INTEGRATION OF MACHINE VISION IN INDUSTRIAL ROBOT FOR AUTOMATED COMPOSITE PANEL PUNCHING

AMEER MOHAMED ABDEEL AZIZ BIN MOHAMED HANAFEE

UNIVERSITI SAINS MALAYSIA

2018

INTEGRATION OF MACHINE VISION IN INDUSTRIAL ROBOT FOR AUTOMATED COMPOSITE PANEL PUNCHING

by

AMEER MOHAMED ABDEEL AZIZ BIN MOHAMED HANAFEE

Thesis submitted in fulfillment of
the requirement for the degree of
Master of Science

November 2018

ACKNOWLEDGEMENT

First and foremost, the ultimate thank to Allah for the guidance, strength and blessing given to me in completing this study. I would like to express my appreciation and gratitude to my supervisor Associate Professor Dr. Zahurin Samad for his inspiring advice, encouragement, patience and guidance for me to establish on what I started. His vast experience, amazing technical knowledge and expertise are vital in guiding me to face so much challenge along the study.

The credit also goes to Mr Ali Shahbana, an Assistant Engineer, Mr Husaini Bin Abu Bakar, Mr Mohd Izzat Ahmad Ghazali and Mr Mohd Nawawi that always been present whenever I need helps, regardless about works or personal life. The kindness from the friendship of them will be unforgettable, especially the advice and arrangement made for my wedding day during tough time.

The appreciations also go to Automation Control Laboratory members, Mr Cham Chin Long and Mr Mohd Aliff Bin Rosli upon technical assistance and friendship. Besides, my appreciation also goes to the Universiti Sains Malaysia (USM), Majlis Amanah Rakyat (MARA) and Ministry of Education (MOE) for the facilities and financial supports.

Last but not least, I wish to extend my whole-hearted thanks to my beloved wife Mrs Yatie Binti Ab. Rahman, our parents and all family members for their unconditional love, moral support, understanding, encouragement and patience. This thesis will be a gift for all of you.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER THREE: METHODOLOGY

CHAPTER FOUR: RESULT AND DISCUSSION

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	3 Dimension
COM	Component Object Model
CSI	Camera Serial Interface
CTOS	Commercial-Off-The-Shelf
DCOM	Distributed Component Object Model
EIH	Eye-in-Hand
EKI	Ethernet KUKA Interface
ETH	Eye-to-Hand
EtherCAT	Ethernet KUKA Control Toolbox
FF	Fieldbus Fashion
FFT	Fast Fourier Transform
FIFO	First In First Out
GPU	Graphics Processing Unit
HDMI	High-Definition Multimedia Interface
HVAC	Heating, ventilating and Air Conditioning
IDLE	Integrated Development and Learning Environment
IE	Industrial Ethernet
IP	Internet Protocol
KCT	KUKA Control Toolbox

KLI	KUKA Line Interface
KR	KUKA Robot
KRC	KUKA Robot Controller
KRL	KUKA Robot Language
LAN	Local Area Network
LIFO	Last In First Out
OLE	Object Linking Embedded
OPC	OLE for Process Control
OpenOPC	Open OLE for Process Control
OS	Operating System
PBVS	Position-Based Visual Servoing
PC	Personal Computer
RGB	Red Green Blue
RPi	Raspberry Pi
RTE	Real-Time Ethernet
SD Card	Secure Digital Card
SimpleCV	Simple Camera Vision
SRC	Secure Source Code
TCP/IP	Transmission Control Protocol
UDA	Unified Data Access
UDP/IP	User Datagram Protocol/Internet Protocol

USB	Universal Serial Bus
XML	Extensible Mark-up Language

LIST OF SYMBOLS

ΔSF	Difference of safety factor
ΔH_c	Difference of travel distance
m	Gradient
C	*SF* intersection
θ	Theta

PENYEPADUAN MESIN PENGLIHATAN DALAM ROBOT INDUSTRI UNTUK PENEBUKAN PANEL KOMPOSIT AUTOMASI

ABSTRAK

Tesis ini menggunakan kawalan servo penglihatan dalam memberi informasi tepat bagi pengulangan tugas untuk objek yang diketahui. Pernyatan masalah di dalam tesis ini melibatkan dua perkara utama. Pertama, penggunaan kaedah konvensional tidak memungkinkan satu stesen kerja untuk memesin panel komposit berlainan bentuk, atau dalam masa yang sama menggunakan lekapan and mata alat berlainan. Kedua, KUKA Robot Controller (KRC) 4 kini tidak berupaya untuk berkomunikasi dengan satu peralatan luar disebabkan protokol pengawalan keselamatannya. Matlamat untuk penyelidikan ini adalah untuk membangunkan pengaturcara mesin penglihatan bagi membantu robot KUKA dalam mengenal dan menentukur pelbagai bentuk panel komposit dengan tepat. Objektif kedua adalah untuk membangunkan dan menyepadukan komunikasi bagi KRC4 dan mikro pengawal Raspberry Pi (RPi) dan untuk menilai prestasi sistem kawalan servo penglihatan bagi penebukan panel komposit automasi. Dengan menggunakan modul socket untuk bahasa pengaturcaraan Python, sistem kawalan suap balik dibina dengan menghubungkan RPi dengan KRC4 melalui Ethernet menggunakan KUKA Robot Language (KRL) bagi membolehkan robot melaksanakan keseluruhan proses. Imej dikesan menggunakan fungsi mesin penglihatan. Nilai faktor bentuk setiap panel yang berbeza disusun melalui graf untuk 15 proses kitaran. Posisi dan putaran panel dibandingkan kepada 3 sistem koordinate ,iaitu, kamera, bahan kerja dan pusat pemesinan. Perbezaan koordinate ini dengan koordinat rujukan ditafsirkan sebagai kralat dan pelarasan dibuat untuk menyingkirkan ralat ini. Kesimpulannya, penyepaduan KUKA robot dengan RPi membolehkan pemesinan panel yang berbeza hanya dengan menggunakan satu stesen kerja sahaja.

