UNIVERSITI PUTRA MALAYSIA

SURFACE DEFECT DETECTION AND POLISHING PARAMETER OPTIMIZATION USING IMAGE PROCESSING FOR G3141 COLD ROLLED STEEL

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By

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Traditionally the surface quality inspection especially for metal polishing purpose is perform by human inspectors. Defect detection is a method of nondestructive testing of material and products to detect defects. This study consists of two parts where the first part is applying vision system to detect and measure surface defects that have been characterized to some level of surface roughness. Specimen of G3141 cold rolled steel is used in this research as it represent the actual material applied in local automotive manufacturer. Gray image of scratch defect on metal surface is detected and information about mean gray pixel value (Ga) is interpreted and converted to surface roughness (Ra) measurement. In this study a new technique is developed where the Ga only read on the specific scratch line without considering the whole image. To realize this, automatic cropping algorithm is developed to detect the region of interest and interpret the Ga value. This techniques will enables the polishing to be done at specific scratch defect area without necessary to develop polishing path throughout the whole surface which is time consuming. Second part is to obtain the optimum polishing parameter by using artificial intelligence technique which is able to predict the grit size, polishing time and polishing force parameter to remove the scratch by polishing process. For the purpose of this study, multiple ANFIS or MANFIS have been selected to predict optimum parameter for polishing parameters. Polishing parameter data can be generated by using MANFIS to predict optimum polishing parameters such as grit size, polishing time and polishing force in order to perform polishing process. However due to lack of study done in the field of flat and dry polishing, the polishing parameter data have to be developed. The polishing parameter data for flat and dry polishing is performed by using robotic polishing arm and the experiment runs design by using full factorial design. Results show that the defect detection algorithm able to detect defect only on the scratch area and able to read the Ga value at detected scratch line and transform it to surface roughness measurement at considerably good level of accuracy compared with manual method. Results from MANFIS have shown that the system is able to predict up to 95% accuracy which is considerably high. The overall results from both parts of this research would inspire further advancements to achieve robust machine vision based surface measurement systems for industrial robotic processes specifically in polishing process.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia untuk memenuhi keperluan untuk ijazah Doktor Falsafah

PENGESANAN KECACATAN PERMUKAAN DAN PENGOPTIMUMAN PARAMETER PENGGILAPAN MENGGUNAKAN PEMPROSESAN IMEJ BAGI G3141 KELULI TERGELEK SEJUK

Oleh

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Secara tradisinya, pemeriksaan kualiti permukaan untuk tujuan penggilapan permukaan logam dilakukan secara insani oleh manusia. Pengesanan kecacatan adalah merupakan suatu kaedah ujian tanpa musnah bagi mengesan kecacatan pada permukaan. Kajian ini terdiri dari dua bahagian iaitu bahagian pertama adalah penggunaan sistem penderia penglihatan untuk mengesan dan mengukur tahap kecacatan permukaan yang telah dikategorikan kepada tahap kekasaran permukaan yang tertentu. Spesimen G3141 keluli tergelek sejuk digunakan dalam kajian ini kerana ia mewakili bahan sebenar digunakan dalam pengeluar automotif tempatan. Maklumat mengenai nilai purata piksel keabuan (Ga) kecacatan kecalaran ke atas permukan logam yang dikesan akan diintepretasikan dan ditukarkan ke bentuk ukuran kekasaran permukaan (Ra). Di dalam kajian ini juga satu teknik baru telah dibangunkan di mana nilai Ga hanya akan dibaca terhadap kecacatan kecalaran berkenaan sahaja tanpa perlu mengambilkira keseluruhan imej. Bagi merealisasikan tujuan ini, pengaturcaraan pemotongan secara automatik telah dibangunkan untuk mengesan kawasan kepentingan dan mengintepretasikan nilai Ga. Teknik ini juga membolehkan process penggilapan dijalankan terus kepada tempat yang mempunyai kecacatan tanpa perlu membangungkan laluan penggilapan ke seluruh permukaan logam yang nyata mengambil masa yang lama. Bahagian kedua kajian ini adalah untuk mendapatkan parameter penggilapan optimum dengan menggunakan teknik kecerdikan buatan yang berkebolehan untuk meramal parameter seperti saiz grit kertas pasir, masa serta daya tekanan penggilapan bagi menghilangkan kecalaran menggunakan proses penggilapan. Bagi tujuan pengkajian ini, ANFIS berbilang atau MANFIS telah dipilih untuk meramal parameter optimum bagi proses penggilapan. Pemilihan data penggilapan boleh dihasilkan menggunakan MANFIS untuk meramal parameter yang optimum seperti saiz grit kertas pasir, masa dan daya tekanan bagi menjalankan proses penpgilapan ini. Walaubagaimanpun disebabkan kekurangan kajian yang dilakukan di bidang penggilapan kering dan rata ini, pemilihan data penggilapan perlulah dibangunkan. Eksperimen telah dijalankan menggunakan robotik industri dan susunan eksperimen adalah menggunakan rekabentuk faktorial penuh melalui rekabentuk eksperimen. Keputusan menunjukkan bahawa pengaturcaraan pengesanan kecacatan mampu untuk mengesan kecacatan kecalaran serta boleh membaca nilai Ga hanya pada kecacatan kecalaran berkenaan dan menukarkan ia kepada ukuran kekasaran permukaan pada ketepatan yang agak tinggi dibandingkan dengan kaedah manual. Hasil

