ملخص البحث

Arabic Summary

ملخص البحث

من المعروف أن خشونة الأسطح تؤثر بشكل كبير على الخصائص الميكانيكية والفيزيقية للأسطح المتلامسة. ومن المهم معرفة هذا التأثير في كثير من التطبيقات مثل التآكل، والاحتكاك، والتزييت، وصلادة التلامس بين الأسطح، و إجهادات التحميل... إلخ. لذلك فإن معرفة وتقدير خشونة أسطح المعادن المختلفة تؤخذ في الاعتبار في مصانع الإنتاج.

ويوجد عدة طرق لقياس خشونة الأسطح تتراوح بين طرق القياس البسيطة مثل أجهزة القياس بالتلامس (Touch comparators) وطرق القياس المعقدة مثل أجهزة القياس الضوئي (Optical techniques). ويمكن تقسيم طرق قياس خشونة الأسطح إلى خمس طرق هي: أجهزة القياس الميكانيكية (Mechanical Profilers)، وأجهزة القياس بالموجات فوق الصوتية (Ultrasonic Methodology)، وأجهزة القياس الميكروسكوبي عالية الدقة (Microscopy)، وأجهزة القياس الضوئية (Optical techniques)، ونظم القياس باستخدام الرؤية بالحاسب (Computer vision).

وعلى الرغم من أن أجهزة القياس الميكانيكية تعتبر الطريقة التقليدية لقياس خشونة الأسطح، إلا أنها تعاني من بعض العيوب مثل: إمكانية خدش السطح المختبر عن طريق السن الماسي، وارتباط دقة القياس بعدة عوامل مثل سمك السن الماسي ومقدار الضغط الواقع على العينة وصلادة السطح المختبر. كذلك فإن قياس خشونة الأسطح بهذه الأجهزة يمثل قياس لخط من العينة وليس مساحة منها. وبذلك لا تمثل القياسات بهذه الطريقة السطح الحقيقي.

وبالنسبة لطرق القياس بالموجات فوق الصوتية تحتاج إلى وسط تلامس لكي تعمل بكفاءة، لذلك فهي تعتبر من ضمن طرق القياس بالتلامس. أما بالنسبة لأجهزة القياس الميكروسكوبي فإنها تعتبر بطيئة وغير مناسبة لفحص العينات في خطوط الإنتاج. وتتميز أجهزة القياس الضوئي بإمكانية قياس خشونة الأسطح بدون تلامس مع السطح المراد قياسه، وكذلك إمكانية قياس مساحة من العينة بدلا من خط واحد. ومن عيوب هذه الأجهزة أنها تستخدم أشعة الليزر

لتصوير السطح مما يجعلها غير مناسبة للقياسات اللحظية (Real time measurement)، وكذلك فإن الأجهزة الضوئية تحتاج إلى ضبط دقيق قبل عملية القياس.

وتعتبر أساليب الرؤية باستخدام الحاسب آخر التطورات لقياس خشونة الأسطح، حيث توفر نفس مميزات الطرق الضوئية إلا أنها تعتبر أقل تكلفة منها. ونظرا للتطورات الحديثة في أجهزة الكمبيوتر وأجهزة القياس الرقمي فإن تحليل الأسطح في الأبعاد الثلاثة (3-D) أصبح واقعا ضروريا. وتعتمد طرق القياس باستخدام الرؤية بالحاسب على الحصول على صورة للسطح المراد اختباره ثم تحليلها باستخدام إمكانات الحاسب. ويعتبر تقدير خشونة الأسطح باستخدام الرؤية بالحاسب مجال هذا البحث.

يقدم هذا البحث نظام جديد باستخدام الرؤية بالحاسب لتقدير خشونة الأسطح في اتجاهين (2-D) وثلاثة اتجاهات (3-D). ويمكن تقسيم النظام المقدم إلى قسمين هما: الأدوات (Hardware) والبرامج (Software). وتتمثل الأدوات في جهاز كمبيوتر متوافق مع جهاز (IBM) ومثبت عليه أحد أنظمة التشغيل (Windows 95/98 or Windows NT)، وكاميرا رقمية (CCD camera) حساسة، وكارت التقاط الصور (Frame grabber)، وميكروسكوب لتكبير السطح المراد قياسه. أما بالنسبة للبرنامج المقترح فقد تم كتابته بلغة البرمجة (MS Visual C++ Version 5) وسمي باسم (SurfVision).

وقد تم تقسيم هذه الرسالة إلى سبعة فصول وملحق كما يلي:

الفصل الأول:

يقدم ملخص للأبحاث السابقة والحالية الخاصة بتقدير تضاريس الأسطح، ويحتوي على ملخص موجز لمعظم الطرق المستخدمة، ووصف تفصيلي لأنظمة الرؤية باستخدام الحاسب. كذلك يحتوي هذا الفصل على مميزات وعيوب كل طريقة من طرق قياس خشونة الأسطح.

الفصل الثاني:

يقدم تعريفا ووصفا رياضيا لمعاملات خشونة الأسطح التي يتم حسابها بواسطة البرنامج المقدم وعددها سبعة وخمسون معاملا. وتنطبق هذه التعريفات على معاملات خشونة الأسطح في اتجاهين (2-D)، والتي يمكن تطبيقها على خط واحد من البيانات.

الفصل الثالث:

يوضح هذا الفصل الطرق والنظريات التي تم استخدامها لعرض مجسم ثلاثي الأبعاد لصور الأسطح التي يتم التقاطها باستخدام نظام الرؤية بالحاسب المقدم خلال هذا البحث. كما يوضح إمكانية النظام في عرض المجسمات ثلاثية الأبعاد لجزء من السطح أو لكل السطح بالنظر إليه من خلال أي نقطة في الفراغ تقريبا.

الفصل الرابع:

يقدم هذا الفصل شرح لأنواع ملفات الصور التي يمكن قراءتها بالبرنامج المقدم خلال هذا البحث وهي (BMP, GIF, TIFF, PCX, TGA, JPG)، كما يوضح مميزات وعيوب كل نوع. ويقدم هذا الفصل أيضا شرحا لأوامر معالجة الصور التي يمكن تطبيقها على الصور الملتقطة للعينات مثل قلب، ودوران، وقص، ومط وضغط الصور.

الفصل الخامس:

يقدم هذا الفصل المنهج (Methodology) المتبع وبعض أساليب البرمجة التي استخدمت لتصميم البرنامج المقدم خلال هذا البحث. ويحتوي الملحق (أ) علي كتيب التشغيل للبرنامج المقدم مع شرح تفصيلي لكيفية استخدامه.

الفصل السادس:

يقدم هذا الفصل المواصفات الفنية للأدوات المستخدمة لتكوين نظام الرؤية بالحاسب المقدم مثل المواصفات الفنية للحاسب المطلوب، والكاميرا الرقمية، وكارت التقاط الصور، .وكذلك يقدم شرحا لكيفية تركيب هذه الأدوات واستخدامها. ويقدم هذا الفصل أيضا التجارب العملية التي تم إجراؤها لمعايرة واختبار النظام المقترح.

الفصل السابع:

يقدم هذا الفصل النتائج التي تم الحصول عليها من التجهيزة المعملية المقدمة، والتطبيقات المختلفة التي أجريت على هذه النتائج مع مناقشة كل جزء يتم التوصل إليه وتحليله للتحقق من صلاحية التجهيزة والبرنامج.