INTEGRATION OF MACHINE VISION IN INDUSTRIAL ROBOT FOR AUTOMATED COMPOSITE PANEL PUNCHING

ABSTRACT

This thesis employs visual servoing control to provide accurate information for repetitive task on the known object. The problem statement on this thesis involves two main points. Firstly, by using the conventional method it is not possible to have one workstation to machine different pattern of composite panels, nor using different fixtures and tools at the same time. Secondly, the current KUKA Robot Controller (KRC) 4 does not have the capability to communicate with an external device due to the controller safety protocol. The aim of this research is to build a machine vision algorithm for assisting KUKA robot in recognizing and calibrating various shapes of composite panels precisely. The second objective is to develop and integrate communication interface program for KRC4 and Raspberry Pi (RPi) microcontroller and to evaluate the performance of visual servoing control system for automated composite panel punching. By using socket module for Python programming language, the feedback control system is built by communicating RPi with KRC4 through Ethernet using KUKA Robot Language (KRL) to enable the robot to execute the whole process. The image are traced using the machine vision function. Shape factor value of each four different panels sorted through the graph for 15 process cycle. Position and rotation of panels are compared to three coordinate systems which are camera, workpiece and machining center. The differences of these coordinates with the reference coordinate translated as error and adjustment was made to remove the error. As a conclusion, KUKA robot integration with RPi enables the machining process of different panels executed in a workstation only.

CHAPTER ONE

INTRODUCTION

1.1 Research background

The conventional production system uses different workstations to do different specific task (Koca and Aksungur, 2016). Automation using robotic arm enables the possibility to execute these different specific tasks by using only one workstation (Castelline, 2011). The reduction of the workstation gives benefit in term of optimization factory shop floor usage, minimization of machine monitoring, effective electricity usage, reduction of the maintenance cost, and increment in the productivity of the product itself.

In order to implement automation using robotic arm, the core of the feature is using visual servoing technique. Visual servoing is a technique that uses feedback information extracted from vision sensor to control the motion of a robot. This technique is used widely by previous researchers with various approaches and applications. For example, Wang et al. (2012) used visual servoing to control robot manipulator by employing image Jacobian matrix in uncalibrated environments. This technique basically can be grouped into two methods, which is position-based control method and image-based control method. They used image-based scheme for its effectiveness due to its simplicity of implementation. Copot et al. (2013) extended some advanced control strategy to deal with disadvantages of this image based architecture. This visual servoing will be used for KUKA robot control system. The communication in visual servoing can be divided into 2 options.

Fist option of the communication interfaces in implementing visual servoing by using Windows platform. Colbert et al. (2010) are the researchers that used vision system algorithm implemented in Python program that used Open OLE for Process Control (OpenOPC) module to communicate and control KUKA Robot (KR) 6/2 six-axis industrial manipulator. OpenOPC can be operated with Windows and non-Windows platform such as Linux, and Mac Operating System (OS) X. On the other hand, RPi is using Raspbian OS. Up to this day, there is no particular testing for this OpenOPC has been operated with Raspbian OS. There is the option that RPi can use Mac OS X, but in order to communicate with KRC 4, this KRC 4 also needs to be configured with KUKA.OPC (KUKA.OLE for Process Control) Server to make them works together. Furthermore, the implementation of Object Linking Embedded for process control (OPC) method often requires major capital investments at the beginning stage.

The second option is by using open source software communication interface. JOpenShowVar is an open source communication software interface that has been introduced by Sanfilippo et al. (2014). The author uses Java programming language to enable KUKA Robot Controller (KRC) 4 to read and write variables with the external system. By development of this software, it helps other researcher to collect more relevant data for research purpose. However, the operation of this software still needs KUKAVARPROXY as a middleware. KUKAVARPROXY is a multi-client server and can serve up to 10 clients simultaneously. This middleware is difficult to be implemented since there is no clear operating procedure to install and operate this software. Besides, researchers need to have prior knowledge of Java programming language.

To execute the robot arm and the machine vision, some communication method is needed that will interact between them and transfer the relevant information back and forth. There are several manufacturers tend to build the manipulators that only can work with add-on technology software packages provided by same manufacturer. The software and hardware from different manufacturers unable to connect to each other when the integration takes place due to the closed network and protected environment. The open source interface is needed to break this wall (DiLuoffo et al., 2018).

1.2 Problem statement

The problem statement of this thesis can be divided into two main points.

1. Various composite panel shapes require several workstations for machining.

Machining or drilling the holes for aerospace composite panels of Airbus 320 has been done using different workstations for different shape of composite panels, since each shape requires different fixtures and tool path. The cycle time for every workstation is different according to the complexity of the panel shape. Introducing this machining process to the autonomous visual servoing robot control system is the right thing to do. Integration of machine vision with KUKA robot programming will improve the capability of one workstation to machine various product complexities (Coppinger, 2018).