dapatan juga telah menunjukkan bahawa sistem MANFIS berupaya untuk meramal sehingga 95% ketepatan. Keseluruhan keputusan dari kedua-dua bahagian kajian akan menjadi pemangkin ke arah usaha untuk menghasilkan sistem pengukuran berasaskan penglihatan mesin yang baik bagi proses robotik industri terutamanya dalam bidang penggilapan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANFIS	Adaptive Neuro Fuzzy Inference System
MANFIS	Multiple Adaptive Neuro Fuzzy Inference System
Ga	Mean Gray Level Value or Average Gray Level Value
ROI	Region of Interest
ANN	Artificial Neural Network
CMP	Chemical Mechanical Polishing
MCP	Mechano Chemical Polishing
GPS	Geometrical Product Specifications
AMPS	Automatic Mold Polishing System
ASIS	Automatic Surface Inspection System
GLCM	Gray Level Co-Occurrence Matrix
CCD	Cubic Couple Device
SIMO	Single Output Multi-Output
MIMO	Multi-Input Multi-Output
Ra	Surface Roughness
MISO	Multi Input Single Output
DOE	Design of Experiment
ECMP	Electrochemical Mechanical Polishing
DOF	Degree of Freedom

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The developments of manufacturing automation have become an important feature in manufacturing that offers competitive advantage especially for multinational companies. The automated manufacturing system is a process performed by a machine without the direct participation of human beings. Most industries are seeking to improve performance and efficiency, increase productivity, cost reduction and quality improvement to produce higher quality products at lower prices.

Automatic defect detection systems are an element of manufacturing automation comprising a deeply rooted and ubiquitous component of modern automated systems. The purpose of automatic defect detection especially using computer vision is to decide if a particular exemplar object or defect is located somewhere in the image whereas localization provides accurate location information on the object (Andreopoulos and Tsotsos, 2013). Automated defect detection has the advantages of increasing productivity and reducing human wages. Besides that, many researches indicate automatic defect detection to be more reliable, better quality, highly efficient, and with good real time performance compared to manual visual method (Duan et al., 2011).

Automatic defect detection through the application vision system has been practiced in various applications and industries including steel manufacturing industries. Many of the techniques applied rely on the efficient algorithm to process the image according to the desired image. This can be achieved by focusing on specific defects and location at the beginning. According to Pishyar and Emadi (2016), defect of steel sheet metal is divided into three category such as surface, textural and dimensional defect. There have been several works for detecting and classifying steel surface defects. Xu et al. (2015) used Shearlet transform to classify surface defect on metal surface by decomposed the image captured into several sub-band. Sarma et al. (2013) presented wavelet transform in metal defect detection with artificial neural network classifier. Based on the surface image features, Babu (2010) applied parameter called Ga (Mean Gray Level Value) that is used to estimate the surface roughness, Ra. According to Ghorai et al. (2013), defect detection techniques have been applied in steel industries to detect defects on metal surfaces. Such techniques applied radiant light, edge-preserving filter, thresholding technique, un-decimated wavelet transform, and mathematical morphology. There are many types of metal defect which are also known as surface imperfection according to ISO 8485:1998 Geometrical Product Specifications (GPS) – Surface imperfection – Terms, Definition and Parameters. However, indicators of metal surface defects which lie on surface roughness is still unavailable. Thus, for surface defect detection, this research is focused on the determination of defect location and surface roughness value of the straight line defect with respect to the Ga measurement. Processing of pixel and other information extraction will only focus on region of interest (ROI) which is the defect. This technique is much simpler without unnecessary complex algorithms and programming. Moreover, it can be done on an authentic image and help prevent losing pixel information. Secondary processes such as polishing are needed to remove this flaw and cast the final touch on the surface.

