UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

SQUARE GROOVE DETECTION BASED ON FÖRSTNER WITH CANNY EDGE OPERATOR USING LASER VISION SENSOR

Osamah Abdullah Ahmed Mohammed Naji

Master of Science in Mechatronic Engineering

2023

SQUARE GROOVE DETECTION BASED ON FÖRSTNER WITH CANNY EDGE OPERATOR USING LASER VISION SENSOR

OSAMAH ABDULLAH AHMED MOHAMMED NAJI

A thesis submitted
in fulfillment of the requirements for the Master of Science in Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this thesis entitled "Square Groove Detection based on Förstner with Canny Edge Operator using Laser Vision Sensor" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Osamah Abdullah Ahmed Mohammed Naji

Date : ....26.02.2023...................................

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronic Engineering.

Signature : ....

Supervisor Name : Dr. Hairol Nizam bin Mohd Shah

Date : ......26.02.2023..........................

DEDICATION

To my beloved father and mother

Thank you for your encouragement and support throughout the entire duration of the study.

To my supervisor and co-supervisor

Thank you for your guidance, support, advices and valuable information.

ABSTRACT

Weld seam recognition is critical for providing information for automated welding control, promoting the advancement of welding sensing technology, and improving welding manufacturing automation. The obtained location information of the weld joint is used in the welding industry to direct the welding torch along the best welding direction, allowing the width and depth variations of the weld joint to be compensated during welding. This research addresses the feature extraction algorithm of the square weld groove to make weld seam recognition more accurate. The acquisition of the weld image is a complicated process, resulting in a large amount of noise. Specific methods must be used to process images. The objectives of this research are to develop a detection algorithm that can extract the feature points of the square-groove; and the second objective is to evaluate the detection algorithm and its ability to extract the image features of the square-groove in terms of the accuracy. In this work, the central line of the laser stripe is extracted based on Canny edge detection with Haralicks facet model. Based on the central line, the Förstner algorithm is used to recognize the corner points of the square weld groove. Following the establishment of a test platform, a series of detection tests for various sizes of the square groove is established. The Förstner algorithm was compared against the Harris algorithm to evaluate which one was more accurate in extracting the square groove's features points. The obtained result showed that the Förstner algorithm's maximum thickness and width measurement errors are 3.193% and 4.00%, respectively. Therefore, the acquired detection results are sufficiently accurate, demonstrating the rationale of the suggested visual sensor's physical design and the validity of the proposed detection algorithms.

PENGESANAN ALUR DUA SEGI BERDASARKAN FÖRSTNER BERSAMA PENGENDALI PINGGIR CANNY DENGAN MENGGUNAKAN PENDERIA PENGLIHATAN LASER

ABSTRAK

Pengecaman jahitan kimpalan adalah penting untuk menyediakan maklumat kepada kawalan kimpalan automatik, mempromosikan kemajuan teknologi penderiaan kimpalan, dan meningkatkan automasi pembuatan kimpalan. Maklumat lokasi sambungan kimpalan yang diperolehi digunakan dalam industri kimpalan untuk mengarahkan obor kimpalan bagi mendapatkan kimpalan yang terbaik sepanjang arah, membolehkan variasi lebar dan kedalaman sambungan kimpalan mempunyai ruang semasa mengimpal. Penyelidikan ini menekankan algoritma pengekstrakan ciri alur kimpalan segi empat sama untuk menjadikan pengecaman jahitan kimpalan lebih tepat. Pemerolehan imej kimpalan adalah proses yang rumit yang menghasilkan bunyi yang kuat. Kaedah khusus akan digunakan untuk memproses imej. Objektif penyelidikan ini adalah untuk membangunkan algoritma pengesanan yang boleh mengekstrak titik ciri alur dua segi; objektif kedua pula adalah untuk menilai algoritma pengesanan dan keupayaannya untuk mengekstrak ketepatan ciri imej alur dua segi. Dalam kerja ini, garis tengah jalur laser diekstrak berdasarkan pengesanan tepi Canny dengan model facet Haralicks. Berdasarkan garis tengah, algoritma Förstner digunakan untuk mengecam titik sudut alur kimpalan dua segi.Berdasarkan platform ujian sedia ada, satu siri ujian pengesanan untuk pelbagai saiz alur persegi dihasilkan. Algoritma Förstner telah dibuat perbandingan dengan operator Harris untuk menilai mana yang lebih tepat dalam mengekstrak titik ciri alur kimpalan. Keputusan yang diperolehi menunjukkan bahawa ralat pengukuran maksimum ketebalan dan lebar algoritma Förstner adalah 3.193% dan 4.00%. Oleh itu, keputusan pengesanan yang diperoleh adalah cukup tepat berdasarkan rasional reka bentuk fizikal penderia visual dan kesahihan algoritma pengesanan yang dicadangkan.