2. Integration problem in automation industry.

The problem of the integration in the production system being an important part that requiring interconnectivity of machines, systems, and product to collect the data through sensors and other devices (Ćwikła and Foit, 2017). Current KRC4 does have uncovered capability to communicate with the external device. Ethernet KUKA Robot Language (KRL) Extensible Mark-up Language (XML) add-on technology software is capable to open the connection to this controller. The add-on technology vision software can be used then. Rather than using this vision software with COGNEX Camera, which is more to the closed network environment, there is another option. Introducing RPi 2 Model B as a current cheaper and open network microprocessor technology in the market. Shauri et al. (2012) integrated the sensor vision to its dual-manipulator hand robot to enable the manipulator work in the real-time operation. The reason to integrate KRC4 with RPi is to expand the capability of integration. RPi has the capability to interact and communicate either through Ethernet or wireless networks (Vujović and Maksimović, 2015; Dudas et al., 2014; Ferdoush and Li, 2014).

1.3 Research objectives

To develop an automated workstation system, several objectives have to be achieved. Three main objectives as below:

1. To develop and integrate communication interface program for KRC4 and RPi microprocessor respectively,
2. To build the algorithm of machine vision system for KUKA Robot Arm in recognizing and calibrating various shapes of composite panels precisely, and
3. To evaluate the performance of the communication interface and machine vision system in automated composite panel punching.

1.4 Scope of studies

The scope of studies generally focuses on visual servo control for KUKA robot arm using vision sensor. Going to the further issue, the studies will be focusing on the integration of external microprocessor that is RPi. RPi was selected due to its ease of use for the internet connection. Even other microcontroller such as Arduino is not straight forward for the internet connection configuration. RPi can be programmed using entire Linux software stack available such as Python, but Arduino only use C/C++ programing language. Image processing can be done by using Arduino with OpenCV or Matlab, but RPi is more powerful image processing due to its inbuilt Graphics Processing Unit (GPU). The machine vision does the image processing by analysing the length and the shape of the image with the coordinates and orientation. Socket module via Integrated Development and Learning Environment (IDLE) of Python (programming language) shell programmed as a server will open the communication connection.

The research will be focused on the architecture and limitation of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol and the configuration of the client and server to be able for two different controllers to send and receive data through Ethernet connection. For example, RPi must have fixed Internet Protocol (IP) address and the similar range of subnet mask with KRC4 network interface IP address. Another method of communication that use OPC will be discussed but no intention to be used in this research since the connection is only for one server with one client. Ethernet communication would be good enough for this purpose. This OPC can interact between multiple server-to-server and client-to-server connection.

Four composite panels are chosen based on several properties, which are different surface area, different in shape and hole location, and similar colour tone. The length and width of composite panel sampling cannot be too long and should be in the camera range view.

For the machine vision, the image processing algorithm will be utilized in the Python standard library module. The result of the image in calibrating the composite panel will be measured at the one edge of the panels. In order to get a high-resolution image, the distance between the image and the composite panel need to be at certain distance, so that the desired scale factor can be achieved.

1.5 Research approaches

This thesis presents a framework for Human-Machine Interface (HMI) for KUKA robot with vision as a sensor. This vision system used to assist KUKA robot to recognise the pattern of composite panels by sending the signal to KRC4 to identify the path of the subprogram that the robot will act.

In this particular section, an overview of some approaches that has been made to illustrate the particular solution of the problem addressed in this thesis is provided. The important key in visual servoing is the data communication. Colbert et al. (2010) and Sanfillipo et al. (2014) are among of the research that leaded in finalizing the research approach.

The method that will be used in this thesis is to establish the communication with KRC 4 and RPi is by deploying Socket module in IDLE, a Python development software. Ethernet KRL XML that deploys Ethernet KUKA Interface (EKI) is used to open the connection of KUKA KRC4 Controller, have the capability to send and receive binary data and XML data to and from an external system. RPi represents as the external system which is functioning as image processor that will send the signal to the manipulator for executing motion program through the Ethernet connection TCP/IP (Transmission Control protocol/ Internet Protocol) protocol.

For calibration of the composite panels, the image pattern recognition functions will be used to detect the image boundary and trace the enclosed rectangle. The shape factor and the total length of the respective image will be set as the properties that differentiate the panels. For the panels that have same shape factor and the length, the absence of the hole become additional parameter that can be measured, due to different panels have different holes position. For this thesis, the panels tested already have holes. In the case where the panels does not have holes, the recognition criteria will be totally different.

For repositioning of the composite panels, the image of the panels will be interpreted into coordinate system and the pixel value represented in coordinate, which will indicate the differences from the desired setting value. The KUKA KRC 4 Robot will move the arm to suit with the setting desired pixel value. Scale factor of the image will be measured to synchronize the movement distance of robot manipulator with pixel value of the image features. Communication is done by using Socket module. KUKA robot enables to hold, recognize and adjust the position of different panels, which eliminates the use of fixture and tool change.

1.6 Thesis outline

The content of this thesis categorized into six chapters. Chapter one illustrate the introduction of the research by describing research background, problem statements, objectives of research, scope of studies and research approaches. Chapter 2 is about the literature of the research itself. Some dissertation from other researchers that discuss the integration challenge in the automation industry, some reliable communication method and its constraint will be cited. Furthermore, the technique and methods of the communication algorithm also will be highlighted as well in this section. For image processing, it describes more on the method of machine vision available in Python. For Chapter 3 is the methodology which includes the hardware setup, the software configuration setup and the programming of the image captured. Chapter 4 presents the results and discussion of the image acquisition, the accuracy and the consistency of the visual servoing punching system. The Chapter 5 conclude the result of machine vision in identifying, calibrating and repositioning sample of composites panels. Besides, the development and integration of interface program, the evaluation of visual servoing control system in punching process will be concluded in this section.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to the integration network system in industry

Many efforts have been made for industrial robots to be used in industry since 1970s. In 1980s, there are almost 9000 industrial robot in use, supplied by approximately 65 robot manufacturers (Duelen and Wendt, 1984). Through the decades, the use of industrial robot increases to be expected that about 414000 robot units will be used in 2019 (Karabegović, 2016). Several research and developments in this field of study have been done later in order to fulfill demands from the automotive industry. Three main focus areas such as kinematics, programming architecture and control become the research mainstream to improve the capability of robot arm.