Polishing is a secondary process performed to remove or repair defects or imperfections and cast final appearance on products. Traditionally it is done manually by an experienced expert. However due to dirt, noise, and the tediousness of the job, the polishing process is nowadays mostly automated. Automated polishing process can be done by industrial robotic arm (Brogårdh, 2007). The robotic arm can both hold the workpiece and perform dry polishing on the polishing tool or vice versa. Some researchers have discussed the development of robotic polishing, including the use of various types of sensors to detect the surface condition (Basanez and Rosell, 2005), control systems for industrial robot in polishing movement (Liao et al., 2008), and path planning in optimizing the time required to perform the polishing process (Li et al., 2010). However, variations in terms of standard and inconsistent perceptions have led to improper definitions of final appearance which rely mostly on each expert's intuition. Hence, it is important to apply correct parameter setting to obtained desired appearance. El Khalick Mohammad et al. (2016) proposed end effector for robotic-based surface Electrochemical Mechanical Polishing (ECMP) process. In this research, polishing force, tool feed rate, rotational speed, current and electrolyte flow rate are taken as the parameters to obtained optimum polishing parameter. However the study does not discussed the optimum polishing parameter obtained. Raju and Pradesh (2015) in their work on design and simulation of die casting mold using robot path applied tool path, feed rate, rotation of speed, number of passes and deformation of tool as their polishing parameters. For flat and dry polishing in this research, polishing parameters are developed based on DOE and applied for prediction and optimization which involved artificial intelligent.

Artificial intelligence has played an important role especially in manufacturing systems. It has been successfully applied in prediction and optimization of process parameters especially in machining of materials. Unlike machining with an abundance of machinability data, there is limited information on the parameters of polishing and such information is normally developed according to the individual needs of industries or organizations. The most common artificial intelligence used in prediction and optimization are expert system (Iqbal et al., 2007), genetic algorithm (Kant and Sangwan, 2015), fuzzy inference system (Tseng and Konada, 2015), artificial neural network, and adaptive neuro fuzzy inference system (ANFIS) (Razak et al., 2010). However new techniques have revealed that prediction and optimization can also be done by using a multiple adaptive neuro fuzzy inference system (MANFIS) which is the modification of ANFIS (Rolim and Schubert, 2012; Suhail et al., 2011). The advantages of MANFIS rely on both advantages of artificial neural network (ANN) and fuzzy logic. ANN has better learning ability such as parallel processing, ability to adaptation, fault tolerance, and distributed knowledge representation, whereas fuzzy logic strategy can deal with reasoning at higher levels.

According to Japanese Industrial Standard (JIS G3141 : 2011) G3141 cold roll sheet steel is specified as best suited for cars manufacturing and electrical appliances due to broader ranges from commercial to deep drawing qualities. The letter 'G' referred to ferrous material and metallurgy. Available with three standards such as SPCC, SPCD and SPCE. SPCC standard which is used by the industry and donated as specimen in this research consist of material composition such as Carbon (C): 0.15%; Manganese (Mn): 0.60%; Phosphorous (P): 0.05%; Sulphur (S): 0.05% and Iron (Fe): 0.15% with negligible impurities.

With the specimen thickness of 0.65 mm, mechanical properties are such as the minimum yield point is 145 N/mm^2, minimum tensile strength is 270 N/mm^2 (MPa) and the elongation of 38%. G3141 cold roll sheet steel is often used as automobiles parts such as front fender and outer side panel. From the visit to one of the automotive manufacturer Shah Alam, the stamping parts are subjected to defect such as scratch and other kind of defects. Polishing process is recently performed manually which is significant and important to remove the defect before it is assemble and paint. The reason is that the defect will clearly appear after painting and to do rework after painting is difficult and expensive compared to loose part before assembly.

1.2 Problem Statement

Numerous techniques exist for surface roughness measurement in polishing. In defect detection, it is preferable to detect the defect and then read the Ga value from the particular defect which is similar in measuring Ra using stylus techniques. Kumar *et al*. (2005) proposed reading the pixel measurement from the image to determine the Ga value and predict the surface roughness of machined metallic surface. Different form defect detection, when the Ga is obtained from the particular defect this will enable the Ga measurement to be more precise rather than taking from the whole image as in machining. Thus for the case involved surface defect, a new algorithm which can detect the location of defect and gather Ga data from the defect is needed to obtain more accurate surface roughness of the defect especially on fine surfaces. The advantage of using gray image processing technique is its reflection of the true image pixels and conserving the original characteristics of the image.