الفصل الثامن:

يقدم هذا الفصل ملخص لهذا البحث، كما يقدم التوصيات المقترحة للأبحاث التي يمكن استكمالها في المستقبل. ومن المميزات التي يوفرها النظام المقترح توفير الإمكانات التالية:

(١) تنفيذ بعض أوامر معالجة الصور (Image Processing) على الصور الملتقطة للسطح مثل: عرض الرسم البياني لمنحنى توزيع درجات الرصاصي في الصورة والمعروف باسم (Gray Level Histogram)، وقص الحواف غير المرغوب فيها من الصورة وخاصة إذا كانت سوداء ولا تمثل جزء منها. كذلك تنفيذ بعض أوامر معالجة الصور الأخرى مثل قلب ودوران ومط وضغط الصورة.

(٢) حساب معاملات خشونة الأسطح في كل من الاتجاهين (2-D) والاتجاهات الثلاثة (3-D) للصور الملتقطة للعينات. ويمكن حساب معاملات خشونة الأسطح باستخدام نظام القياس المتري (millimeter/micrometer) ونظام القياس الإنجليزي (inch/micro inch).

(٣) عمل قطاعات أفقية ورأسية في الصورة لعرض منحنى الخشونة للسطح عند أي نقطة. ومن خلال منحنى الخشونة يمكن تنفيذ عدة أوامر مثل: قياس المسافة بين قمم (Peaks) وقيعان (Valleys) المنحنى، وقياس مسافات متعددة على المنحنى، وعرض منحنى توزيع ارتفاعات نقط المنحنى (Amplitude Density Curve) ومنحنى مساحات التحميل (Bearing Area Curve).

(٤) عرض مساحة من السطح أو كل السطح في الأبعاد الثلاثة (3-D) لرؤية تضاريس السطح. ويمكن عرض السطح ثلاثي الأبعاد نظريا من أي نقطة نظر في الفراغ.

(٥) البرنامج المقدم متكامل مع كل من برنامجي الأوتوكاد (AutoCAD) وميكروسوفت وورد (MS Word)، لذلك فإن كل النتائج المحسوبة وكل المنحنيات التي يتم رسمها بالبرنامج يمكن نقلها إلى هذين البرنامجين.

Abstract

ABSTRACT

It is well known that the surface roughness greatly influences the mechanical and the physical properties of contacting parts. The understanding of this effect is important in many applications such as wear, friction, lubrication, tightness of joint, contact rigidity, contact stress, loaded area and thermal conductivity. Therefor, surface roughness of different products causes concern to industry.

Many methods of measuring surface finish have been developed ranging from the simple touch comparator to sophisticated optical techniques. There are five categories of surface finish measurement methods: Mechanical Profilers, Ultrasonic Methodology, Ultrahigh Precision Measurement Methodology (Microscopy), Optical Methodology (Light Scattering) and Computer Vision Systems. Each method has its own advantages and disadvantages.

The mechanical profiler instruments, which are considered to be the conventional way to measure surface roughness, have many limitations. The important disadvantages are that the probe can damage the surface, the lateral resolution of the stylus is limited by the width of the diamond tip and the probe is subjected to wear after prolonged use. Also the surface topography produced by this method is considered as a one-dimensional profile so that it is not truly representative of the surface.

The ultrasonic methods are inhibited by the need for contact, if they were to work efficiently. The Microscopy instruments are very slow and undesirable techniques for an on-line surface inspection. The optical techniques have the advantages of being noncontact, faster than contact methods, and have the capability of measuring surface roughness over an area. The optical techniques are usually realized by applying laser speckle photography techniques, and therefore not applicable for real time measurements. Furthermore, an accurate alignment of the optical arrangements is also required, making real-time use even more difficult.

The vision systems are the latest technology for measuring surface roughness. It offers the same advantages of the optical techniques and is considered relatively less expensive. In recent years, coinciding with the development of microcomputers, digital instruments and other measurement techniques, the analysis of three-dimensional (3-D) surface topography has become realistic. The vision systems depend on acquiring an image for the surface to be tested then analyzing this image using the microcomputer facilities. The vision systems are represented the scope of this work.

From the forgoing, a software package was developed totally in-house. The package was developed such that it can be used independently without referring to any other software. The package includes the unique feature of containing a multitude of surface roughness parameters that are not included in any other package hitherto. Also, The software allows the building up of a data base information system during surface inspection. This database was made to allow the future inclusion of artificial intelligence module for automated calibration of the system. The software is fully integrated with AutoCAD and MS Word. The software has the professional look interface that is used by most Windows 95 application.

This work introduces a new vision system for measuring surface roughness in either 2-D or 3-D. The proposed vision system is divided into two parts, hardware and software. The hardware includes an IBM compatible personal computer with Windows 95 operating system, frame grabber as a capturing board, CCD (Charged Couple Device) camera, and a Microscope. The software is written especially to perform different analysis on the captured images.

The proposed software is written using Microsoft Visual C++ version 5.0 and it can run under Windows 95, Windows 98 or Windows NT operating systems. The suggested name for this software is *SurfVision.*

This thesis is divided into eight chapters and one appendix as follows:

Chapter 1: Introduces a literature review of the current and the previous researches in the field of surface roughness measurements. A brief description of all methods used to assess surface roughness is described as well as a full description of the vision systems. The advantages and disadvantages of each method are also discussed.

Chapter 2: This chapter illustrates the definitions and the mathematical formulas for surface roughness parameters. Fifty-seven parameters were taken in consideration through this work. The definitions are explained for the 2-D roughness profiles, which can be applied to a single line of data.

Chapter 3: This chapter illustrates the techniques and the theories used by the *SurfVision* package to display the 3-D of the surface topography for the images captured by the vision system. It also shows the capability of displaying the 3-D surface topography for a specific part of the image as well as for the whole image. The 3-D view can be displayed, virtually, from any point of view.

Chapter 4: This chapter explains the different types of image file formats supported by the *SurfVision* package and the image-processing operations that can be applied to the images. It presents the means of reading several types of image file formats such as BMP, GIF, TIFF, PCX, TGA and JPG. It also includes the different techniques that can be applied to the image such as flipping, inverting, rotating, cropping and stretching the image.

Chapter 5: This chapter introduces the methodology and the main programming techniques used to build up the *SurfVision* package. The manual of using this package is fully explained in appendix (A).

Chapter 6: This chapter illustrates the hardware setup for the proposed vision system. It introduces the technical specifications for each hardware component such as the PC, the frame grabber, the CCD camera, and the microscope. It also introduces the experimental work that was carried out to test and to calibrate the proposed vision system.

Chapter 7: This chapter introduces the results obtained from the experimental work and. It also discusses the results to verify the capability and the validation of the proposed vision system.

Chapter 8: This chapter introduces the conclusions of this work and the recommendations for further researches. From this work it is concluded that the proposed vision system offers the following capabilities:

1. Performing different image processing commands on the captured images such as displaying the grey level histogram and cropping the unwanted borders. Other image processing commands can be performed such as flipping, inverting and rotating the image.

2. Calculating the roughness parameters in either 2-D or 3-D for the images, which were captured by the frame grabber capturing board. The roughness parameters can be calculated using both the metric and the English units, i.e. micrometers and micro inches.

3. Creating horizontal and vertical sections through the image to view the roughness profile at any point. From the profile's graph many commands can be performed such as: measuring distances between peaks and valleys, measuring multiple distances along the profile and displaying both the amplitude density curve (ADC) and the bearing area curve (BAC) of the profile.