Since last few decades, the integration and networking system have made the industrial robots more advance. The ability to communicate and work simultaneously gives much more advantage in the industry. This control system is utilized for operating equipment such machineries, shop floor process, telephone network switching, steering and stabilizing of ships, aircraft and other applications. The implementation of device networking units has increased from recent years in the factory automation (Montironi et al., 2014; Lüder et al., 2010; Zhang and Jin, 2013).

2.2 Visual servoing

By definition, visual servoing is the term used for describing the system using camera as a sensor to provide the information for the robot manipulator (Kyrki et al., 2006). For the past recent years, this so called advance automation methodology has gone through some research and development to enhance and counter the problematic parameters that affect the robustness and efficiency of the visual servoing system.

The advantages of industrial robot in assembly, manufacturing and other technology are the ability to execute the repetitive task by continuously repeating the same paths and motions. For this reason there are numbers of researchers start to investigate and implement closed loop control system to monitor the accuracy of repetitive by integrating some sensors. Vision system is one kind of control system used to send the input to the robot (Mersmann, 2011; Elmasry et al., 2012).

2.2.1 The challenge in visual servoing

Shauri et al. (2012) said that sensing and manipulating the robot for small objects are among the most challenging task. The manipulator requires a very high degree of coordinated actuation in executing the task. The author proposed a method that applies visual servoing structure for recognition by camera, and impedance control for the robot arm to produce the required kinematics adjustments according to the measured data by the camera. The author used data socket functions to receive and transmit data produced by the Target Personal Computer (PC) and executed on the robot via PC Target on a MATLAB/Simulink environment. This method require to use the hybrid eye-in-hand (EIH) and eye-to-hand (ETH) multi-camera for small object image acquisition as shown in Figure 2.1and 2.2.

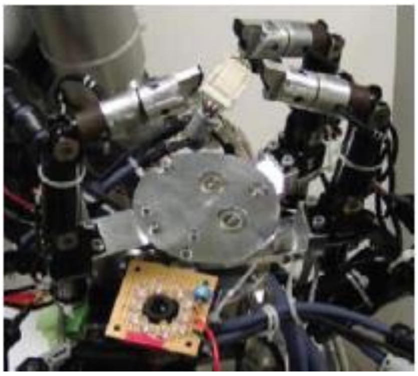


Figure 2.1 Eye-to-hand (ETH) multi-camera (Shauri et al., 2012)

2.2.2 Method in visual servoing

Colbert et al. (2010) have developed a vision algorithm program for 6 arm robot to reconstruct 3D geometry of a novel object using Cython NumPy arrays for image processing. This method enables the recovery of the shape, pose, position and orientation of unknown objects using just three images of the object. This implementation shows the utilization of Python OpenOPC software to open the communication channel of KUKA Robot Controller.

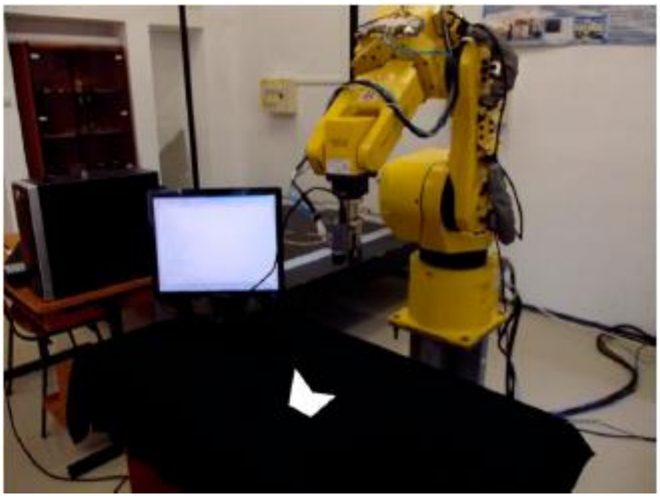


Figure 2.2 EIH camera setup (Copot et al., 2013)

EIH camera was used to evaluate the performance of image based control strategy for 6 degree of freedom robot arm (Copot et al., 2013). Meanwhile, another experiment setup arranged the camera facing the robot manipulator as shown in Figure 2.3 (Wang et al., 2012).

2.3 The vision system application

Švaco et al. (2014) deployed the vision system to send an image captured to provide the noncontact method of reading errors. These reading errors are the input to measure the absolute robot position. Even in the transport system, this vision system is the reason behind the ability of the luggage routing system in the airport to be navigated and mapped autonomously (Mapanga and Kumar, 2012).

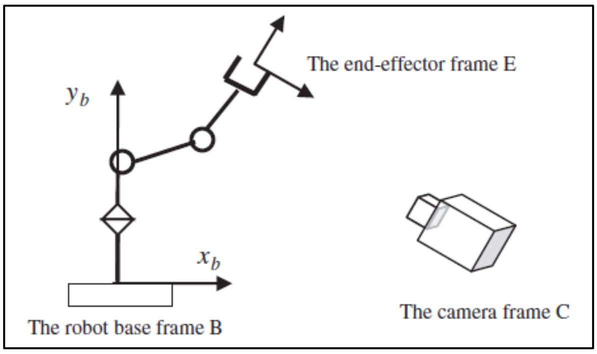


Figure 2.3 Camera setup for image acquisition (Wang et al., 2012)

In fact, the food industry also utilizes vision system in their inspection line (Nashat et al., 2013). The development of these vision control algorithms gives benefits to the production process in providing better accuracy of quality control systems (Montironi et al., 2014, Castellini et al., 2011, and Zhou et al., 2013), task control-oriented data and status monitoring-oriented data (Li et. al, 2015).