ACKNOWLEDGMENTS

In the name of Allah, the Entirely Merciful, the Especially Merciful. First and foremost, Alhamdulillah, all praise to Allah who has given me the strength and bounty to complete this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

1. Naji, O.A.A.M., Shah, H.N.M., Anwar, N.S.N. et al. Square groove detection based on Förstner with Canny edge operator using laser vision sensor. Int J Adv Manuf Technol 125, 2885–2894 (2023). https://doi.org/10.1007/s00170-023-10862-y. (Accepted) (Scopus index) (WOS index)

2. Naji O.A.A.M., Shah H.N.M., and Anwar N.S.N., 2021. Laser Line profile Recognition Using Canny Edge Detector with Haralicks Facet Model. *Malaysian Technical Universities Conference on Engineering and Technology 2021 (MUCET 2021)*. (Scopus index)

3. Naji O.A.A.M., Shah H.N.M., Anwar N.S.N., and Johan N.F., 2020. Advances in Visual Sensor based on laser structured light and its application for Robotic welding. *International Journal of Advanced Trends in Computer Science and Engineering IJATCSE, Volume 9, No.5, September - October 2020, ISSN 2278-3091.*

CHAPTER 1

INTRODUCTION

1.1 Background

Due to the fast development of industrial automation, welding automation is becoming more extensively recognized and utilized in industrial domains, particularly in the welding of massive steel construction equipment with high difficulty and high need, such as aircraft and ships (Li et al., 2017). The key to achieving welding automation is automatic seam detection (Wanjara et al., 2013; Wilhelm et al., 2017). Therefore, accurate information about the welding groove is required throughout the welding process, such as the centreline of the weld, depth, and width, all of which are connected to the acquisition of image and feature extraction of the weld groove. Using a sensor for obtaining the image that has a complete information of weld seam is the premise of feature extraction (Lv et al., 2017).

The detection of the weld seam groove based on laser structured light has become one of the most popular vision sensors in welding. It is used widely to detect different types of welding joints, such as narrow butt joints (Fan et al., 2019; Shao, Liu and Wu, 2019; Xue et al., 2019), tee-joints (Zhang et al., 2014, 2018), lap joints (Zhang et al., 2019), and V-joints (Zou and Chen, 2018; Guo et al., 2019; Xiao et al., 2019; Fan et al., 2021). Although the vision sensor based on laser structured light has a number of advantages over classic mechanical sensors, extracting the image features of various grooves remains a challenge. The most critical issue related to laser vision sensors is the image-processing algorithm's efficiency and accuracy in extracting the image features of different types of weld joints (Huang and Kovacevic, 2012).

The welding torch is guided by the acquired position information of the weld joint to follow the ideal welding path, compensating for weld joint width and depth variations during welding (Wilson, 2002). The detection algorithm should acquire useful position information as well as the weld joint's geometrical characteristics (Lu et al., 2018). The three subprocesses of weld seam extraction or recognition are image preprocessing, laser line profile extraction, and feature recognition (Abo-Serie et al., 2017).

In the first step, the goals specifically encompass of the enhancement of the photograph and denoising, which is in particular essential for the extraction of weld seam features in welding surroundings. Weld spatter, Surface reflection, and smoke appearing in the captured image ought to be removed. Gaussian filter (Huang and Kovacevic, 2012) and Median filter (Li et al., 2007) are often used in many previous research for the purpose of the image denoising. The main use of the median filter is to eliminate the "pepper and salt" noise and keep the threshold information of the image, whereas the Gaussian filter is used to reduce the amount of high-frequency noise in a photograph. In addition, a morphological filter is also used by many researchers to improve the quality of welding images (Lee et al., 2009).