4. Displaying the 3-Dimensional view of the surface topography to qualitatively assess the surface quality. The 3-Dimensional view can be displayed for either an area from the image or for the whole image, virtually, from any point of view.

5. The introduced software is fully integrated with the AutoCAD and the MS Word software, so that the calculated roughness parameters and the profile' graphs can be exported to these software.

TABLE OF CONTENTS

List of Figures .... **viii**

List of Tables .... **xiii**

Nomenclature .... **xv**

Abstract **1**

CHAPTER 1

LITERATURE REVIEW *5*

1. Importance of Surface Roughness: **5**

2. Classification of Roughness Parameters: **7**

3. Methods of Measuring Surface Roughness: **8**

3.1. Mechanical Profilers (Stylus Method): 9

3.2. Ultrasonic Methodology: 10

3.3. Ultrahigh Precision Measurement Methodology (Microscopy): 13

3.4 Optical Methodology (Light Scattering): 14

3.4.1 Light Scattering Theory: 15

3.4.2 Classification of Light Scattering Methods: 17

3.4.2.1 Specular Scatter Method: 18

3.4.2.2. Diffuse Scatter Method: 20

3.4.2.3. Specular and Diffuse Method: 21

3.4.2.4. Angular Distribution Method: 21

3.4.2.5. Totally Integrated Scatter (TIS) Method: 23

3.4.3. Types of Light Sources: 23

3.4.4. Optical Profilometers: 23

3.4.5. On Line Optical Measurement Techniques: 24

3.5. Computer Vision Systems: 24

4. The Objectives of the Research: **47**

CHAPTER 2

ROUGHNESS PARAMETERS *48*

1. The Amplitude Parameters: **49**
1.1. Arithmetic Average Height (R_a): 49
1.2. Root Mean Square Roughness (R_q): 50
1.3. Ten-Point Height (R_z): 50
1.4. Maximum Height of Peaks (R_p): 51
1.5. Maximum Depth of Valleys (R_v): 52
1.6. Mean Height of Peaks (R_{pm}): 52
1.7. Mean Depth of Valleys (R_{vm}): 52
1.8. Maximum Height of the Profile (R_t or R_{max}): 53
1.9. Maximum Peak to Valley Height (R_{ti}): 53
1.10. Mean of Maximum Peak to Valley Height (R_{tm}): 53
1.11. Largest Peak to Valley Height (R_y): 54
1.12. Third Point Height (R_{3y}): 54
1.13. Mean of the Third Point Height (R_{3z}): 54
1.14. Profile Solidity Factor (k): 55
1.15. Skewness (R_{sk}): 55
1.16. Kurtosis (R_{ku}): 57
1.17. Amplitude Density Function (ADF): 58
1.18. Auto Correlation Function (ACF): 59
1.19. Correlation Length (β): 59
1.20. Power Spectral Density (PSD): 60
2. The Spacing Parameters: **60**
2.1. High Spot Count (HSC): 61
2.2. Peak Count (P_c): 61
2.3. Mean spacing of Adjacent Local Peaks (S): 62
2.4. Mean spacing at Mean Line (S_m): 63
2.5. Number of Intersections of the Profile at the Mean Line (n(0)): 63
2.6. Number of Peaks in the Profile (m): 64
2.7. Number of Inflection Points (g): 65
2.8. Mean Radius of Asperities (r_p): 65
3. The Hybrid Parameters: **66**
3.1. Profile Slope at Mean Line (γ): 66
3.2. Mean Slope of the Profile (Δ_a): 67

3.3. RMS Slope of the Profile (Δ_q): 68
3.4. Average Wavelength (λ_a): 68
3.5. RMS Wave Length (λ_q): 68
3.6. Relative Length of the Profile (l_o): 69
3.7. Bearing Area Length (t_p) and Bearing Area Curve: 69
3.8. Stepness Factor of the Profile (S_f): 71
3.9. Waviness Factor of the Profile (W_f): 71
3.10. Roughness Height Uniformity (H_u): 71
3.11. Roughness Height Skewness (H_s): 72
3.12. Roughness Pitch Uniformity (P_u): 72
3.13. Roughness Pitch Skewness (P_s): 72

CHAPTER 3

THREE DIMENSIONAL REPRESENTATION *73*

1. Three Dimensional Coordinate Systems: **74**
2. Three Dimensional Display Techniques: **75**
3. Three-Dimensional Transformations: **76**
3.1. Translation Process: 77
3.2. Rotation about the Coordinate Axes: 78
3.3. Concatenation of Transformations: 81
4. Projections of Three-Dimensional Models: **81**
5. Viewing the 3-D Surface Topography: **83**

CHAPTER 4

IMAGE FILE FORMATS AND IMAGE MANIPULATION *89*

1. Supported Image File Formats: **89**
1.1. BMP Files: 89
1.1.1. The BMP Format: 90
1.1.2. The BITMAPFILEHEADER Structure: 91
1.1.3. The BITMAPINFO Structure: 92
1.1.4. The BITMAPINFOHEADER Structure: 92
1.1.5. The RGBQUAD Structure 93

1.1.6. The BMP Data: 94
1.2. GIF Files: 94
1.3. JPG (JPEG) Files: 95
1.4. PCX Files: 95
1.5. TGA Files: 96
1.6. TIFF Files: 96
2. Image Processing Operations: 98
2.1. Cropping Images: 98
2.2. Resizing Images: 98
2.3. Flipping and Inverting Images: 98
2.4. Rotating Images: 101
2.5. Reversing Image Colours: 102
2.6. Colours Histograms: 102
2.6.1. Colour Definition Methods: 103
2.6.1.1. The RGB Method: 103
2.6.1.2. The HSL Method: 104
2.6.1.3. CMYK Model: 105
2.7. Changing Image Brightness: 105
2.8. Changing Image Contrast: 105
2.9 Converting Image to Grey Scale: 108

CHAPTER 5

METHODOLOGY OF THE SURFVISION PACKAGE........... 109

1. Programming language: 109
2. Programming Algorithms: 114
2.1. Extracting the Grey Levels from the Image: 114
2.2. Calibrating the System: 116
2.3. Calculating 2-D Roughness Parameters: 118
2.3.1. Amplitude Parameters: 120
2.3.2. Spacing Parameters: 121
2.3.3. Hybrid Parameters: 129
2.4 Calculating the 3-D Roughness Parameters: 130

2.5 Calculating 3-D Gray Level Histogram: 132

CHAPTER 6

EXPERIMENTAL WORK *134*

1. Hardware and Software Setup: **134**
1.1. Hardware Setup: 138
1.1.1. The PC Micro Computer: 138
1.1.2. The Metallurgical Microscope: 138
1.1.3. The CCD Camera: 139
1.1.4. The Frame Grabber: 140
1.2. The Software Package: 141
2. Experimental Procedures: **142**
2.1. Calibrating the Vision System: 142
2.1.1. Calibrating the System for Spatial Distances: 142
2.1.2. Calibrating the System for Height Distances: 145
2.2. Settings of the ELF-VGA EVC Software: 146
2.2.1. The Grab Settings: 147
2.2.2. The Video Settings: 147
2.2.3. Saving the Captured Image: 148
2.3. Preparing to Acquire Images: 149
2.3.1. The Constant: 149
2.3.2. Getting the Best Grey Level Histogram: 150
2.4. Testing the Vision System: 151
2.4.1. Testing the 2 μin specimen: 152
2.4.1.1. Getting the First Image: 152
2.4.1.2. Changing the Brightness of the Image: 154
2.4.1.3. Changing the Contrast of the Image: 155
2.4.1.4. Changing the Saturation of the Image: 155
2.4.3. Testing the 4 μin specimen: 160
2.4.4. Testing the 8 μin specimen: 164