Flat and dry polishing is normally carried out in a factory to overcome surface imperfections or defects before it is transferred to other sections and does not require a mirror finish. Such imperfections cannot be avoided due to dusty environments, machine operations, and handling and transportation of materials. Studies relating to polishing parameter data for this type of polishing have been relatively scanty and there is no study focusing on dry polishing. The study by Torniie et al. (2015) is on the effect of pad surface temperature under dry and wet conditions. However it is related to CMP process. The two types of polishing process that commonly practiced are chemical mechanical polishing (CMP) and mechano chemical polishing (MCP). They mostly focus on glass polishing for optic purposes and wafer industries. There are a number of research studies on CMP (Zantye and Kumar, 2004) and MCP (Chen and Shu, 2003). These kinds of polishing have the same purpose, which is to obtain a mirror finish although carried out on different materials. Realizing the gap in the literature, more research is needed in developing polishing data for dry polishing to enable the polishing data to be automatically predicted using artificial intelligence.

Parameter prediction using artificial intelligence has been widely explored. It is common to come across multi-input single-output (MISO) system for prediction. Furthermore, the data obtained is complete and from known sources. However, it is difficult to perform predictions when the data is incomplete and the subject comes from unknown sources. For example, for defects without complete information and unknown sources, and the only way to obtain the data is by digging the information on the surface or the defect itself. Suhail et al. (2011) have applied MANFIS for machinability data selection for turning operation. Different area of research such as face recognition, smart homes, medical, hydrology, vibration and traffic control have also applied MANFIS with successful result. However every MANFIS structure proposed is different from each one. MANFIS has the ability to perform single-input and multi-output system and multi-input multi-output system. Thus, with different MANFIS structure proposed for this research, there is a need to investigate MANFIS' capability to perform predictions under insufficient parameter data for dry polishing where the output is judged without any specific standards.

1.3 Objective of the Study

The objectives of this research are:

1. To develop a surface defect detection model using mean gray level value (Ga) of images for G3141 Cold Rolled Steel.
2. To identify significant polishing parameters using multiple adaptive neuro fuzzy inference system (MANFIS) using design of experiment for G3141 Cold Rolled Steel.
3. To develop MANFIS structure for polishing parameter optimization of G3141 Cold Rolled Steel.

1.4 Scope of the Study

This research focuses on straight lines defect of G3141 cold rolled sheet steel (SPCC Standard). Surface roughness (Ra) is an important element in this research because it is obtained by using the linear regression model and Ga from the image. The scope of this research is detection of straight line defect or scratch on G3141 cold roll sheet steel and Ra obtained from the surface detection model will be applied for parameter prediction performed by MANFIS. The thickness of the specimen is 0.65mm which focus on flat surface with dry polishing process which is similarly performed at automotive manufacturer in Shah Alam. Experiment of polishing process is performed using Comau 6 DOF industrial robot and programme is written by using teach pendant. This work presents a new prediction approach to the polishing process using design of experiment to obtain polishing data such as grit size, polishing time and polishing force.

1.5 Research Methodology

Based on research flow in Figure 1.1, the research is divided into 3 phases such as early research phase, research and experimental development phase and final phase. Early research phase is where the fundamental of research begins. In research and experimental development phase the specimen is prepared and the scratch is measured in terms of surface roughness (Ra) with stylus equipment and then the specimen image is captured. At the same time, algorithm for surface defect detection is also developed. For surface defect detection, image processing algorithm is developed to detect the scratch and classify the image using Ga where with the model created the surface roughness is able to be identified. Therefore the surface roughness data should be more or less the same with the stylus ones.

In order to develop the polishing parameter data, the experiment is performed by using full factorial. This is done in polishing parameter development. After the full factorial design is determined, setup is done on Comau robot to performed polishing process experiment based on selected parameter such as grit size, polishing time and polishing force. This is the stage where the polishing parameter data for flat and dry surface for G3141 cold rolled steel is develop. At the same time MANFIS structure is developed by using MATLAB Simulink tools and the polishing parameter data obtained from the experiment is trained by using ANFIS. By using MANFIS, the polishing data were predicted.

In the final phase, result and data are analyzed and discussed to determine whether the objectives of the research are achieved. Conclusion and recommendations are drawn to enables the continuation of the research. The research concluded in the final phase.

