9th INTERNATIONAL SYMPOSIUM ON MEASUREMENT AND QUALITY CONTROL (9th ISMQC)
November 21-24, 2007, IIT Madras

MODELING THE LIGHTING CONDITIONS FOR THE ESTIMATION OF SURFACE ROUGHNESS BY MACHINE VISION USING DESIGN OF EXPERIMENTS

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Abstract: *The influence of the lighting conditions on the grey level distribution and thereby on the estimation of the surface roughness using machine vision system is reported in this work. The light to specimen distance, the grazing angle and the inclination of the striations are varied and their effect on the image parameter, the arithmetic average of the grey level is studied. Mild steel, brass and aluminium specimens are machined for different roughness for the study. Trials were made using the design of experiments procedure and the influence of the different factors are studied. Taguchi's signal to noise ratio method is applied to find the optimal lighting conditions. A model is developed to establish the relationship between the lighting conditions and the image parameter*

Key words: *Machine Vision; roughness; Design of experiments; ANOVA; Signal to Noise ratio*

1. INTRODUCTION

Producing defect free components is a requirement in the manufacturing industry. The development in the field of industrial automation and the requirement for 100% inspection of the quality of the product has necessitated the use of in-process inspection systems and high-speed measurements. Hence lot of research is being done in that direction to automate the inspection process. Surface quality inspection for the required surface finish is one field where lot of research is being done. The traditional way of measuring the surface roughness is by moving the stylus over the surface and correlating the vertical movement in terms of surface roughness. Though it s widely accepted and practiced in industry, the measurement procedure is slow and not amenable for automation. Hence many non-contact methods using optics and ultrasonic means are tried for quicker evaluation of the work piece.

Machine vision, a non-contact optical technique is finding wide application in the field of inspection. Machine vision is extensively used in the field of robotics, electronic industries and in agriculture. Many research works have also been reported using machine vision for surface roughness inspection. In the inspection of surface roughness by machine vision technique, the light is directed on the surface of the part to be studied. The light scatters differently for different surface roughness. This variation in the scattering causes variation in the grey level distribution pattern of the image when captured by a machine vision system. Many researchers have worked in this field and have analysed the grey level distribution for various surfaces with different surface roughness. Different image-based parameters have been evaluated for characterizing the surface image. Parameters like Mean, Standard Deviation (SD), Root Mean Square (RMS) of the grey level distribution (Luk et al, 1989; Gupta & Raman, 2001), Fourier descriptors (Tsai et al, 1998; Tsai & Tseng, 1999; Priya & Ramamoorthy, 2007), arithmetic average of the grey level (Lee & Tarng, 2001; Ho et al, 2002; Kumar et al, 2005; Elango & Karunamoorthy, 2007) have been used by researchers for correlation with surface roughness.

The scattering pattern of the grey scale image of the surface depends on the surface as well as on the incident lighting conditions. Lot of studies has been made about the influence of the roughness on the image-based parameter. In the reported studies the lighting position was set at an appropriate angle for capturing the image. It is understood from the illustration that Lee (2001, 2004), Ho (2002) in their studies on roughness inspection by vision system in turning operations have set the light at an approximate angle of 45^0 to the reflecting surface. Priya (2007) used a diffused light source, which was kept at an angle of approximately 45^0 incidence to the specimen surface. They were able to correlate the image-based parameter with the actual roughness by fixing the light at a fixed position. As there is little study available about the effect of these lighting conditions on the image-based parameter, the study about the influence of the lighting conditions on the image-based parameter will be useful for roughness evaluation. Hence this work is an attempt to study the lighting conditions and its influence on the evaluation of surface roughness

Statistical design of experiments is used to investigate the effects of the different lighting conditions on the image-based parameter to arrive at valid and objective conclusions. Taguchi's robust design using S/N ratio, an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation to the quality of the products is used in this study to the performance of the factors at different levels.

2. EXPERIMENTAL PROCEDURE

The experimental procedure consists of different stages. In the first phase the experimental setup and the preparations of the specimen are made. In the next phase the surface images of the specimens are captured by the machine vision system. In the third phase the images are analysed and the image-based features are retrieved. In the last phase the influence of the different factors is studied and the level of the factors which gives the best image-based parameters are found and the model for predicting the image parameter is developed.