The second step of weld seam extraction is laser line profile recognition; its performance relies upon the workpiece's surface form and structure. The laser center line should be extracted due to the fact the laser stripe in the picture is possible to have a variable width. One of the method that is used for central line of the laser stripe is by using Radon transformation (Toft, 1996) and Hough transformation (Ballard, 1981; Li et al., 2007; Deng et al., 2011; Lu et al., 2018). Liangyu et al. (2007) extracted the laser line by adopting inside stalk transformation. Given that the laser stripe position in the image has the highest pixel intensity (Haug and Pritschow, 1999; Muhammad et al., 2018), several research projects look for the highest pixel in every column or row of the image to extract the laser profile's centerline. Huang et al. (2012) extracted the laser line primarily based on a method that is so-called the second central difference of the row index of every pixel on the laser stripe. To improve detection accuracy similarly, a few subpixel extraction techniques, such as Gaussian approximation (Naidu and Fisher, 1991) and the method of center of gravity (Naidu and Fisher, 1991; Li et al., 2017), are also used to recognize the position of the centerline of laser line profile. In addition, the method that is based on edge detection can be used to recognize the laser center line (Zhixin et al., 2017). Another technique uses the Laplacian of Gaussian filter (LOG) (Kim et al., 1996) to search every row or column of the image and calculate the result to acquire the laser line profile. The LOG filter considers the width info of the laser stripe of the weld seam groove so that the interference of a few welding spatter noises may be unnoticed and ignored. Moreover, Wu et al. (2015) extracted the laser line by filtering, image segmentation, and binarization. Although the above methods were able to extract the laser line profile of the weld seam groove, they are ineffective for a curved laser stripe, such as a square groove. These methods are also sensitive to noise, such as welding dust, welding spatter, and strong arc.

Feature recognition is the final step in the weld seam recognition process. The feature points include points on the weld seam and associated points that mirror the structural features of the weld. These points are frequently found on the centerline's turning points. The shape of the weld joint influences the diversity and distribution of turning points. In an ideal circumstance, extracting the features point on the laser centre line is simple; but, in practice, the skeleton isn't always a continuous line and can even be discontinuous, and noise that is caused by the welding torch can also impair the extraction of the feature or turning point position. The template-based method (Nele et al., 2013) is efficient and applied in several studies but it's tough to apply in the case of more than one turning points present simultaneously, also it is consuming time when extracting the image features. The image differentiation method (Huang and Kovacevic, 2012) is another way for extracting the corner points. This method uses the second central difference of each pixel's row index on the laser stripe to determine the seam centre, which is the intersection of the corner points. Muhammad et al. (2018) extracted the corner points of V-groove based on pixels' intensity distribution and neighborhood search. In addition, Wu et al. (2015) extracted the corner point of the V-groove based on the highest intensity of light projected on the weld seam groove. Liangyu et al. (2007) extracted the corner points of V-groove by the character point detected by analyzing slope.

In conclusion, most of the previous methods focus on the identification and detection of the weld groove such as narrow butt joints (Fan et al., 2019; Shao et al., 2019; Xue et al., 2019), tee-joints (Zhang et al., 2014, 2018), lap joints (Zhang et al., 2019), and V-joints (Guo et al., 2019; Xiao et al., 2019; Fan et al., 2021), and research on the detection of the square-groove is scarce. In addition, the weld-gap or width of weld seam groove has been considered constant in most of the papers. The majority of research publications focus on identifying and extracting the weld seam groove's corner points, rather than on depth calculation and value comparison, and some of these proposed methods are sensitive to the noise induced by various disturbances near or in the seam region.

This research focuses on detecting the laser line stripe and corner points of the square groove in welding application. Therefore, a method based on Förstner (1987) with Canny edge (Canny, 1983) operators using laser vision sensor is used for square groove detection.

1.2 Problem statement

Although laser vision sensor has several advantages over classic mechanical sensors, extracting the image features of various types of grooves remains a challenge. One of the essential issues related to laser vision sensors is the accuracy of the image processing algorithm that is able to accurately extract the image features of various types of the weld seam groove (Huang and Kovacevic, 2012). The detection method should be able to acquire quality position information and weld joint's geometrical characteristics, such as depth and width. To acquire this information about the weld seam groove, the weld joint's feature points, such as the groove's corner points, must be accurately extracted.

Many researchers have been studying weld seam recognition. There are many proposed methods for extracting the image features of the groove. For example, Liangyu et al. (2007) proposed an algorithm of single point filtering and binarization processing to extract the feature points of the V-type. Wu et al. (2015) proposed an image processing that is based on modified Hough algorithm for extracting the image features of the V-groove. In addition, Muhammad et al. (2018) proposed sequential image processing and feature extraction algorithms that can extract the geometrical seam properties of the V-groove; the detection method is based on a median filtering technique that involves enhancing the image object. Jichang et al. (2019) proposed a combined laser structure (single line and cross line structured light) to extract the features of the V-type groove, and the detection algorithm is based on an optical triangulation method. All of the previous methods showed promising results, and they were able to extract the image features of different types of weld grooves. However, the challenge is that most of the previous methods focus on identifying and detecting the weld groove, such as narrow butt joints, tee-joints, lap joints, and V-joints, and research on the detection of the square-groove is scarce.

