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DESIGN AND DEVELOPMENT OF INTELLIGENT 3D MODEL RECOGNITION AND INSPECTION SYSTEM IN DIE STAMPING INDUSTRY

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Abstract

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(Keywords: 3D Model Recognition, Automated Visual Inspection, Die Stamping Industry)

Discussion on development of the vision system which focused on 3D model recognition and inspection is centered in this research. This research embarks on two main issues that pose as main problems that need to be resolved. The first issue is based on the fact that many industries produce different type of product in the same production line. To overcome this problem, cost-effective appearance-based method is proposed to replace traditional method which based on model of object. This method is based on neural network that characterize each type of stamped part by using image moments.

The second issue is based on the fact that many existing defect inspection algorithms are not feasible for Small and Medium Industries (SMIs) due to complexity of techniques and equipments. To overcome this problem, a new defect inspection algorithm for stamped part is developed and tested. The method is based on Canny edge detector to extract the surface defects based on optimal thresholding value. The data used for the experiments are five stamped parts which are collected using CCD camera. In 3D recognition results, it is observed that the first three image moments were able to increase neural network accuracy more than 95%. This results shows that the appearance-based method is very promising for 3D recognition purpose in automated visual inspection. On the other hand, the inspection results show that pose of stamped parts is significantly reduced the algorithm performance. For each pose, only partial surface defects that is able to be detected. This shows that the specular reflectance that responsible for the shiny surface of stamped parts should be consider in future research.

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CHAPTER 1

INTRODUCTION

1.1 Background to Study

Human inspectors are capable of observing manufacturing product or part and reaching an effective decision as to whether it is good or bad based on the quality standard. In traditional manufacturing process, they are commonly used to perform quality inspection job. Usually, after the production process, several samples of manufacturing part are taken into the quality control room to be inspected. The product that exhibits a defect should be dissociated while an acceptable product continuously down the manufacturing process.

In fact, this manual inspection has two main drawbacks. First, inspectors may get sick, bored and tired especially when doing the same job all the time. Khan et. al. (2005) posits that human inspector's observation is inconsistent among operators. Consequently, the defective product may pass the quality control process and reach the customer. This situation may lead to customer dissatisfaction which finally influences the whole production demand and supply chain. Indeed, the use of human inspectors is obviously inefficient. On the contrary, industries with well management

are able to solve the problem by applying total quality management system which guarantees correct production process to minimize the defect probability as low as possible. The concept of automation has been greatly dominance in large industries including the visual inspection process. The purpose of automation is to improve the efficiency of manufacturing operation by reducing human involvement.

In quality control process, the manual inspection has been replaced by Automated Inspection System (AVI) which integrates the vision sensor, computer and auto rejecting mechanism. The human vision is substituted by vision sensor, human expertise coded in computer program and the removal of defective product is performed by automatic mechanical controller. The AVI is more flexible than manual inspection and able to respond the quick product design changes. In this way, the manufacturing processes are automated and thus increase productivity and product quality. Nowadays, the use of AVI system is pervasive and become basic tool in quality assurance.

Despite the advantage of AVI system, the knowledge of vision system development is not well established and still leaves many issues that need to be resolved. Each application domain has different nature of problem which is unique and requires special treatment. To respect these problems, let us take a look back of some historical development in AVI. The first machine vision issue for industrial inspection was started in 1970. In the middle of 1980 there was only little progress shown in automobile manufacturers. During that time, from 1970 up to 1990, defective product rates in modern manufacturing have been decreased from 0.1% to 0.001% (Pham and Alcock, 2003).

However, after 1990 the academic papers that proposed AVI system for industrial processes were increase significantly. Two years later, Modayur and Shapiro (1992) posits that the AVI system had been used widely in industries such as textile, automobile, electronics, aerospace, food and so on. Besides these applications, the Automatic Visual Inspection (AVI) is also used for grading, sorting, counting, monitoring, and controlling the manufacturing processes. The results show that machine vision is able to perform inspection job more precisely and accurately in comparison to manual inspection. Unfortunately, the development process that translates existing principles into real AVI system is complex and often requires high end hardware resources. Many existing AVI systems were developed based on high-end equipment and software system and only suitable for large enterprises. Consequently, the SMIs have great difficulties to adopt the AVI system in their manufacturing processes.