2.1 Experimental setup

From the available literature and preliminary trials made, it is found that the distance of the light, the grazing angle and the striations are some of the factors, which influence the image parameter. Hence an experimental setup is fabricated so that these parameters can be varied and its influence studied. Fig.1 shows the schematic arrangement of the experimental setup fabricated to study the influence of the lighting conditions. The equipment for conducting the test consists of a base with adjustable specimen mount table, a light source with variable mount, CCD camera on its mount. The base is well rigid to support the arrangement mounted over it. The CCD camera is mounted vertically over a camera mount and is positioned to focus over the circular table at the bottom. The light is fixed over a mount that can be fixed at any radial distance and slide along a semicircular frame and make the light to incident on the specimen at any required angle. The specimen is placed over a circular table that can be adjusted along a vertical axis and also be adjusted to any angular position in a horizontal plane so that the study on striations (tool marks) at any particular angle can be made. Flat test specimens of mild steel, brass and aluminium were prepared with different surface roughness. After machining the specimen, the average surface roughness R_a of the surface was measured by using Taylor Hobson Surtronic 3+ roughness measuring instrument

2.2 Machine vision system

In the next phase the surface images of the work piece were captured using a machine vision system. The basic vision system consists of a CCD camera: WATEC, a image processing software, a image processing board and a computer. The CCD camera captures the surface image with 768 x 574 resolution, 1/30 s grabbing speed and gives 8-bit digit output. The work piece and the lighting position were varied and set at different position as per the experimental design and the surface images were grabbed and stored in the memory for further analysis.

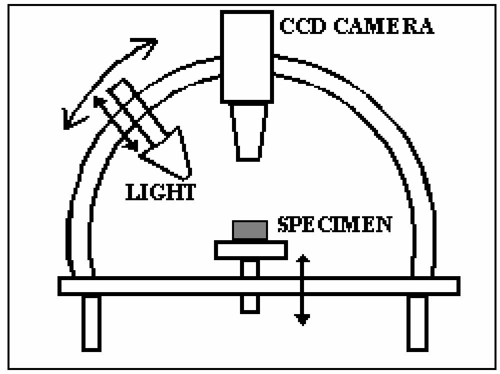

Fig. 1. Schematic of the experimental setup

2.3 Image-based parameter

From the literature it is found that many image-based parameters can be retrieved from the surface images for correlation with the actual surface roughness. In this paper arithmetic average of the grey level (G_a) is used for analysis (Lee & Tarng, 2001; Ho et al, 2002; Kumar et al, 2005). Arithmetic average of the grey level is based on the distribution of grey level along a line feature. Arithmetic average of the grey level is the average of the grey level of the surface image deviated from the mean grey level.
Arithmetic average of the grey level is expressed as

$$G_a = \frac{1}{n}\sum_{i=1}^{n}|g_i - g_m|$$

Where n is the number of pixels in the distribution

$g_1, g_2, \ldots g_n$ are the grey values of a surface image along the line

g_m is the mean of the grey values and this can be determined by

$$g_m = \frac{1}{n}\sum_{i=1}^{n} g_i$$

The grey level G_a has been calculated for all the specimen after capturing the image of the surfaces.

3. DESIGN OF EXPERIMENTS

Design of experiments is the process of planning and executing the experiments effectively by means of scientific approach, so that valid and objective conclusions can be arrived. Taguchi used statistical design of experiments to investigate the effects of multiple factors on the performance. Taguchi method has been applied for

optimizing the influence of the affecting parameters in manufacturing. (Davim, 2001; Choudhury and Bartarya, 2003; Ghani et al, 2004). In this paper the Taguchi technique is used to find the influence of lighting conditions on the image parameter.
Preliminary experiments were conducted to find the factors influencing the image parameter. It was found that the factors grazing angle, the inclination of the striations and the light to specimen distance were affecting the arithmetic average grey level of the surface image. Hence these factors were varied at different levels

Table 1 The controlling factors and their levels

S N	Factors	Levels		
		1	2	3
1	Grazing angle- A	65	50	35
2	Inclination of the striations-B	90	75	60
3	Light to specimen distance-C	50	75	100

for the study. The image parameter G_a was estimated from the surface image for all the conditions. Table 1 shows the different factors selected and their levels.

The grazing angle, the angle of striations to the light and distance of the light to specimen and the interactions between them are considered for the study. As the factors are at three levels and their interactions need to be studied, Taguchi's L_{27} orthogonal array (Ross, 1998) is chosen for designing the experiments. The L_{27} orthogonal array has 27 rows corresponding to the number of trials to be conducted for different combinations of the level of the factors and 13 columns which can be assigned to major factors and interactions considered in this study. Based on the relationship between the factors and interaction from the linear graph (Park, 1996) the 1st column of the array is assigned to the grazing angle, the 2nd column to the angle of striations and 5th column to the light to specimen distance. The combination of factors is selected at random and the trials were conducted by setting the factors at different levels and for the 27 combinations the surface images were captured and stored in the memory. Arithmetic average grey level G_a is evaluated from all the surface images, which is the response of the trials.