Montironi et al., (2013) presented the adaptive strategy for automatic EIH camera placement in a 3-D space during a robotized vision based quality control. The advantages approach proposed are improving the overall efficiency of the system, allowing a current image acquisition and possible to perform the inspection by template matching.

The author focused to determine the position on the scene by using Fast Fourier Transform (FFT) algorithm to the image. FFT algorithm was used to automatically determine the angular position of the obstacle and reposition the camera. Template matching method is suitable for this application since the camera captures the angular position and compares it with reference image. Small object was advantages in using template matching. However, the experiment that need to be executed in this research are using large workpiece images. Thus, this approach is not suitable to implement in this research.

In spite of approach used by researcher, the step of methodology might be useful to be focused on. The flowchart in Figure 2.4 illustrated the task for strategy workflow, Task 1 and Task 2 can be considered the reference for the research approach.

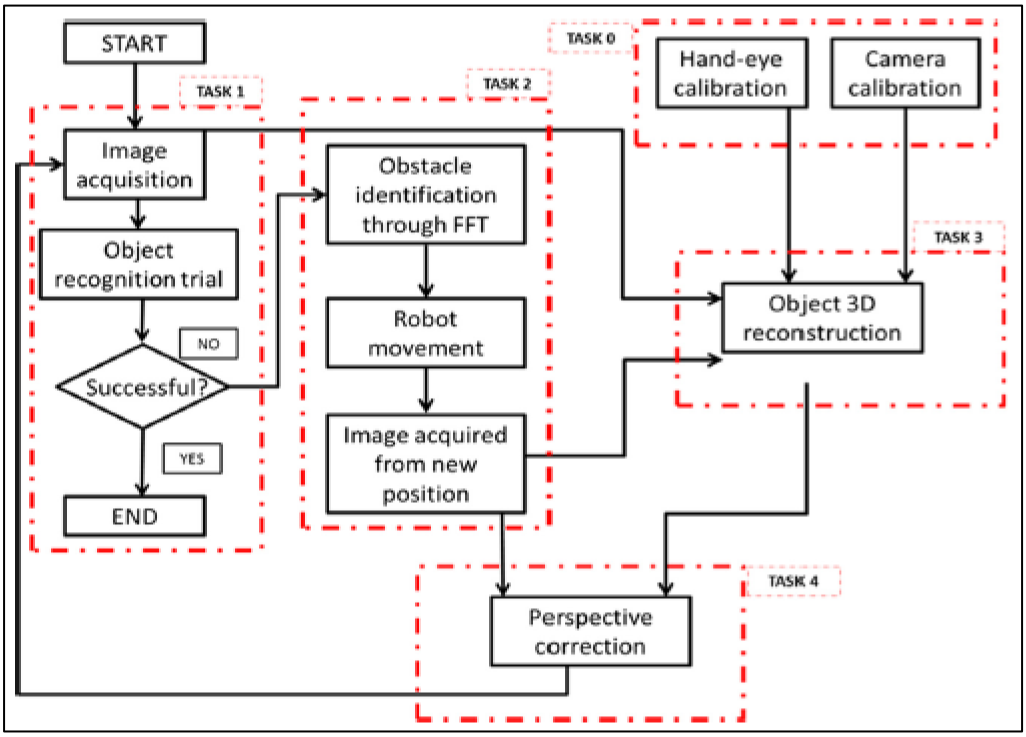


Figure 2.4 Strategy workflow (Montironi et al., 2013)

2.4 Data acquisition

In identifying and repositioning of the composite panels, the calibration of the parameters that determine the properties of an object and scaling factor of camera used, have to be identified first. From the raw image, python program need to use the image processing functions available in the software that can recognize these parameters.

To maximize the quality of the image, the surrounding lighting is preferable to be controlled as much as possible to reduce the image noise. However, there are still pixel-level noise left. This noise can disturb the detection of features on the image. The morphology function is useful to clean up this mess (Oostendorp et al., 2012).

2.4.1 Image digitization

The image captured will be stored with a set of number. The digitization of image means the image frame is divided with rectangular arrays and one small rectangular represent as a pixel.

A colour image is defined as RGB image that consists of red, green and blue pixels that hold different value (Awcock and Thomas, 1996). Meanwhile, a grayscale image consists of pixel value that represents the grey level. For 8 bit image, the grey value of the pixel varies from 0 to 255, that is 0 value of pixel indicates the image is black, meanwhile the 255 value is white.

When the image is binarized, the function has to identify which pixels need to be converted to black and which to white. The process of this separation is named as ‘threshold’. The pixel that has grayscale value fall under the threshold is changed to white. Meanwhile, the pixel that above the threshold value is turned to black.

The default setting in SimpleCV system uses Otsu’ method to determine the binarize values as showed in Figure 2.5 (Oostendorp et al., 2012). So, a binary image is the image that contains of pixel value either 0 for black and 1 for white. Python has the tools to manipulate this image and collect the desired data.