In fact, the SMIs play one of the most significant roles in Malaysia. Recently, Ministry of International Trade and Industry (MITI) posits that the manufacturing SMIs in Malaysia contributed 30% to Gross Domestic Product (GDP) in 2008, MITI (2010). Back in the 2003, 34.9 percent of output from the manufacturing sector was contributed by the SMIs (Leete, 2007). The author reviewed that the largest number of SMIs in the manufacturing sector is found in textile and apparel (23.2 per cent), metal and non-metallic mineral products (16.7 per cent).

Unfortunately, most of the local SMIs had not installed an internal Information Technology (IT) infrastructure. As explained in (Leete, 2007), Small and Medium Industry Association of Malaysia reported that the purchase of IT system could cost

between RM10,000 to RM30,000 – beyond the budget of many SMIs. Therefore, the automated Visual Inspection System must be lower than RM 10,000 to be accepted by the SMIs. Taking this situation into account, this study is intended to study the feasibility of AVI system to improve SMIs quality control process in Malaysia. The focus of the study is to find feasible solution for AVI system development that is relevant for the SMIs budget.

1.2 Problem Statement

As described earlier, the inspectors are tending to create mistakes like being inconsistent, imprecise and inaccurate. Different individuals tend to report different results for the same object thus creating inconsistency in quality control process. In worse cases, the inspectors read and record wrong values during the inspection job that leading to inaccuracies. These difficulties are occurring because the human inspectors performance influenced by factors such as age, physical health, attitude, habits, and emotions. Therefore, it is highly preferable to replace the manual inspection with AVI system to avoid limitation of manual inspection.

Moreover, AVI system can be used for metrology, object recognition, surface defect detection and assembly verification and. However, in this study we are interested in two main issues which are the automatic object recognition problem and surface defect detection problem.

The first issue is related to problems of recognition of 3D model of product or part. As the market can rapidly changes therefore SMIs is required to respond this as quickly as possible. In the real industrial environments especially for flexible manufacturing, a production line can produce different type of product according to the management requirements and market change. This case increases the needs for a machine vision system to recognize different part or product. Consequently, the object recognition becomes one of most important problem in AVI system. According to computer vision literature, there are mainly two methods to do this, model-based method and view-based method.

Currently, most of 3D model recognition techniques are heavily based on Computer Aided Design (CAD) model that stored the full 3D information in a single file. However, this method requires high computer speed and large memory. Commonly, multi sensor system and laser scanner are most popular. Indeed, the SMIs have significant limitation due to this hardware requirement as mention before. A new kind of method is very demanded to enable the SMIs to adopt low-cost AVI system for their quality inspection.

In this study, we avoid the use of CAD model due to limitation in SMIs. Therefore, a different kind of family method in model recognition is proposed to replace the model-based methods. This method is known as view-based method which able to recognize 3D shape of part or product based on 2D image only. In this method, AVI system is only need one image sensor (camera), lighting system and a standard desktop computer. This method does not require CAD model that is stored in database and complicated computer program such as image matching, verification and 3D

reconstruction, as to name a few. In contrast to model-based method, view-based method relies on features extracted from the image.

The second issue is related to the inspection of surface defects. Any defect in surface might reduce the value of product in terms of visual appearance or even performance. For instant, surface defect such as dents and scratch in car body panel will cause customer dissatisfaction. Moreover, there are several parts require high precision dimensional tolerance especially if there should be mating with other component. However, this study is intended on surface defect problems. Similarly to object recognition, there are many available special tools such as such as laser scanning and stereo vision for surface inspection in manufacturing environment. However, the limitation in SMIs require cost-effective solution which reasonably for surface inspection. Consequently, the AVI system is required to be developed with the minimum hardware requirement but able to produce reasonable performance for the quality inspection purpose.

From the illustration above, the two major problems associated with the automation of SMIs have been identified as follows.

1) Automated visual inspection system needs view-based 3D model recognition method.
2) Automated visual inspection system needs cost-effective surface defect detection method.

1.3 Research Question

Two research questions generated based on problem described above are as follows:

a) Is there any view-based solution in 3D model recognition problems for SMIs?

b) Is there any cost-effective inspection algorithms to detect surface defect for SMIs?

1.4 Objectives of Study

The overall objective of this research is to design and to develop automated visual inspection prototype for SMIs application. The study is focused on the 3D model recognition and automated surface defect detection problems.

The specific objectives in this study are described in the following sentences.

1) To incorporate model recognition method in AVI system for SMIs.
2) To develop an inspection algorithm that is suitable for SMIs.