The objective of the study is to find the lighting conditions that will give the best G_a value that correlates well with the actual roughness. For this purpose we have to find the lighting conditions that will give the minimum variation of G_a. Hence Taguchi's signal to noise ratio approach can be used to identify the influencing factors, which can reduce the variability in the measurement of image parameter. The best setting of the different levels of the factors can be evaluated by this approach. Taguchi defined three quality characteristics, nominal the best, smaller the better, and larger the better to evaluate the S/N ratio. As the variation of the G_a from the calibrated values should be reduced in our study, the smaller the better characteristic is used in the study. The expression for calculating the S/N ratio is given by

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

where
S/N is the signal to noise ratio
n is the number of repetitions of the experiments.
y_i is the measure value of the quality characteristics.

4. RESULTS AND DISCUSSION

The plan of experiments was designed to determine the influence of the lighting conditions on the image parameter arithmetic average of the grey level (G_a). Three specimens of different material were taken for analysis. Surface images of each specimen were captured by setting the lighting conditions at different levels. By using the developed software the image parameter - arithmetic average of the grey level (G_a) was estimated. The image parameter for all the specimen were found and tabulated as shown in table 2. The statistical treatment of the data was made into two phases. The first phase is the application of analysis of variance technique (ANOVA) to find the influence of the factors and the interaction. The second phase is analyzing the means and S/N ratio by conceptual approach, which involves graphing the effects and identifying the factors visually the levels that give better performance.

ANOVA is a method of portioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment. In the present work, analysis of variance is carried out on the image parameter response to find the effect of the lighting conditions. Table 3-5 shows the results of the ANOVA with the arithmetic average of the grey value (G_a) for the three specimens. This analysis was carried out for 5% significance (for a confidence level of 95%). The last column in table shows the percentage contribution of each factor on the total variation of the observation, thereby indicating its influence on the result. Taguchi's signal to noise ratio is applied on the observed data and the figure 2-4 shows the effect of the different levels over the response of the experiment for the three specimens.

On comparison of the ANOVA table and from the S/N graphs for the three specimens it is found that the influence of the lighting condition on the image parameter is not similar. The chosen factors have different degrees of influence on the image parameter for the materials chosen.

4.1 Effect of Grazing angle

The grazing angle influences differently for the different material surface chosen. Brass is more sensitive to grazing angle. It has the highest influence of all the factors. From the S/N graph it can be seen that when the angle is at the least value, we get the maximum signal to noise ratio. Grazing angle has little influence on the aluminium surface. The physical influence is much lower than the other factors. The S/N graph also confirms that the variation of the level of the factor has no influence on the image parameter. The grazing angle has a low physical significance on the mild steel surface. The setting level of 35^o that gives the highest S/N ratio is the level at which image parameter has to be estimated for all the metals.

4.2 Effect of Striations

On comparison of the effect on the three materials it is found that this has the highest influence on all the material. For mild steel its effect is maximum where it contributes almost 75% of the effect. The S/N graph also confirms that its contribution is high. This has the maximum difference between the levels. Keeping the striations at different nclination gives different S/N ratio. Aluminium also shows the same trend. The physical significance of Aluminium is 65%. This factor has the highest ranking among the S/N ratio. Though the physical significance of this effect is less in the case of the brass the trend shows the same pattern as that of the aluminium. Striations have to be kept perpendicular for aluminium and at 60^o for the other two metals.

4.3 Effect of light to specimen distance

Light to specimen distance has less physical significance among the three. This factor levels show different type of influence on the metals. In the case of mild steel the effect increases and then decreases indicting the middle level of 75 mm is the best for study. For aluminium it decreases and remains constant and indicates that the lower level of of 50 mm is the best for study. In the case of brass the middle level is the best for study as inferred from the S/N graph.