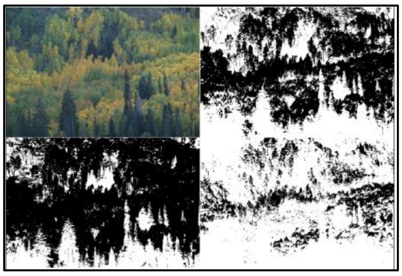


Figure 2.5 Top Left: Color image. Top Right: Otsu's method binarized. Bottom Left: Low threshold value. Bottom Right: High threshold value (Oostendorp et al., 2012).

For past literature, Park and Lee (2003) took binary data after digitizing the image data to make use of the advantages upon binary data in differentiating an object from its near-monotonic surrounding. The image distortion is taken to the count when capturing the image from video when object moves fast. Distortion image result will influence the pixel value during data acquisition. The error will occur during capturing the image, just after the robot do some adjustment upon workpiece position.

2.4.2 Pattern recognition

Several methods have been proposed by researchers to recognize and define the characteristics of the specific product properties. Pattern recognition by computer vision has improved either in the inspection process or the program algorithm selection for the robot arm manipulator. Brosnan and Sun (2004) and Iyer and Sinha (2005) used morphological operation to inspect the food product and to identify the condition of cracks in underground pipeline respectively.

Han and Shi (2007) used wavelet analysis to detect defects on texture surface of the industrial product, meanwhile Quevedo et al. (2008) used for fractal analysis. Others preferred the diffusion method (Tsai et al., 2010) and the edge detection scheme (Li et al., 2012).

All of these methods had been successfully implemented for the inspection of the product. These methods can still be applied to recognize the pattern of the product before proceed to the machining process. It is good to know that robot arm can identify which panels it has to pick up.

2.4.3 Repositioning

Kyraki et al. (2006) investigated the error characteristics in vision system and associated the uncertainty of the control system to execute the pose estimation, visual servoing, and control strategy. The sources of error are from the factors such as spatial quantization, feature detection, and the image distortion. These researchers specifed that the image noise can be modelled as zero- mean random variables on assumption been made that there is no systematic calibration error.

The researchers used Position-Based Visual Servoing (PBVS) to determine the pose transformation between the current and the desired position of the image. To define the position, the researcher decomposed the transformation matrices into translation and rotation.

Later, the translation vector is rotated to correspond to the camera frame axes. By doing this, the uncertainty for this rotated vector can be found using the uncertainties in both the rotation matrix and translation vector.

2.4.4 Measurement error and accuracy

In order to specify the composite panels shape, the calibration should be done to find the shape factor, and scaling factor. The calibration process may produce some errors due to the image distortion caused by sensitivity of light density, non-perpendicularity of the camera optical axis to the workpiece surface and incorrect object distance.

Zhu et al. (2014) used four laser displacement sensors to ensure the camera optical axis is perpendicular to the panel surface and used the correct object distance in order to minimize error. They also stated that standard accuracy for the fastening holes in aerospace industry should be kept to within ± 0.2 mm. The camera accuracy that achieved by their 2D vision system is approximately ± 0.1 mm. The camera accuracy is defined as the camera resolution or pixel size.

In visual servoing, the camera accuracy will correspond with the robot manipulator accuracy. KUKA KR16 robot with KRC4 has the accuracy of approximately ± 0.05mm (KUKA, 2012a).

With the condition stated by Zhu et al. (2014), obviously the accuracy of the camera has to be measured and compared with the robot manipulator accuracy.

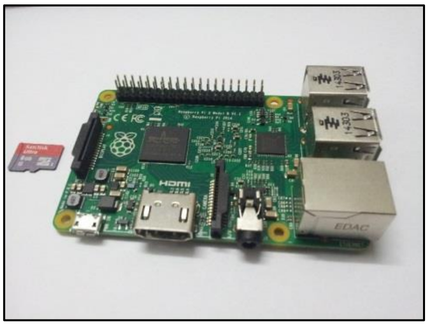
2.5 RPi microcontroller

In the past few years, there are several applications that have been configured by hobbyists with the RPi. RPi is a powerful tool that can do a lot of things. This microcontroller has powerful multimedia and 3D graphics capabilities, potential to be used as a controller to control hardware with Python, used as a media center or develop games in Scratch (Upton and Halfacree, 2012).

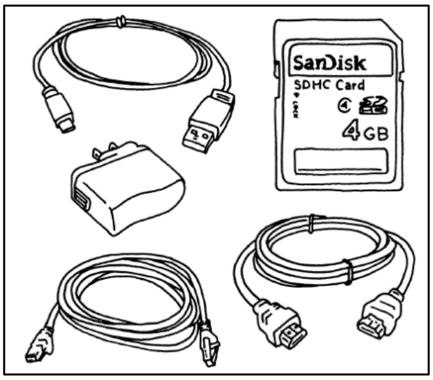
There are a lot of applications on RPi, especially video feed from Youtube website that tells in very detail the steps and methods used to work with RPi. Scott (2015) briefly explained on how Simple Camera Vision (SimpleCV) module do the image processing in Python. Moreover, Findlater (2014) and 74Samy (2013) had demonstrated the vision in RPi to assist the robot. Meanwhile, Patrick and Michael (2014) are among the hobbyists that brilliantly contribute some of their knowledge in latest technology for human kind benefits.

2.5.1 RPi equipment

Figure 2.6 (a) shows the main body of RPi. Meanwhile Figure 2.6 (b) shows the HDMI cable, Ethernet cable (RJ45), Secure Digital (SD) card (with an adapter for RPi model A) and a micro Universal Serial Bus (USB) power supply. High-Definition Multimedia Interface (HDMI) cable straight away can be plugged to a monitor, while keyboard and mouse (USB head type) can be directly plugged to the USB port on RPi (Ada, 2015).