CHAPTER 7

SYSTEM VERIFICATION AND CAPABILITIES *168*

1. Preparing to Analyze the Acquired Images: **168**

2. Testing the 2 μin Specimen: **169**

2.1 Checking the Accuracy of the System: 169

2.1.1 Sections across the Lays: 169

2.1.1.1 Displaying the Profile' Graphs: 171

2.1.2 Sections along the Lays: 175

2.1.2.1 Displaying the Profile' Graphs: 176

2.2 Calculating the 2-D Roughness Parameters: 176

2.3 Calculating the 3-D Roughness Parameters: 183

2.4 Displaying the 3-D Surface Topography: 183

3. Testing the 4 μin Specimen: **189**

4. Testing the 8 μin Specimen: **201**

5. Assessing the Surface Defects: **213**

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS *214*

1. Conclusions: **214**

1.1 Advantages of the Proposed Vision System: 215

1.2 Limitations of the Proposed Vision System: 215

2. Recommendations for Future Work: 216

2.1. Experimental Work: 216

2.2. Computational Work: 216

BIBLIOGRAPHY **218**

APPENDIX (A)

THE SURFVISION PACKAGE USER'S MANUAL *234*

ARABIC SUMMARY *314*

العنوان:	Assessment of surface texture using computer vision techniques
المؤلف الرئيسي:	Gad Almawla, Al Amir Samy
مؤلفين آخرين:	Abd Almaksoud, T. M.، Koura, M. M. F.، Soliman, Hassan H.، El Ewa, Ibrahim Mohamed(Super، Super.)
التاريخ الميلادي:	1999
موقع:	المنصورة
الصفحات:	1 - 358
رقم MD:	536407
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة دكتوراه
الجامعة:	جامعة المنصورة
الكلية:	كلية الهندسة
الدولة:	مصر
قواعد المعلومات:	Dissertations
مواضيع:	الخواص الفيزيائية ، خشونة الأسطح ، معالجة الصور ، الرؤية بالحاسب
رابط:	https://search.mandumah.com/Record/536407

Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department

Assessment of Surface Texture Using Computer Vision Techniques

A Thesis submitted to

The University of Mansoura

For the Degree of

Doctor of Philosophy

By

El-Amir Samy Gad-Elmawla

Assistant Lecture in the Production Engineering and Mechanical Design Department

Supervisors

Prof. M. M. Koura

Ain Shams University
Faculty of Engineering
Design and Production Engineering Department
Egypt

Dr. T. M. A. Maksoud

University of Glamorgan
School of Design and Advanced Technology
United Kingdom

Prof. I. M. Elewa

Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department
Egypt

Dr. H. H. Soliman

Mansoura University
Faculty of Engineering
Electronics & Communication Engineering Department
Egypt

1999

Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department

Assessment of Surface Texture Using Computer Vision Techniques

A Thesis submitted to

The University of Mansoura

For the Degree of

Doctor of Philosophy

By

El-Amir Samy Gad-Elmawla

Assistant Lecture in the Production Engineering and Mechanical Design Department

Supervisors

Prof. M. M. Koura
Ain Shams University
Faculty of Engineering
Design and Production Engineering Department
Egypt

Dr. T. M. A. Maksoud
University of Glamorgan
School of Design and Advanced Technology
United Kingdom

Prof. I. M. Elewa
Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department
Egypt

Dr. H. H. Soliman
Mansoura University
Faculty of Engineering
Electronics & Communication Engineering Department
Egypt

1999

List of Figures

Figure (1-1): A surface profile combines roughness, waveness and form........................ 8

Figure (1-2): Light Scattering Methods 19

Figure (1-3): Measuring scattering intensity using the intensity ratio 26

Figure (1-4): layout of LUK and HUYNH Vision System 28

Figure (1-5): A diagram of the CUTHBERT's Experimental Set-up............................. 37

Figure (1-6): Schematic of GRIFFITHS's Light Scattering Rig.................................... 42

Figure (1-7): Change in total intensity for a series of ground Surfaces with different roughness 43

Figure (2-1): Definition of the Arithmetic Average Height (R_a) 49

Figure (2-2): Definition of the Ten-Point height parameter ($R_{z(ISO)}$, $R_{z(DIN)}$).................. 51

Figure (2-3): Definitions of the Parameters R_p, R_v, R_{pm}, R_{vm}, R_t (R_{max}) 52

Figure (2-4): Definition of the Maximum Peak to Valley Height Parameters (R_{ti})........ 54

Figure (2-5): Definitions of the third point Height Parameters (R_{3y} ,R_{3z}) 55

Figure (2-6): Definition of Skewness (R_{sk}) and the Amplitude Distribution Curve....... 56

Figure (2-7): Definition of Kurtosis (R_{ku}) Parateter 57

Figure (2-8): The Amplitude Density Function (ADF)... 58

Figure (2-9): Calculating HSC above a selected level.. 61

Figure (2-10): Calculating the Peak Count (P_c) parameter within a selected band......... 62

Figure (2-11): Calculating the Mean spacing of Adjacent Local Peaks (S).................... 62

Figure (2-12): Calculating the Mean spacing at Mean Line (S_m) 63

Figure (2-13): Calculating the Number of Intersections of the Profile at Mean Line..... 64

Figure (2-14): Calculating the Number of Peaks along the Profile 64

Figure (2-15): Calculating the Number of Inflection Points along the Profile 65

Figure (2-16): Calculating the Profile Slope at Mean Line 67

Figure (2-17): Calculating the Mean Slope of the Profile 67

Figure (2-18): Calculating the Relative Length the Profile (l_o) 69

Figure (2-19): Calculating the Bearing Area Length (t_p) of the Profile 70

Figure (2-20): The Bearing Area Curve of a Profile 70

Figure (3-1): The Right-hand rule and the Cartesian Coordinate System of the three-dimensional representation 75

Figure (3-2): Flowchart of the function Get3DPoint ( ) 78

Figure (3-3): Flowchart of the function used to create the 4*4 translation matrix 79

Figure (3-4): Determination of the Positive Rotation Angles Using the Right-Hand Rule 79

Figure (3-5): Flowchart of the function that concatenates two 4*4 matrices 82

Figure (3-6): Process of displaying a three-dimensional model 82

Figure (3-7): Determining the point of view using two angles 84

Figure (3-8): Flowchart of the Function Used to Draw the 3-D View of Surface Topography 88

Figure (4-1): Layout of a BMP file 90

Figure (4-2): Cropping the Black Border from the Image 99

Figure (4-3): Flipping and Inverting the Image 100

Figure (4-4): Rotating an Image by 90 Degrees 101

Figure (4-5): Reversing the image colours 102

Figure (4-6): Grey Level Histogram for an Image 103

Figure (4-7): Changing the Brightness of an Image 106

Figure (4-8): Changing the Contrast of an Image 107

Figure (5-1): Block Diagram for the Main Classes of the SurfVision Software 111

Figure (5-2): Flow chart of the ExtractGreyLevels( ) Function 115

Figure (5-3): Block Diagram of the CalibrateSystem ( ) Class 117

Figure (5-4): Flow Chart of the Technique Used to Calculate the 2-D Roughness Parameters 119