Table 2 : The factor levels and the corresponding image parameter (G_a) observed

Test	Factor A	Factor B	Factor C	Mild Steel			Aluminium			Brass		
				Ga_1	Ga_2	Ga_3	Ga_1	Ga_2	Ga_3	Ga_1	Ga_2	Ga_3
1	65	90	50	13.03	14.5	13.05	8.35	8.38	8.31	8.64	8.1	9.32
2	65	90	75	15.82	18.49	15.82	9.33	9.35	9.32	5.62	5.82	5.18
3	65	90	100	13.08	13.14	13.11	11.87	11.5	11.9	6.39	7.25	7.24
4	65	75	50	9.03	8.46	8.46	9.51	9.48	9.53	9.78	8.51	8.95
5	65	75	75	5.06	4.45	4.35	9.53	9.55	9.5	10.99	11.46	11.46
6	65	75	100	6.06	6.52	6.48	10.01	9.95	10.05	9.05	10.07	10.07
7	65	60	50	8.67	9.04	9.08	13.1	13	12.9	13.8	11.31	12.13
8	65	60	75	4.92	4.1	4.2	15.92	15.8	15.6	6.4	5.57	5.57
9	65	60	100	6.42	6.98	6.88	20.07	20.1	20.2	8.28	9.15	9.15
10	50	90	50	13.2	15.2	13.2	9.57	9.5	9.6	8.87	6.94	6.49
11	50	90	75	12.24	12.78	12.5	9.95	9.9	9.96	6.66	6.27	6.27
12	50	90	100	13.62	13.48	13.41	10.05	10.05	10.2	10.69	10.84	10.84
13	50	75	50	7.85	8.36	8.46	10.61	10.5	10.55	8.33	8.77	8.77
14	50	75	75	7.84	8.61	8.52	15.32	15.33	15.25	7.62	9.04	9.05
15	50	75	100	7.95	8.45	8.36	12.81	12.75	12.6	6.82	7.62	7.62
16	50	60	50	6.59	7.11	7.21	8.9	8.6	8.8	6.17	6.12	5.48
17	50	60	75	5.97	5.58	5.65	19.42	19.42	19.25	6.06	4.97	4.97
18	50	60	100	7.53	8.65	8.45	12.07	12.1	12.05	5.49	4.69	4.69
19	35	90	50	8.55	8.83	8.83	8.8	8.69	8.75	6.74	7.72	6.33
20	35	90	75	9.89	10.92	10.8	10.25	10.3	10.4	5.97	6.11	6.11
21	35	90	100	7.97	8.14	8.15	13.26	13.3	13.2	9.92	8.88	8.88
22	35	75	50	11.42	12.39	12.29	9.03	9.1	9.15	7.16	8.54	6.43
23	35	75	75	5.6	6.53	6.68	9.1	9.2	9.3	8.56	8.64	8.64
24	35	75	100	5.81	5.62	5.55	11.04	11.05	11.1	4.31	4.35	4.35
25	35	60	50	6.97	7.41	7.31	16.92	16.8	16.85	5.18	5.93	5.93
26	35	60	75	6.4	6.5	6.48	15.5	15.45	15.55	5.84	5.47	5.47
27	35	60	100	5.82	6.11	6.01	11.8	11.75	11.8	3.25	4.11	4.11

4.4 Interaction effects

From the ANOVA of the three specimens it is found that the interactions among the three factors have statistical significance as well they have physical significance. The S/N graphs for the three specimens show different type of influence for different levels. Particular trend is not identified in any of the interaction. The interaction effect between grazing angle and striations increases in one specimen whereas it decreases in the other cases.

Table 3. ANOVA table for the arithmetic average grey level for the13.2µm R_a mild steel specimen

Source of variation	Sum of squares	Degrees of freedom	Variance	F-test	$F_{\alpha = 5\%}$	Percentage of contribution (%)
Grazing angle (A)	40.577	2	20.289	16.788*	3.15	6.17
Inclination of the striations (B)	481.144	2	240.572	199.064*	3.15	73.13
Light to specimen distance (C)	34.327	2	17.164	14.202*	3.15	5.22
AxB – interaction	117.093	4	29.273	24.222*	2.53	8.90
AxC – interaction	23.987	4	5.997	4.962*	2.53	1.82
BxC – interaction	57.921	4	14.480	11.982*	2.53	4.40
Error	74.928	62	1.209	-	-	0.37
Total	829.9772	80	328.983	-	-	100.00

* Statistically significant

Table 4. ANOVA table for the arithmetic average grey level for the 0.68µm R_a aluminium specimen

Source of variation	Sum of squares	Degrees of freedom	Variance	F-test	$F_{\alpha = 5\%}$	Percentage of contribution (%)
Grazing angle (A)	1.107	2	0.553	0.221	3.15	0.20
Inclination of the striations (B)	344.710	2	172.355	68.935*	3.15	61.74
Light to specimen distance (C)	81.695	2	40.847	16.337*	3.15	14.63
AxB – interaction	100.703	4	25.176	10.069*	2.53	9.02
AxC – interaction	108.105	4	27.026	10.809*	2.53	9.68
BxC – interaction	42.739	4	10.685	4.273*	2.53	3.83
Error	155.016	62	2.500	-	-	0.90
Total	834.076	80	279.143	-	-	100.00

* Statistically significant

Table 5. ANOVA table for the arithmetic average grey level for the 0.52µm R_a brass specimen