1.5 Scope of Study

The following are the limitations and assumptions of the research that has been made:

1. The analysis is focused on view-based method for model recognition
2. The focus of domain study is on quality inspection process in sheet metal stamping.
3. The specular reflectance has not been considered due to complexity of computational effort and equipments because of the SMIs limitation.

1.6 General Methodology

First of all, state of the art of Automated Visual Inspection (AVI) System in the literature is reviewed to find the potential solutions to fulfill the objectives of this research. Secondly, the AVI system is designed and developed. Then, object recognition and inspection algorithms are designed. The 3D recognition algorithm consists of three main stages: segmentation, feature extraction and classification which are described as follows.

1. The captured image is segmented using optimal threshold
2. The segmented object of interest is used to compute features vector to characterize the 3D objects.
3. Neural network is used to classified the actual object type

For inspection algorithm, there are basically two main steps: color converter and edge detection based on optimal threshold which are described in the following sentences.

1. The captured image is converted from RGB (red, green, blue) color channel into grayscale channel.
2. The Canny edge detector is used to detect any surface defect.

These algorithms are developed under MATLAB programming language.

1.7 Contribution

The main contributions of this research are:

- The integration and testing of appearance-based object recognition method in AVI system for die stamping industries.
- An automated surface defect detection method based on Canny edge detection for die stamping industries.
- Papers published related to this research according to 3D model recognition and AVI system are:
    1. Habibullah A., Nanna S., Shahrin S., Training neural networks using clonal selection algorithm and particle swarm optimization: A comparisons for 3D object recognition, Proc. the *IEEE* 11th International Conference on Hybrid Intelligent Systems (HIS), pp. 692-697, Melaka, Malaysia, 2011.
    2. Habibullah A., Nanna S., Shahrin S., Multilevel Thresholding Method Based on Aggressive Particle Swarm Optimization, Proc. the *Springer-Verlag* 2nd International Conference on Software Engineering and Computer Systems, Part I, 179, pp. 747–757, Pahang, Malaysia, 2011.
    3. Fikri A., Habibullah A., Nanna S., and Muhammad H., 3D Fabric Feature Extraction and Defect Classification Using Low-Cost USB Camera, Proc. *SPIE*, International Conference on Graphic and Image Processing (ICGIP), Manila, Philippines, 2010.
    4. Habibullah A., Defect Inspection Algorithm in Intelligent Real Time Vision System for Small and Medium Industries, *MSc Thesis*, Universiti Teknikal Malaysia Melaka, 2010

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11. Zulkifli T., Anton S. P., M.A. Burhanuddin, Habibullah A., Maintenance Decision Support Fuzzy System in Small and Medium Industries Using

Decision Making Grid, Proceeding of the *IEEE* International Conference on Advanced Computer Theory and Engineering, pp. 680-684, 2008.

12. Zulkifli T., Prabuwono, A.S., M.A. Burhanuddin, Habibullah A., A Review of Optimization Models and Techniques for Maintenance Decision Support Systems in Small and Medium Industries, Proc. the 1st Makassar International Conference on Electrical Engineering and Informatics, pp. 153-158, Makassar, Indonesia, 2008.
13. Habibullah A. and Anton S. P., The design and development of automated visual inspection system for press part sorting, Proceeding of the *IEEE* International Conference on Computer Science and Information Technology, pp. 683-686, 2008.

- Awards that is obtained related to this research are:
  1. Bronze Medal in Invention, Innovation and Technology Exhibition (ITEX) with Product "Improvement of Product Quality Inspection using User Friendly and Low Cost Machine Vision System", KLCC, Kuala Lumpur, Malaysia, 2009.
  2. Bronze Medal in Invention, Innovation and Technology Exhibition (ITEX) with Product "Embedded Vision Technology for Smart Scale System", KLCC, Kuala Lumpur Malaysia, 2009.
  3. Bronze Medal in Malaysia Technology Expo (MTE) with product "Web Based Maintenance Decision Support System for Small and Medium Industries", Putra World Trade Centre (PWTC), Kuala Lumpur, Malaysia, 2009.

4. Bronze Medal in Malaysia Technology Expo (MTE) with product "Automatic Wudhu Machine Based on Vision", PWTC, Kuala Lumpur, Malaysia, 2009.

1.8 Structure of Project Report

This Report is structured in 7 chapters. The focus on this study is the development of AVI system that is suitable for SMIs environment. A case study of stamped parts are developed and tested to evaluate the proposed methodology.