Figure (5-5): Flow chart of the function GetMainAmp( ) Used to Calculate R_a, R_q, R_{sk}, R_{ku} 120

Figure (5-6): Flow chart of the function CreateSortedData ( ) used to create the SortedData [ ] array 122

Figure (5-7): Flow Chart of the Function GetRestAmp ( ), which is Used to Calculate the Rest of the Amplitude Parameters 123

Figure (5-8): Flow Chart of the Function BearingArea( ), which is Used to Calculate the Parameters: t_p, n(0), n(h), HSC, γ, S, S_m 125

Figure (5-9): Flow Chart of the Function BearingArea( ), which is Used to Calculate the Parameters: t_p, n(0), n(h), HSC, γ, S, S_m … Continue 126

Figure (5-10): Calculating the direction of the profile at any point 127

Figure (5-11): Flow Chart of the Function GetInflections ( ), which is Used to Calculate the Number of Inflection Points along the Profile 128

Figure (5-12): Flow Chart of the Function HybridPara ( ), which is Used to Calculate the Hybrid Parameters 129

Figure (5-13): Flow Chart of the Function Calc3DParameters ( ), which is Used to Calculate the 3-D Roughness Parameters 131

Figure (5-14): Flow Chart of the Function CalcHistogram( ), which is Used to Draw the Gray Level Histogram 133

Figure (6-1): Layout of the Hardware/Software Setup for the Proposed Vision System 135

Figure (6-2): Photograph of the Proposed Vision System 136

Figure (6-3): The Image Width for 200X Magnification 144

Figure (6-4): The Image Height for 200X Magnification 144

Figure (6-5): The Grab Settings Used through the Experimental Work 147

Figure (6-6): The Video Settings Control Panel 148

Figure (6-7): The Voltage Regulator Settings 150

Figure (6-8): The Image 2L_1 for the 2 μin specimen (Br=32, Co=32, Sa=32)........... 153

Figure (6-9): The Grey Level Histogram for the Image 2L_1.BMP............................ 153

Figure (6-10): The Grey Level Frequencies Dialog Box for the Image 2L_1.BMP..... 154

Figure (6-11): The Image 2L_2 for the 2 μin specimen (Br=0, Co=32, Sa=32)........... 157

Figure (6-12): The Grey Level Histogram for the Image 2L_2.BMP.......................... 157

Figure (6-13): The Image 2L_3 for the 2 μin specimen (Br=0, Co=48, Sa=32)........... 158

Figure (6-14): The Grey Level Histogram for the Image 2L_3.BMP.......................... 158

Figure (6-15): The Image 2L_4 for the 2 μin specimen (Br=0, Co=48, Sa=12)........... 159

Figure (6-16): The Grey Level Histogram for the Image 2L_4.BMP.......................... 159

Figure (6-17): The Image 4L_1 for the 4 μin specimen (Br=0, Co=48, Sa=12)........... 161

Figure (6-18): The Grey Level Histogram for the Image 4L_1.BMP.......................... 161

Figure (6-19): The Image 4L_2 for the 4 μin specimen (Br=8, Co=48, Sa=12)........... 162

Figure (6-20): The Grey Level Histogram for the Image 4L_2.BMP.......................... 162

Figure (6-21): The Image 4L_3 for the 4 μin specimen (Br=8, Co=52, Sa=12)........... 163

Figure (6-22): The Grey Level Histogram for the Image 4L_3.BMP.......................... 163

Figure (6-23): The Image 4L_1 for the 4 μin specimen (Br=0, Co=48, Sa=12)........... 165

Figure (6-24): The Grey Level Histogram for the Image 8L_1.BMP.......................... 165

Figure (6-25): The Image 8L_2 for the 8 μin specimen (Br=10, Co=48, Sa=12)......... 166

Figure (6-26): The Grey Level Histogram for the Image 8L_2.BMP.......................... 166

Figure (6-27): The Image 8L_3 for the 8 μin specimen (Br=10, Co=56, Sa=12)......... 167

Figure (6-28): The Grey Level Histogram for the Image 8L_3.BMP.......................... 167

Figure (7-1): Six 2-D Sections for the Image 2L_4 using the Grey Scale Units 172

Figure (7-2): The Six 2-D Sections for the Image 2L_4 using the English Units......... 173

Figure (7-3): The Six 2-D Sections for the Image 2L_4 using the Metric Units 174

Figure (7-4): The Six 2-D Sections for the Image 2L_4 using the Metric Units 177

Figure (7-5): Large Area from the “2L_4” Specimen 188

Figure (7-6): Medium Area from the “2L_4” Specimen 188

Figure (7-7): The Six 2-D Sections for the Image “4L_3” using the English Units 190

Figure (7-8): The Six 2-D Sections for the Image “4L_3” using the Metric Units....... 191

Figure (7-9): Large Area from the “4L_3” Specimen 200

Figure (7-10): Small Area from the “4L_3” Specimen 200

Figure (7-11): The Six 2-D Sections for the Image “8L_3” using the English Units ... 202

Figure (7-12): The Six 2-D Sections for the Image “8L_3” using the Metric Units..... 203

Figure (7-13): Large Area from the “8L_3” Specimen 212

Figure (7-14): Large Area from the “8L_3” Specimen 212

Figure (7-15): A Scratched Area from the 2 μin Specimen 213

LIST OF TABLES

Table (1-1): The Relationship Between Roughness Parameters and Surface Function.... 6

Table (4-1): The BITMAPFILEHEADER Structure 91

Table (4-2): The BITMAPINFOHEADER Structure 93

Table (4-3): Representing the White Light Colours using RGB and HSL Methods 104

Table (6-1): Specifications of the CCD Camera 139

Table (6-2): Specifications of the ELF-VGA Frame Grabber 140

Table (6-3): The Image Width and Height for Different Magnifications 143

Table (6-4): The Specimen Scheme Properties that can be stored for each image....... 145

Table (6-5): The Constant Settings in the Experimental Work 150

Table (6-6): Specifications of the RUBERT Scales Specimens 151

Table (6-7): The Video Settings for the Image "2L_1.BMP" 152

Table (7-1): Calculated R_a (in µm) for Six Sections across the Lays 170

Table (7-2): Calculated R_a (in µin) for Six Sections Across the Lays 170

Table (7-3): Calculated R_a (in µin) for Sections Along the Lays Using the Same Calibration Used for Horizontal Sections 175

Table (7-4): Calculated R_a (in µin) for Sections Along the Lays After Calibrating the System for Vertical Lays 175

Table (7-5): Roughness Parameters and its Corresponding Symbols 178

Table (7-6) : The Calculated roughness parameters for the Six Horizontal Sections using the Metric Units 179

Table (7-7) : The Calculated Roughness Parameters for the Six Horizontal Sections Using the English Units 181

Table (7-8): The Calculated 3-D Roughness Parameters for the Specimen "2L_4" Using the Metric Units 184

Table (7-9): The Calculated 3-D Roughness Parameters for the Specimen "2L_4" Using the English Units 186

Table (7-10): Calculated R_a (in μin) for Six Sections for the Image "4L_3" 189

Table (7-11): Calculated Ra (in μm) for Six Sections for the Image "4L_3"............... 189