Moreover, the width or weld gap of the weld seam groove, with varying forms of groove, has been held constant in most research papers (Rout et al., 2019), which is very important aspect in the welding quality, because during the welding process sometimes there will be a change in the position of the weld joints and to ensure that there is a quality welding, the detection algorithm should be able to extract the feature points even if there is a slight change in the weld position during the welding process.

Lastly, the majority of research publications focus on identifying and extracting the weld seam groove's corner points, rather than on depth calculation and value comparison. The main reason for employing the laser structured light is to compute the depth of the weld seam groove, therefore, a method to calculate groove depth and width and compare with the real value needs to be developed.

In conclusion, most of the previous methods focus on the identification and detection of the weld groove such as narrow butt joints, tee-joints, lap joints, and V-joints, and research on the detection of the square-groove is scarce. In addition, the weld-gap or width of weld seam groove has been considered constant in most of the papers. The majority of research publications focus on identifying and extracting the weld seam groove's corner points, rather than on depth calculation and value comparison, some of the proposed methods are susceptible to noise caused by various disturbances near or in the weld seam region. Therefore, a method that is able to extract the image feature of the square groove accurately is needed.

1.3 Objectives

The aim of this research focused on the detection and the extraction of the feature points of the square-groove in the welding application, these points are as follows:

1- To develop a detection algorithm that can extract the laser line profile of the square-groove.

2- To develop a detection algorithm that can extract the corner points of the square-groove.

3- To evaluate the proposed method in terms of the accuracy.

1.4 Scope

According to different phases of a weld quality control task, the whole weld quality sensing, monitoring, and control system can be categorized into three subsystems such as pre-process, in-process, and post-process subsystem. The main objective of the pre-process subsystem is to obtain the position and weld joint geometry to guide the welding torch along the best welding path.

Therefore, the phases of a weld quality control task of this research is the pre-process subsystem and its main aim is to acquire the position and geometry information of the weld joint. The laser vision sensor is based on a combination single line laser and vision sensor. Z-LASER is the chosen single-line laser. DFK 72AUC02 is the industrial camera that will be used. The image processing and feature extraction will be done by using Halcon software. The workpieces will be made of mild steel. The experiments will take place in a well-lit setting. The workpieces will be positioned in the centre of the workstation.

1.5 Contribution of the research

This research addresses the feature recognitions algorithm of the square groove to make weld seam recognition more accurate. The recognition of the weld image is a complicated process, and thus, has a large amount of noise. Specific method must be used to process images and extract the feature points. The feature extraction of the square groove can be accurately detected using the proposed method which is the Förstner with Canny edge operator using laser vision sensor. The results show that the proposed algorithm can extract the laser stripe's central line and the square groove's corner points with high accuracy. This research's findings have the following advantages: (1) Through Canny edge detection with Haralicks facet model, the centerline of the laser stripe can be extracted without any discontinuity, which demonstrates this method's ability for extracting curved groove without any discontinuity such as square groove; (2) To extract feature points of the square weld groove, Förstner algorithm, which has a good anti-interference ability and can meet the high accuracy criteria of weld identification, is proposed.

1.6 Thesis overview

This thesis is organized into five chapters which are shown as follow:

Chapter 2 Literature Review: This chapter discusses the fundamental theories and operating principles related to the weld seam detection. The second part introduces the sensing and the monitoring for the welding process and the role of the laser based on the structured light for the seam detection. A critical review of the previous work is done in order to find the research gap.

Chapter 3 Research Methodology: The first section of this chapter presents developing the hardware of the laser vision sensor. The selected hardware components and their properties are shown in chapter three. The second section discusses the proposed method for extracting the laser line of the square groove. It further discusses the corner point recognition method.

Chapter 4 Results: The results obtained are presented in this chapter. This chapter discussed the findings of the extraction of the image feature of the square groove. It further discusses the position information and geometrical details of the square groove that can be obtained by acquiring and processing the picture of the projected laser stripe that follows the object's profile.

Chapter 5 Conclusion and Recommendations: This chapter concludes the summary of the work done to extract the image feature of the square groove. Conclusions are made based on the findings performance. Recommendation for the future work is suggested in this part.