Chapter two

This chapter briefly reviews some previous work in automated visual inspection methodology. Firstly, the existing image acquisition device used and proposed in literature is reviewed. Secondly, the techniques and method proposed by others for object recognition and automated surface defect detection problems are given.

Chapter three

This chapter presents the design and development methodology of the proposed automated visual inspection system.

Chapter four

This chapter presents the 3D model recognition and inspection algorithms. The view-based method which is based on segmentation, feature extraction and neural network

are described in detail. Then, the inspection algorithm which is mainly based on Canny edge detection is given.

Chapter five

This chapter discussed the experimental results of the proposed algorithms. The stages in each algorithm is analyzed and discussed carefully. Strength and limitation of proposed algorithms is also given.

Chapter six

Finally, this chapter concludes the research study in 3D model recognition and inspection for stamped parts. Some future direction is given to suggest where this research can continue. One of the most important suggestions is the incorporation of 3D object reconstruction for AVI. This will also enables AVI system to cover other inspection tasks such as metrology and assembly verification.

1.9 Summary

The SMIs play one of the most significant roles in Malaysia. However, they face great difficulties to automate their manufacturing process due to financial budget. Especially, the quality inspection process is still mainly based on manual inspection. The major problem in using human for inspection is obviously leads to undetected defective item. Inspector has high degree of inconsistency, inaccuracy and inefficiency in comparison with AVI.

The SMIs needs to adopt AVI system to improve their quality inspection process. Unfortunately, the existing AVI system is not feasible according the SMIs limitation. Therefore, the development of AVI should rely on cost-effective solution to reduce the development process and cost.

This study has been trying to close this gap to enable SMIs in using the AVI for their quality control process. The AVI development process is required to be developed with minimum hardware as possible. The following chapter continues with a discussion on the literature of automated visual inspection system including object recognition and automated surface defect detection.

CHAPTER 2

AUTOMATED VISUAL INSPECTION SYSTEM

2.1 Introduction

This chapter describes the review of the state of the art according to the two issues described in Chapter 1. Firstly, the review according to AVI progress is given. Then, the feasibility of object recognition methods for AVI system is presented. Finally, the review of automated surface defect detection method in die stamping industries is given.

2.2 Automated Visual Inspection Application

The automated visual inspection to increase product quality has been addressed since four decades ago. The basic components of AVI structure contains only three components which are camera, monitor and control/process consol. The data is analyzed using microcomputer which has very limited image processing capability and the output is simply good or bad depending on the status of the inspected product. Typically, the development of AVI algorithms is intended for automated defect detection purpose Shirvaikar (2006).

Several survey papers have been published regarding to progress in AVI development. The first comprehensive survey was presented by Chin and Harlow (1982) with 288 references. The survey is more focus on electronics industries with short review in metal-based industries. This review continued by Chin (1988) with more than 600 references. Recently, (Thomas et al., 1995) review most widely used AVI algorithm that is suited for real-time application. On the other hand, (Malamas et. al., 2003) surveys the tools of modern software and hardware in developing industrial vision system. As shown in Figure 2.1 (Malamas et. al., 2003), the typical AVI system is becoming more complex in comparison to its original development. Modern AVI system has additional components such as network interface, manufacturing control system, robots and image processing hardware.

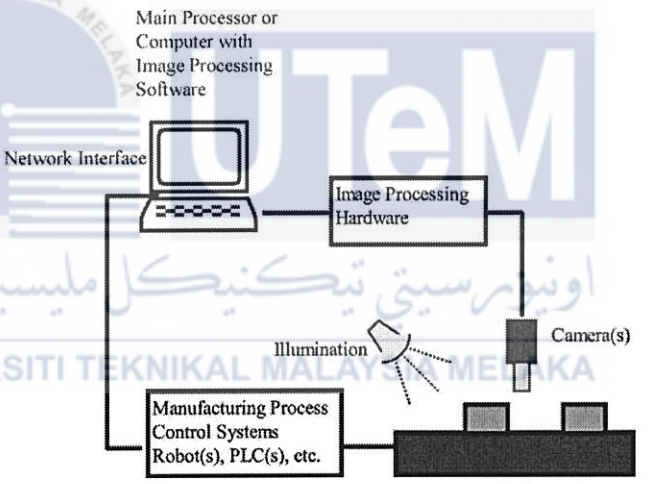

Figure 2.1 Typical Industrial Vision System

The authors elucidate that the potential product features to be inspected include the dimensional, structural, surface and operational quality. In the paper, there are 39 different application fields that have been addressed as user of the industrial vision system.