Table (7-12): The Calculated Roughness Parameters for the Image (4L_3) Using the Metric Units 192

Table (7-13): The Calculated roughness parameters for the image (4L_3) Using the English Units … Continue 194

Table (7-14): The Calculated 3-D Roughness Parameters for the Specimen "4L_3" Using the Metric Units.. 196

Table (7-15): The Calculated 3-D Roughness Parameters for the Specimen "4L_3" Using the English Units 198

Table (7-16): Calculated Ra (in μin) for Six Sections for the Image "8L_3"............... 201

Table (7-17): Calculated Ra (in μm) for Six Sections for the Image "8L_3"............... 201

Table (7-18): The Calculated Roughness Parameters for the Image (8L_3) Using the Metric Units 204

Table (7-19): The Calculated Roughness Parameters for the Image (8L_3) Using the English Units... 206

Table (7-20): The Calculated 3-D Roughness Parameters for the Specimen "8L_3" Using the Metric Units.. 208

Table (7-21): The Calculated 3-D Roughness Parameters for the Specimen "8L_3" Using the English Units 210

NOMENCLATURE

ACF	Auto Correlation Function	μm
ADF	Amplitude Density Function	--
g	Number of Inflection Points	Inflections
H_s	Roughness Height Skewness	--
HSC	High Spot Count	Count(s)
H_u	Roughness Height Uniformity	--
K	Profile Solidity Factor	--
l_o	Relative Length of the Profile	--
m	Number of Peaks in Profile	Peaks
n(0)	Number of Intersections of the Profile at the Mean Line	Intersections
P_c	Peak Count	Count/cm
P_s	Roughness Pitch Skewness	--
PSD	Power Spectral Density	--
P_u	Roughness Pitch Uniformity	--
R_{3y}	Third Point Height	μm
R_{3z}	Mean of the Third Point Height	μm
R_a	Arithmetic Average Height	μm
R_{ku}	Kurtosis	--
RMS	Root Mean Square	μm
R_p	Maximum Height of Peaks	μm
rp	Mean Peak Radius of Curvature	μm
R_{pm}	Mean Height of Peaks	μm
R_q	Root Mean Square Roughness	μm
R_{sk}	Skewness	--
R_t, R_{max}	Maximum Height of the Profile	μm
R_{ti}	Maximum Peak to Valley Height	μm
R_{tm}	Mean of Maximum Peak to Valley Height	μm
R_v	Maximum Depth of Valleys	μm
R_{vm}	Mean Depth of Valleys	μm
R_y	Largest Peak to Valley Height	μm

R_z	Ten-Point Height	µm
S	Mean spacing of Adjacent peaks	µm
SD	Standard Deviation	--
S_f	Stepness Factor of the Profile	--
t_p	Bearing Line Length and Bearing Area Curve	%
S_m	Mean spacing at Mean Line	µm
W_f	Waviness Factor of the Profile	--

Abbreviations:

2-D	Two Dimensional
3-D	Three Dimensional
ADC	Amplitude Density Curve
AFM	Atomic Force Microscope
API	Application Programming Interface
BAC	Bearing Area Curve
BMP	Type of graphics format stands for Windows Bitmap
bpp	Bit Per Pixel
CAD	Computer Aided Design / Computer Aided Drafting
CCD	Charge Coupled Device
CCS	Cartesian Coordinate System
CLA	Center Line Average
CMYK	Cyan, Magenta, Yellow, blacK
CPP	Contact Probe Profilometry
CRT	Cathode Ray Tube
DOS	Disk Operating System
EVC	Elf VGA Capture boead
FFT	Fast Fourier Transformation
GDI	Graphics Device Interface
GIF	Type of graphics format stands for Graphics Interchange Format
GUI	Graphics User Interface
h/v	Horizontal/Vertical resolution
HSL	Hue, Saturation, Lightness
JPG/JPEG	Type of graphics format stands for Joint Photographic Experts Group

LZW	Type of data compression techniques
MFC	Microsoft Foundation Class
MHz	Mega Hertz
MPM	Multi Parameters File
MTM	Modeling Transformation Matrix
MW	Miga Watt
PCX	Type of graphics format stands for Z-Soft corp.
PTM	Projection Transformation Matrix
RGB	Red, Green, Blue
RLE	Type of data compression techniques
SEM	Scanning Electron Microscope
SERM	Scanning Electron Reflection Microscope
STM	Scanning Tunneling Microscope
TEM	Transmission Electron Microscope
TGA	Type of graphics format stands for TrueVision Targa
TIFF	Type of graphics format stands for Tagged Image File Format
TIS	Total Internal Scatter
VGA	Video Graphics Array

Greek

β	Correlation Length	μm
γ	Profile Slope at Mean Line	Degrees
Δ_a	Mean Slope of the Profile	Degrees
λ_a	Average Wavelength	μm
Δ_q	RMS Slope of the Profile	Degrees
λ_q	RMS Wave Length	μm

Abstract

ABSTRACT

It is well known that the surface roughness greatly influences the mechanical and the physical properties of contacting parts. The understanding of this effect is important in many applications such as wear, friction, lubrication, tightness of joint, contact rigidity, contact stress, loaded area and thermal conductivity. Therefor, surface roughness of different products causes concern to industry.

Many methods of measuring surface finish have been developed ranging from the simple touch comparator to sophisticated optical techniques. There are five categories of surface finish measurement methods: Mechanical Profilers, Ultrasonic Methodology, Ultrahigh Precision Measurement Methodology (Microscopy), Optical Methodology (Light Scattering) and Computer Vision Systems. Each method has its own advantages and disadvantages.

The mechanical profiler instruments, which are considered to be the conventional way to measure surface roughness, have many limitations. The important disadvantages are that the probe can damage the surface, the lateral resolution of the stylus is limited by the width of the diamond tip and the probe is subjected to wear after prolonged use. Also the surface topography produced by this method is considered as a one-dimensional profile so that it is not truly representative of the surface.

The ultrasonic methods are inhibited by the need for contact, if they were to work efficiently. The Microscopy instruments are very slow and undesirable techniques for an on-line surface inspection. The optical techniques have the advantages of being noncontact, faster than contact methods, and have the capability of measuring surface roughness over an area. The optical techniques are usually realized by applying laser speckle photography techniques, and therefore not applicable for real time measurements. Furthermore, an accurate alignment of the optical arrangements is also required, making real-time use even more difficult.

The vision systems are the latest technology for measuring surface roughness. It offers the same advantages of the optical techniques and is considered relatively less expensive. In recent years, coinciding with the development of microcomputers, digital instruments and other measurement techniques, the analysis of three-dimensional (3-D) surface topography has become realistic. The vision systems depend on acquiring an image for the surface to be tested then analyzing this image using the microcomputer facilities. The vision systems are represented the scope of this work.

From the forgoing, a software package was developed totally in-house. The package was developed such that it can be used independently without referring to any other software. The package includes the unique feature of containing a multitude of surface roughness parameters that are not included in any other package hitherto. Also, The software allows the building up of a data base information system during surface inspection. This database was made to allow the future inclusion of artificial intelligence module for automated calibration of the system. The software is fully integrated with AutoCAD and MS Word. The software has the professional look interface that is used by most Windows 95 application.

This work introduces a new vision system for measuring surface roughness in either 2-D or 3-D. The proposed vision system is divided into two parts, hardware and software. The hardware includes an IBM compatible personal computer with Windows 95 operating system, frame grabber as a capturing board, CCD (Charged Couple Device) camera, and a Microscope. The software is written especially to perform different analysis on the captured images.

