4.20 | 4.13 | 4.21 | 4.18 | 4.34 | 4.22 | 4.13 | 3.91 | 4.07 | 3.89 |
| F8          | 1.46 | 1.56 | 1.57 | 1.33 | 1.39 | 1.68 | 1.46 | 1.28 | 1.67 | 1.79 | 1.42 | 1.17 | 1.54 | 1.75 | 1.19 |
| F9          | 0.60 | 0.71 | 0.69 | 0.57 | 0.58 | 0.74 | 0.71 | 0.60 | 0.71 | 0.76 | 0.69 | 0.55 | 0.68 | 0.78 | 0.56 |
| F10         | 0.12 | 1.33 | 1.13 | 0.85 | 0.72 | 1.24 | 0.55 | 0.22 | 1.00 | 2.12 | 0.83 | 0.51 | 0.77 | 2.06 | 0.06 |
| F11         | 4.63 | 9.41 | 9.02 | 6.28 | 7.03 | 10.76 | 5.54 | 3.13 | 9.90 | 16.90 | 5.58 | 3.02 | 6.75 | 15.34 | 2.79 |
| F12         | 1.00 | 0.99 | 0.99 | 1.00 | 1.00 | 0.99 | 0.99 | 1.00 | 0.99 | 0.99 | 1.00 | 0.99 | 0.99 | 1.00 | 0.99 |

### Table 8 Confusion Matrix

| Feature No. | G  | S  | M  | SB | E  | Classified as | G  | S  | M  | SB | E  | Classified as |
|-------------|----|----|----|----|----|----------------|----|----|----|----|----|----------------|
| 15          | 0  | 0  | 0  | 0  | 0  | G              | 12 | 0  | 0  | 2  | 1  | G              |
| 0           | 15 | 0  | 0  | 0  | 0  | S              | 0  | 15 | 0  | 0  | 0  | S              |
| 0           | 0  | 15 | 0  | 0  | 0  | M              | 0  | 0  | 15 | 0  | 0  | M              |
| 0           | 0  | 0  | 15 | 0  | 0  | SB             | 0  | 0  | 0  | 15 | 0  | SB             |
| 0           | 0  | 0  | 0  | 15 | 0  | E              | 0  | 0  | 0  | 0  | 15 | E              |
Table 9. Comparison between Vision and CMM readings

| CMM reading (mms) | Vision reading (mms) |
|------------------|----------------------|
| 35.42            | 35.4345              |
| 40.44            | 40.4786              |
| 45.61            | 45.6654              |
| 50.42            | 50.4986              |
| 55.63            | 55.6543              |
| 60.43            | 60.4564              |
| 65.62            | 65.6543              |
| 70.42            | 70.4342              |

Figure 4 Correlation between Vision and Stylus roughness

Surface roughness inspection

Table 4, 5, 6 and 7 shows sample texture feature values obtained for EDM, shaped, milled and sandblast surface image, respectively. Texture features calculated for the different surface images are then used for computing the correlation with the roughness values (Actual Ra) obtained by the stylus method. The readings obtained from the stylus method (Figure 3), is considered as standard and are used for validating vision roughness parameters. Figure 4 shows the correlation between the contrast value (predicted) with the roughness (Actual Ra) obtained from the stylus instrument. Since there is a good correlation between contrast (f1) and Ra value obtained from the stylus instrument. Thus, contrast value (f1) can be used as a vision roughness parameter.

3.5. Dimensional inspection

Table 9 shows the results obtained after the dimensional inspection. Coordinate measuring machine (CMM) readings are used as the standard for calibrating the readings obtained from the vision system.
4. Conclusion

Surface texture classification is carried out on machined surfaces produced by machining processes viz. shaping, sand-blasting, milling, and EDM. The surface texture was identified using a combination of gray level co-occurrence matrix and classifier. The classifiers gave an accuracy of 96%. The method can also be used for performing roughness measurements. It was observed that there was a good correction between vision roughness and that of Ra value obtained from the stylus method. The method can also be used in performing the dimensional inspection. It was found that the minimum accuracy of dimensional inspection obtained is 96%. Thus, the current research demonstrates that the entire product inspection can be done in a single set-up and thus saves the cost of the inspection. Also, the method can be used in the online inspection of machined components and products.

Summary:
- Method presented in this work is capable of identifying images having textures of Shaping, Milling, Grinding, EDM and Sandblasting processes.
- Method can be used for measuring component dimensions e.g., length, diameter, etc.
- Method is also useful in measuring surface roughness of manufactured components.
- By this method 100% inspection is possible.
- Method is non-contact in nature and hence suitable for online inspection.
- Method cannot be used in the texture identification of smooth surfaces (e.g., Polished surface).

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