(a)



(b)

Figure 2.6 (a) RPi microcontroller with SD card, (b) Basic equipment to work with RPi microcontroller (Richardson and Wallace, 2012)

2.6 Data communication

The key in the visual servoing system is the data communication. The interfaces for the communication has been explored to identify the architecture so that the optimum and reliable data transfer can be achieved.

2.6.1 Object Linking Embedded for Process Control (OPC)

Object Linked Embedded (OLE) is a compound document technology from Microsoft based on its Component Object Model (COM), which allows an object such as a graphic, video clip, spreadsheet and other several info to be imbedded into a document as known as ‘container application’.

OLE for Process Control (OPC) is an open standard used to remotely acquire extensive Distributed COM (DCOM) configuration. The DCOM provides the communication substrate under Microsoft’s COM+ application server infrastructure to enable the communication among software components distributed across networked computers.

Şahin and Bolat (2009) developed remote monitoring and control of a web-based distributed OLE for OPC system. OPC that using Microsoft’s Object Linking and Embedding (OLE) technology enables different control devices to communicate with one another by exchanging data. Figure 2.7 and 2.8 illustrate the communication without OPC and with OPC.

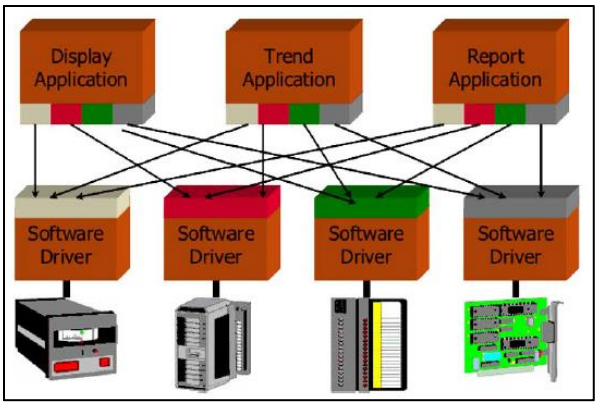


Figure 2.7 Communication without OPC (KUKA, 2012b)

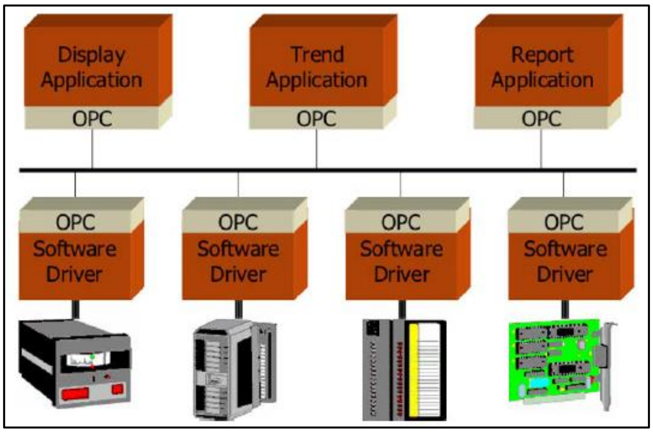


Figure 2.8 Communication with OPC (KUKA, 2012b)

Hong and Jianhua (2004) designed the unified data access (UDA) model that uses OPC interfaces to provide an efficient, consistent way to exchange information with other applications. The OPC implemented more in automation software when Hong and Jianhua (2006) used the integration system in automation industry. OPC Unified Architecture (OPC UA) is the evolution of the OPC system and XML specification that adopts a very complex software infrastructure in realising data exchanges (Cavalieri and Chiacchio, 2013).

The XML specification had been combined with OPC to be called as OPC XML-DA specification that became the standard way to represent hierarchy structure data exchange (Yin and Zhou, 2012). In fact, the utilization of OPC server into the EcosimPro model has implied new possibilities for analysing the environment simulation close to the real world (Zamarreño et al., 2014). There are differences between Ethernet network system and OPC system. The Ethernet network transfer data from one master to another one slave. One device or controller needs to be a server and the other controller needs to be a client. The significance of server and client will be discussed later in the next chapter.

For the OPC network system, the server and client connections are not limited to one server and one client. One server can transfer data to multiple clients. Furthermore, one client also can send data to more than one server. Besides, the configuration of DCOM which is both tedious and error prone, requires the client machine to run a Microsoft Window's OS only.

This literature however will discuss about OPC system so that in future work, there will be continuity research focusing more on OPC system and its significance. As for the limitation of software implementation for OPC, Ethernet network is the suitable system to be deployed in this thesis.

2.6.2 Ethernet data communication

In the effort to make industry of manufacturing more efficient and competitive, control systems deployed by industry are rapidly shifted to use Ethernet network system. This Industrial Ethernet (IE) benefits the automation system to achieve higher objectives in control, supervision and diagnosis. Ethernet network is the technology that uses master/slave or server/client model for real-time transmission control protocol/Internet protocol through the application of programming interface as showed in Figure 2.9. Meanwhile, Figure 2.10 shows the architecture for the adoption of client-server model.

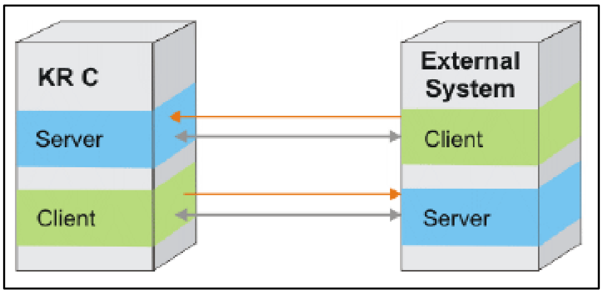


Figure 2.9 Client-server mode (KUKA, 2012b)

The IE uses the standard Ethernet protocols for high speed data transfer with good compatibility, suitable communication for higher levels in industrial automation architecture. Liang (2015) addressed two different design implementation for a traditional cascade control system based on Fieldbus Fashion (FF) and IE for closed loop control that were implemented on controller for data acquisition and device actuation. This two level communication is mainly over IE. The IE enables a more responsive and flexible system that transmit real-time data from the production floor.