The proposed software is written using Microsoft Visual C++ version 5.0 and it can run under Windows 95, Windows 98 or Windows NT operating systems. The suggested name for this software is *SurfVision.*

This thesis is divided into eight chapters and one appendix as follows:

Chapter 1: Introduces a literature review of the current and the previous researches in the field of surface roughness measurements. A brief description of all methods used to assess surface roughness is described as well as a full description of the vision systems. The advantages and disadvantages of each method are also discussed.

Chapter 2: This chapter illustrates the definitions and the mathematical formulas for surface roughness parameters. Fifty-seven parameters were taken in consideration through this work. The definitions are explained for the 2-D roughness profiles, which can be applied to a single line of data.

Chapter 3: This chapter illustrates the techniques and the theories used by the *SurfVision* package to display the 3-D of the surface topography for the images captured by the vision system. It also shows the capability of displaying the 3-D surface topography for a specific part of the image as well as for the whole image. The 3-D view can be displayed, virtually, from any point of view.

Chapter 4: This chapter explains the different types of image file formats supported by the *SurfVision* package and the image-processing operations that can be applied to the images. It presents the means of reading several types of image file formats such as BMP, GIF, TIFF, PCX, TGA and JPG. It also includes the different techniques that can be applied to the image such as flipping, inverting, rotating, cropping and stretching the image.

Chapter 5: This chapter introduces the methodology and the main programming techniques used to build up the *SurfVision* package. The manual of using this package is fully explained in appendix (A).

Chapter 6: This chapter illustrates the hardware setup for the proposed vision system. It introduces the technical specifications for each hardware component such as the PC, the frame grabber, the CCD camera, and the microscope. It also introduces the experimental work that was carried out to test and to calibrate the proposed vision system.

Chapter 7: This chapter introduces the results obtained from the experimental work and. It also discusses the results to verify the capability and the validation of the proposed vision system.

Chapter 8: This chapter introduces the conclusions of this work and the recommendations for further researches. From this work it is concluded that the proposed vision system offers the following capabilities:

1. Performing different image processing commands on the captured images such as displaying the grey level histogram and cropping the unwanted borders. Other image processing commands can be performed such as flipping, inverting and rotating the image.

2. Calculating the roughness parameters in either 2-D or 3-D for the images, which were captured by the frame grabber capturing board. The roughness parameters can be calculated using both the metric and the English units, i.e. micrometers and micro inches.

3. Creating horizontal and vertical sections through the image to view the roughness profile at any point. From the profile's graph many commands can be performed such as: measuring distances between peaks and valleys, measuring multiple distances along the profile and displaying both the amplitude density curve (ADC) and the bearing area curve (BAC) of the profile.

4. Displaying the 3-Dimensional view of the surface topography to qualitatively assess the surface quality. The 3-Dimensional view can be displayed for either an area from the image or for the whole image, virtually, from any point of view.

5. The introduced software is fully integrated with the AutoCAD and the MS Word software, so that the calculated roughness parameters and the profile' graphs can be exported to these software.

Chapter 1

LITERATURE REVIEW

TABLE OF CONTENTS

List of Figures .... **viii**
List of Tables .... **xiii**
Nomenclature .... **xv**
Abstract **1**

CHAPTER 1

LITERATURE REVIEW *5*

1. Importance of Surface Roughness: **5**
2. Classification of Roughness Parameters: **7**
3. Methods of Measuring Surface Roughness: **8**
3.1. Mechanical Profilers (Stylus Method): 9
3.2. Ultrasonic Methodology: 10
3.3. Ultrahigh Precision Measurement Methodology (Microscopy): 13
3.4 Optical Methodology (Light Scattering): 14
3.4.1 Light Scattering Theory: 15
3.4.2 Classification of Light Scattering Methods: 17
3.4.2.1 Specular Scatter Method: 18
3.4.2.2. Diffuse Scatter Method: 20
3.4.2.3. Specular and Diffuse Method: 21
3.4.2.4. Angular Distribution Method: 21
3.4.2.5. Totally Integrated Scatter (TIS) Method: 23
3.4.3. Types of Light Sources: 23
3.4.4. Optical Profilometers: 23
3.4.5. On Line Optical Measurement Techniques: 24
3.5. Computer Vision Systems: 24
4. The Objectives of the Research: **47**

CHAPTER 2

ROUGHNESS PARAMETERS *48*

1. The Amplitude Parameters: **49**
1.1. Arithmetic Average Height (R_a): 49
1.2. Root Mean Square Roughness (R_q): 50
1.3. Ten-Point Height (R_z): 50
1.4. Maximum Height of Peaks (R_p): 51
1.5. Maximum Depth of Valleys (R_v): 52
1.6. Mean Height of Peaks (R_{pm}): 52
1.7. Mean Depth of Valleys (R_{vm}): 52
1.8. Maximum Height of the Profile (R_t or R_{max}): 53
1.9. Maximum Peak to Valley Height (R_{ti}): 53
1.10. Mean of Maximum Peak to Valley Height (R_{tm}): 53
1.11. Largest Peak to Valley Height (R_y): 54
1.12. Third Point Height (R_{3y}): 54
1.13. Mean of the Third Point Height (R_{3z}): 54
1.14. Profile Solidity Factor (k): 55
1.15. Skewness (R_{sk}): 55
1.16. Kurtosis (R_{ku}): 57
1.17. Amplitude Density Function (ADF): 58
1.18. Auto Correlation Function (ACF): 59
1.19. Correlation Length (β): 59
1.20. Power Spectral Density (PSD): 60
2. The Spacing Parameters: **60**
2.1. High Spot Count (HSC): 61
2.2. Peak Count (P_c): 61
2.3. Mean spacing of Adjacent Local Peaks (S): 62
2.4. Mean spacing at Mean Line (S_m): 63
2.5. Number of Intersections of the Profile at the Mean Line (n(0)): 63
2.6. Number of Peaks in the Profile (m): 64
2.7. Number of Inflection Points (g): 65
2.8. Mean Radius of Asperities (r_p): 65
3. The Hybrid Parameters: **66**
3.1. Profile Slope at Mean Line (γ): 66
3.2. Mean Slope of the Profile (Δ_a): 67

3.3. RMS Slope of the Profile (Δ_q): 68
3.4. Average Wavelength (λ_a): 68
3.5. RMS Wave Length (λ_q): 68
3.6. Relative Length of the Profile (l_o): 69
3.7. Bearing Area Length (t_p) and Bearing Area Curve: 69
3.8. Stepness Factor of the Profile (S_f): 71
3.9. Waviness Factor of the Profile (W_f): 71
3.10. Roughness Height Uniformity (H_u): 71
3.11. Roughness Height Skewness (H_s): 72
3.12. Roughness Pitch Uniformity (P_u): 72
3.13. Roughness Pitch Skewness (P_s): 72

CHAPTER 3

THREE DIMENSIONAL REPRESENTATION........ 73

1. Three Dimensional Coordinate Systems:........ 74
2. Three Dimensional Display Techniques: 75
3. Three-Dimensional Transformations: 76
3.1. Translation Process: 77
3.2. Rotation about the Coordinate Axes: 78
3.3. Concatenation of Transformations: 81
4. Projections of Three-Dimensional Models: 81
5. Viewing the 3-D Surface Topography: 83