Source of variation	Sum of squares	Degrees of freedom	Variance	F-test	$F_{\alpha = 5\%}$	Percentage of contribution (%)
Grazing angle (A)	73.504	2	36.752	30.842*	3.15	32.86
Inclination of the striations (B)	46.075	2	23.038	19.333*	3.15	20.60
Light to specimen distance (C)	13.771	2	6.885	5.778*	3.15	6.16
AxB – interaction	69.161	4	17.290	14.510*	2.53	15.46
AxC – interaction	23.815	4	5.954	4.996*	2.53	5.32
BxC – interaction	82.971	4	20.743	17.408*	2.53	18.54
Error	73.879	62	1.192		-	1.07
Total	383.175	80	111.853		-	100.00

* Statistically significant

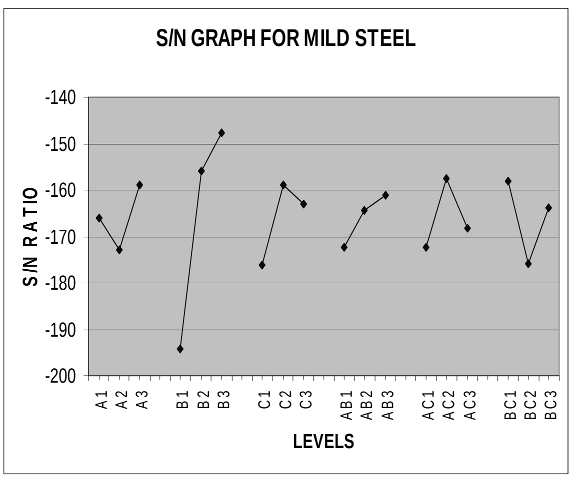

Fig. 2. S/N graph for mild steel specimen

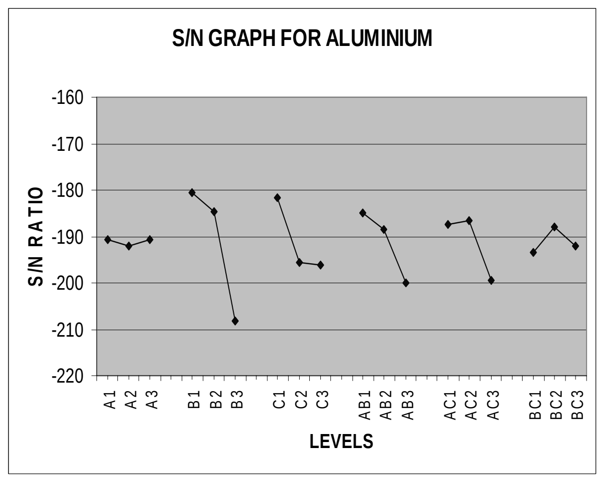

Fig. 3 S/N graph for aluminium specimen

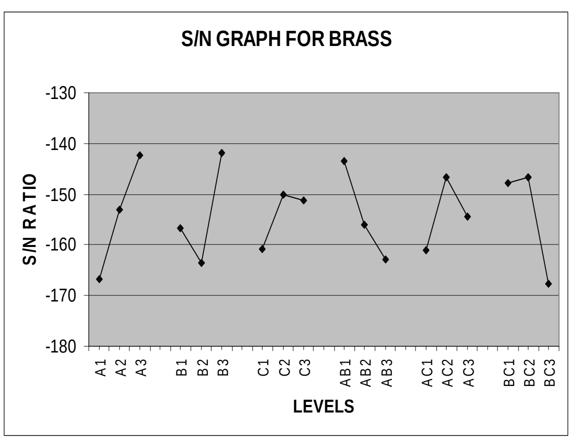

Fig. 4. S/N graph for brass specimen

5. MODELING

Empirical models to represent the linear relation between the lighting conditions and the image parameter based on the experimental data are given below.

For mild steel

$$G_a = -5.180 + 0.04472A + 0.185B - 0.0272C$$

For Aluminium

$$G_a = 20.183 + 0.005765A - 0.155B + 0.041C$$

For Brass

$$G_a = 1.965 + 0.07695A + 0.03556B - 0.0136C$$

Where

A – Grazing angle
B – Inclination of the striations
C – Light to specimen distance

6. CONCLUSIONS

The effect of lighting conditions on the image parameter is studied in this work. From the above experimental study it is found that the lighting conditions influence the image parameter differently for different materials. The inclination of the striations has the maximum influence on the image parameter. The grazing angle has no effect on aluminium surface, but has to be kept at lesser angle for reflective surfaces like brass. The light to specimen distance has lesser influence on the materials.

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