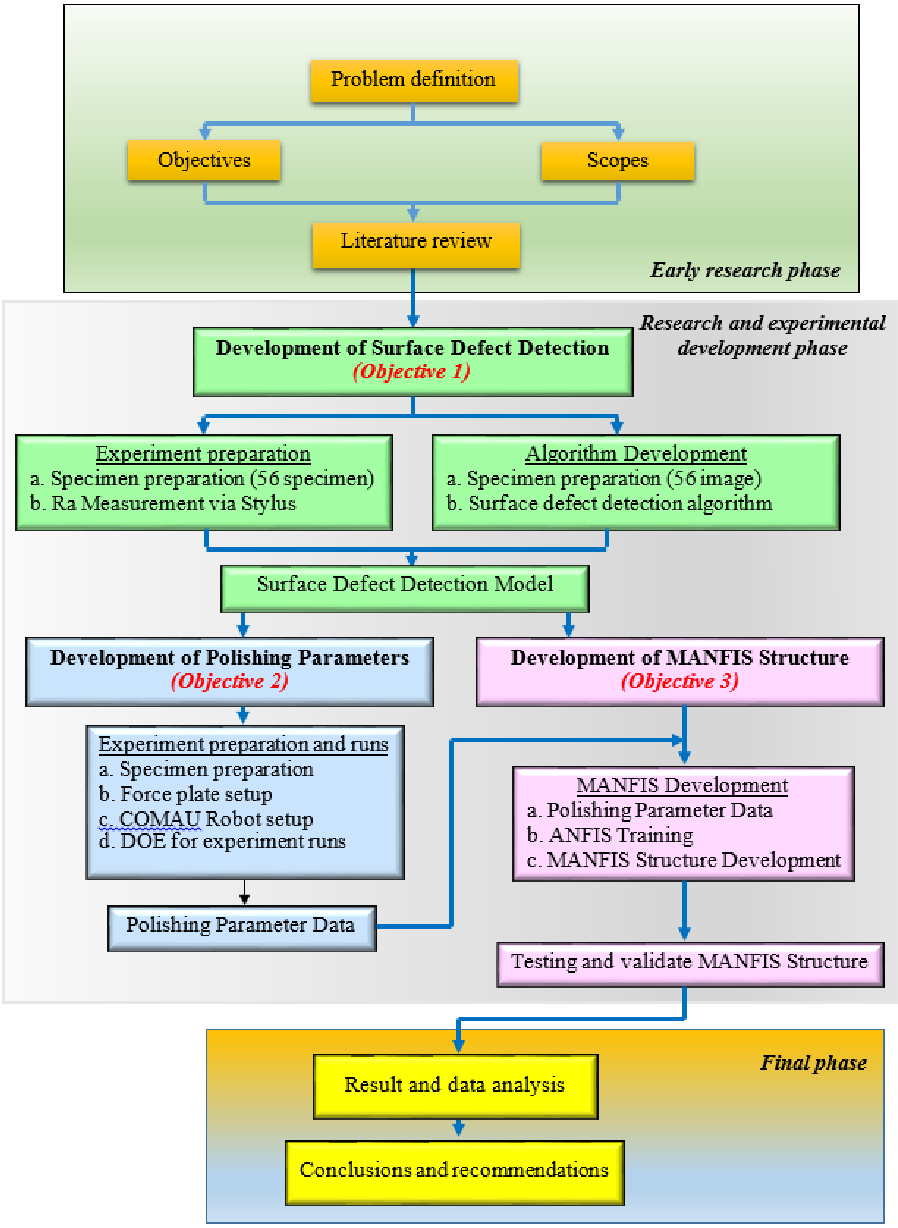

Figure 1.1: Research Methodology Flowchart

1.6 Thesis Outline

This thesis is divided into six chapters. Chapter 1 consists of the background of the research, problem statement, research objectives, and the scope of work. In Chapter 2, the literature review elaborates on surface defect detection and parameter optimization.

It explains the importance of Ga and Ra. The method and strategy used will be discussed in every chapter which include experimental materials and setup details. Chapter 3 discusses the development of the surface defect detection roughness model and the new technique to capture the structure and shape of straight line defects. The model will be tested to determine its accuracy compared to expected measurements. Chapter 4 discusses parameter influence in polishing and interaction and will include the surface roughness model obtained from design of experiment. Chapter 5 includes the advantages and disadvantages of MANFIS, which are trained and tested by the data obtained from the design of experiment method in Chapter 4. Chapter 6 discusses the contribution and conclusion of the research in reference to the research objectives. Suggestions for further research are then offered. Figure 1.2 shows the research flow.

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