CHAPTER 4

IMAGE FILE FORMATS AND IMAGE MANIPULATION....... 89

1. Supported Image File Formats: 89
1.1. BMP Files: 89
1.1.1. The BMP Format: 90
1.1.2. The BITMAPFILEHEADER Structure: 91
1.1.3. The BITMAPINFO Structure: 92
1.1.4. The BITMAPINFOHEADER Structure: 92
1.1.5. The RGBQUAD Structure 93

1.1.6. The BMP Data: 94
1.2. GIF Files: 94
1.3. JPG (JPEG) Files: 95
1.4. PCX Files: 95
1.5. TGA Files: 96
1.6. TIFF Files: 96
2. Image Processing Operations: 98
2.1. Cropping Images: 98
2.2. Resizing Images: 98
2.3. Flipping and Inverting Images: 98
2.4. Rotating Images: 101
2.5. Reversing Image Colours: 102
2.6. Colours Histograms: 102
2.6.1. Colour Definition Methods: 103
2.6.1.1. The RGB Method: 103
2.6.1.2. The HSL Method: 104
2.6.1.3. CMYK Model: 105
2.7. Changing Image Brightness: 105
2.8. Changing Image Contrast: 105
2.9 Converting Image to Grey Scale: 108

CHAPTER 5

METHODOLOGY OF THE SURFVISION PACKAGE........... 109

1. Programming language: 109
2. Programming Algorithms: 114
2.1. Extracting the Grey Levels from the Image: 114
2.2. Calibrating the System: 116
2.3. Calculating 2-D Roughness Parameters: 118
2.3.1. Amplitude Parameters: 120
2.3.2. Spacing Parameters: 121
2.3.3. Hybrid Parameters: 129
2.4 Calculating the 3-D Roughness Parameters: 130

2.5 Calculating 3-D Gray Level Histogram: ... 132

CHAPTER 6

EXPERIMENTAL WORK ... 134

1. Hardware and Software Setup: ... 134
1.1. Hardware Setup: ... 138
1.1.1. The PC Micro Computer: ... 138
1.1.2. The Metallurgical Microscope: ... 138
1.1.3. The CCD Camera: ... 139
1.1.4. The Frame Grabber: ... 140
1.2. The Software Package: ... 141
2. Experimental Procedures: ... 142
2.1. Calibrating the Vision System: ... 142
2.1.1. Calibrating the System for Spatial Distances: ... 142
2.1.2. Calibrating the System for Height Distances: ... 145
2.2. Settings of the ELF-VGA EVC Software: ... 146
2.2.1. The Grab Settings: ... 147
2.2.2. The Video Settings: ... 147
2.2.3. Saving the Captured Image: ... 148
2.3. Preparing to Acquire Images: ... 149
2.3.1. The Constant: ... 149
2.3.2. Getting the Best Grey Level Histogram: ... 150
2.4. Testing the Vision System: ... 151
2.4.1. Testing the 2 μin specimen: ... 152
2.4.1.1. Getting the First Image: ... 152
2.4.1.2. Changing the Brightness of the Image: ... 154
2.4.1.3. Changing the Contrast of the Image: ... 155
2.4.1.4. Changing the Saturation of the Image: ... 155
2.4.3. Testing the 4 μin specimen: ... 160
2.4.4. Testing the 8 μin specimen: ... 164

CHAPTER 7

SYSTEM VERIFICATION AND CAPABILITIES.................. *168*

1. Preparing to Analyze the Acquired Images: **168**

2. Testing the 2 µin Specimen: **169**

2.1 Checking the Accuracy of the System: 169

2.1.1 Sections across the Lays:.. 169

2.1.1.1 Displaying the Profile' Graphs: 171

2.1.2 Sections along the Lays:.. 175

2.1.2.1 Displaying the Profile' Graphs: 176

2.2 Calculating the 2-D Roughness Parameters:.. 176

2.3 Calculating the 3-D Roughness Parameters:.. 183

2.4 Displaying the 3-D Surface Topography:.. 183

3. Testing the 4 µin Specimen: **189**

4. Testing the 8 µin Specimen: **201**

5. Assessing the Surface Defects: **213**

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS...................... *214*

1. Conclusions: **214**

1.1 Advantages of the Proposed Vision System: 215

1.2 Limitations of the Proposed Vision System:.. 215

2. Recommendations for Future Work:.. 216

2.1. Experimental Work:... 216

2.2. Computational Work:... 216

BIBLIOGRAPHY **218**

APPENDIX (A)

THE SURFVISION PACKAGE USER'S MANUAL............... *234*

ARABIC SUMMARY.. *314*

العنوان:	Assessment of surface texture using computer vision techniques
المؤلف الرئيسي:	Gad Almawla, Al Amir Samy
مؤلفين آخرين:	Abd Almaksoud, T. M.، Koura, M. M. F.، Soliman, Hassan H.، El Ewa, Ibrahim Mohamed(Super، Super.)
التاريخ الميلادي:	1999
موقع:	المنصورة
الصفحات:	1 - 358
رقم MD:	536407
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة دكتوراه
الجامعة:	جامعة المنصورة
الكلية:	كلية الهندسة
الدولة:	مصر
قواعد المعلومات:	Dissertations
مواضيع:	الخواص الفيزيائية ، خشونة الأسطح ، معالجة الصور ، الرؤية بالحاسب
رابط:	https://search.mandumah.com/Record/536407

جامعة المنصورة
كلية الهندسة
قسم هندسة الإنتاج والتصميم الميكانيكي

تقييم درجة خشونة السطح
باستخدام الرؤية بالحاسب

رسالة مقدمة من

الأمير سامي جاد المولى يوسف
مدرس مساعد بقسم هندسة الإنتاج والتصميم الميكانيكي
كلية الهندسة - جامعة المنصورة

كجزء من المتطلبات للحصول على درجة **الدكتوراه** في
هندسة الإنتاج

الإشراف

أ.د. منير محمد فريد قورة
أستاذ بقسم التصميم وهندسة الإنتاج
كلية الهندسة - جامعة عين شمس

أ.د. طلال محمد عبد المقصود
أستاذ بقسم التصميم والتكنولوجيا المتقدمة
كلية الهندسة - جامعة جلامورجان
المملكة المتحدة (UK)

أ.د. إبراهيم محمد عليوة
أستاذ بقسم هندسة الإنتاج والتصميم الميكانيكي
كلية الهندسة - جامعة المنصورة

د. حسن حسين سليمان
مدرس بقسم هندسة الإلكترونات والاتصالات
كلية الهندسة - جامعة المنصورة

١٩٩٩

Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department

Assessment of Surface Texture Using Computer Vision Techniques

A Thesis submitted to

The University of Mansoura

For the Degree of

Doctor of Philosophy

By

El-Amir Samy Gad-Elmawla

Assistant Lecture in the Production Engineering and Mechanical Design Department

Supervisors

Prof. M. M. Koura

Ain Shams University
Faculty of Engineering
Design and Production Engineering Department
Egypt

Dr. T. M. A. Maksoud

University of Glamorgan
School of Design and Advanced Technology
United Kingdom

Prof. I. M. Elewa

Mansoura University
Faculty of Engineering
Production Engineering and Mechanical Design Department
Egypt

Dr. H. H. Soliman

Mansoura University
Faculty of Engineering
Electronics & Communication Engineering Department
Egypt

1999