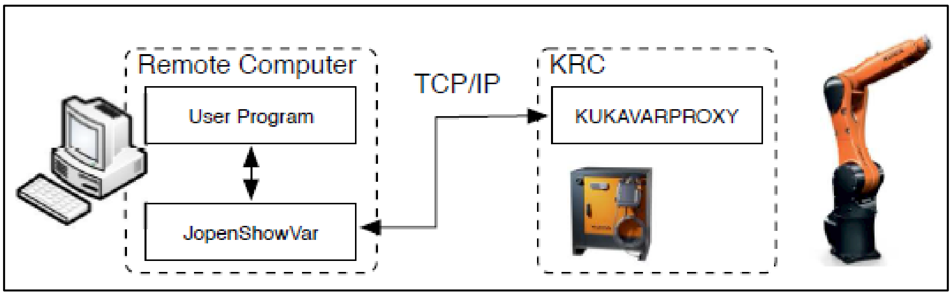


Figure 2.10 The proposed architecture for adoption client-server model (Sanfilippo et al., 2014).

Elshuber and Obermaisser (2013) explored the ability of extending firmware of Commercial-Off-The-Shelf (CTOS) router to support ethernet network in order to achieve reduction of hardware cost, upgrading the infrastructure to be used for real time communication and availability of field-tested hardware.

Hung et al. (2004) used ethernet network systems for factory automation networks to integrate the framework of the synchronous equipment control. Walaszyk and Batog (2013) used ethernet connectivity for its measuring device and visualization software to control and optimize the efficiency of heating on and air conditioning (HVAC) systems. Figure 2.11 illustrates the communication scheme between KUKA Control Toolbox (KCT) and the manipulator through ethernet.

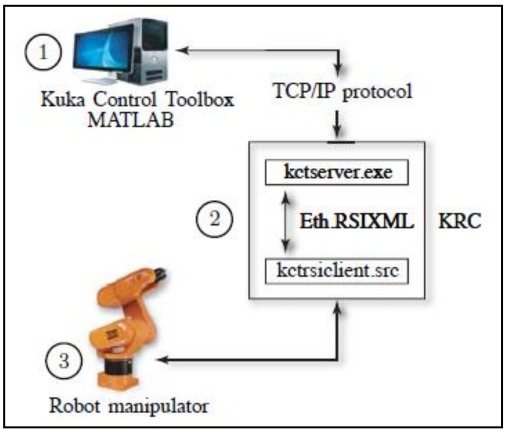


Figure 2.11 Communication scheme between KCT and the manipulator through ethernet (Chinello et al. 2010)

Some researcher such Cena et al. (2009) also studied the performance of ethernet network for better understanding of the real-time behaviour of this protocol. They also presented the analysis of transmission error that came from several sources of electromagnetic noise.

Vitturi et al. (2011) introduced Real-Time Ethernet (RTE) networks, namely as Ethernet POWERLINK and Ethernet for Control Automation Technology (EtherCAT). These RTE are deployed for a coordinated motion control application. The EtherCAT device is already been provided together with KRC4 and integrated well with KUKA ROBOT Language (KRL) for designated input/output.

KRL is the standard programming language of KUKA robot (Schöpfer et al., 2010, Schreiber et al., 2010, Mühe et al., 2010). KRL is ease of use interface language only run on KRC, executed to the real-time constraints. For the research purpose, this KRL are limited in providing the data acquisition only.

Taking this opportunity as the advantage in developing robot program, the EtherCAT device in Figure 2.12 will be utilized in this research for activating the real time input signal in pattern recognition of composite panels.

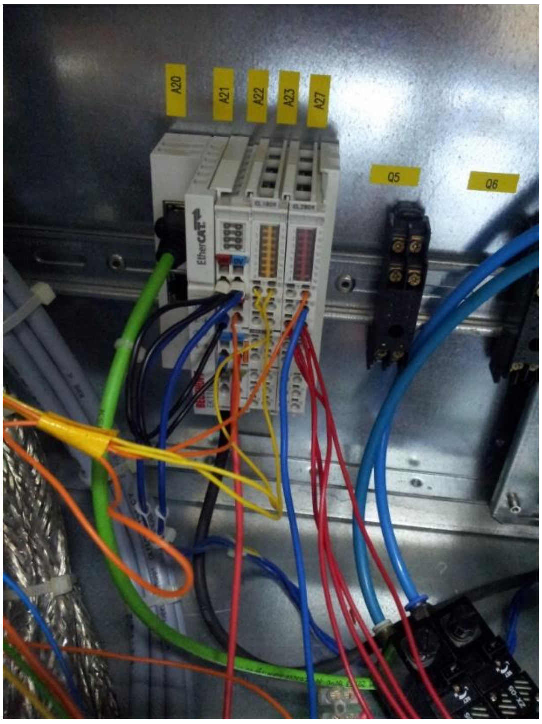


Figure 2.12 EtherCAT device inside KRC4 Controller

2.7 Summary

The literature described and discussed in the previous sections over the advantages of the data communication via ethernet networks guides the research in integrating the robot controller to the possible external systems.