UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF AUTONOMOUS ROBOT FOR FLATNESS INSPECTION SYSTEM

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours.

by

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours. The member of the supervisory is as follow:

………………………………

Mr SHAHRIZAL BIN SAAT

ABSTRAK

Kadang-kala, jalan lebuh raya yang tidak mempunyai sudut kerataan yang tepat menyebabkan pengumpulan lopak air semasa hujan. Pengumpulan lopak air ini mengurangkan geseran tayar di jalan raya dan mungkin menyebabkan kenderaan tergelincir di jalan, akhirnya menyebabkan kes-kes kemalangan maut di jalan raya. Selain itu, pihak pengurusan jalan raya juga tidak dapat mengukur kedataran jalan raya dengan tepat. Dengan ini, projek tersebut bertujuan untuk mencipta sebuah robot automatik yang boleh mengukur kedataran jalan raya supaya pihak pengurusan jalan raya boleh menyediakan pemantauan yang lebih baik dan pengurusan di jalan raya.

Sistem tersebut dapat mengetahui lokasi dan kedataran jalan raya. Sistem yang digunakan dalam projek ini adalah melalui mikropengawal PIC18F4550 yang dapat mengawal seluruh sistem semasa dalam operasi. Sistem tersebut beroperasi dengan menggunakan pengesan IMU yang dapat mengukur kuasa tertentu dan kadar sudut robot tersebut. Dalam pengesan IMU tersebut, ia menggunakan gabungan pecutan dan giroskop. Input untuk sistem ini adalah jarak dan kedataran jalan raya manakala output maklumat dari sistem ini akan dipaparkan dalam komputer dengan “grafik User Interface”(GUI) melalui perisian Visual Studio 2015 (VS).

Dengan maklumat yang dikumpul, ia mewakili sudut cerun di jalan dan menunjukkan lokasi yang tepat pada setiap tempat yang mempunyai kedataran yang berbeza. Dengan ini, pihak pengurusan jalan raya dapat menjalankan pengurusan yang lebih baik terhadap jalan raya.

ABSTRACT

Along the road of highway, some of the location have improper flatness causing accumulation of puddles during raining time. The interaction between the road and the vehicle is affected by these puddles which decrease the efficiency of the vehicle tyres friction on the road, in particularly severe cases, even determine the loss control of vehicle skidding, therefore compromising the driver’s and passenger’s safety. Sometimes, road management team is not able to measure the flatness of the road accurately. Hence, this project purposely to design and fabricate intelligent mobile robot for flatness inspection of the road to provide better monitoring and management on the road.

The designed system is able to find out the location and the flatness of the road. This project developed the system using PIC 18F4550, the PIC microcontroller controlling the entire program system developed. The system equipped with IMU sensor that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes. The input to this system would be distance and flatness of the road. While the output from this system would be the collected data and information which displayed in the computer with Graphical User Interface(GUI) develop using Visual Studio 2015.

With the result collected, it represented the current slope angle of the road and shows which location flatness is under standard, hence management team could carry out their management on the location.

DEDICATION

This report dedicated to:
my beloved supervisor;
my beloved parents.

ACKNOWLEDGEMENT

I would like to thank Mr Shahrizal Bin Saat as my supervisor for his guidance on completing this project. I would also like to thank all my friends that support me during working on this project.

First and foremost, we would like to thank to our Universiti Teknikal Malaysia Melaka (UTeM) for helping me funding this project.

Besides, we would like to thank to Universiti Teknikal Malaysia Melaka (UTeM) especially to the Department of Electronics & Computer Engineering Technology (JTKEK), Faculty of Engineering Technology (FTK) for providing us with good environment and facilities to complete this project. Thanks also to the Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) librarian and related staff for providing us valuable information throughout the project.

Finally, an honourable mention goes to our families, Mr Shahrizal Bin Saat and all members for their cooperation and supports on us in completing this project. Without helps of the particular that mentioned above, we would face many difficulties while doing this project.

TABLE OF CONTENT

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULT & DISCUSSION

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

IMU	-	Inertial Measurement Unit
GUI	-	Graphical Use Interface
VS	-	Visual Studio
I2C	-	Inter-Integrated Circuit
RPS	-	revolutions per second
PIC	-	Peripheral Interface Controller
MCU	-	Microcontroller
UART	-	Universal Asynchronous Receiver/Transmitter
I2C	-	Inter-integrated Circuit
ADC	-	Analog to Digital Convertor
GPS	-	Global Positioning System
DOF	-	Degree of Freedom
SSD	-	Selecting the Sensor Data
HHM	-	hidden Markov model
EMG	-	electromyography
HRI	-	human robot interaction
CMOS	-	Complementary Metal Oxide Silicon
DLL	-	Dynamic link library
LCD	-	Liquid crystal display
LED	-	Light emitted diode
G-forces	-	Gravitational force
DC	-	Direct Current
et al	-	and others

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the road flatness measurement issues. The problem background and problem statement describe the details of this project later in this chapter. This is followed by research objectives and scopes of study which involves the design and development of an autonomous robot for flatness inspection system.

1.1 Background

Along the road of highway, some of the location have improper flatness causing accumulation of puddles during raining time. The interaction between the road and the vehicle is affected by these puddles which decrease the efficiency of the vehicle tyres friction on the road, in particularly severe cases, even determine the loss control of vehicle skidding, therefore compromising the driver’s and passenger’s safety. Sometimes, road management team is not able to measure the flatness of the road accurately. Hence, this project purposely to design and fabricate intelligent mobile robot for flatness inspection of the road to provide better monitoring and management on the road. The designed system is able to find out the location and the flatness of the road which will later be proposed after this.

Figure 1.1. Accumulation of puddles on highway road during rain time.

1.2 Problem Statement

Sometimes, improper flatness of the road causes some serious problem like accumulation of puddles during raining time. The interaction between the road and the vehicle is affected by these puddles which decrease the efficiency of the vehicle tyres friction on the road and may causes accident due to loss control of skidding vehicle. This project investigate the design criteria required for road flatness inspection and measure the slope angle of the road surface along the highway. It is necessary for the road management team to carry out monitoring and maintenance on the road to measure the flatness of the road accurately. Beside issues of flatness, an exact location of road which have to be fixed also an important factor for them. The problem can be improved by introducing an intelligent mobile robot for flatness inspection to measure which location flatness is under standard, hence maintenance can be carry out by the management team.

1.3 Objective of The Study

The aim of this project is to measure the flatness of the road with an intelligent mobile robot for flatness inspection. The intelligent mobile robot will be able to carry out flatness measurement of the road automatically. The distance and location which is under standard will be recorded, so road management team can carry out maintenance more easy. The data and information received will be processed and displayed in computer with Graphical User Interface(GUI) which can be references and records for the road management team. With intelligent mobile robot carry out road monitoring job, it can ease the road management team to save more human resources and time. With the intelligent mobile robot for flatness inspection, it not just able to reduce possibility accident at improper flatness road surface area but also reduce the human resources and time.

1.4 Scope of The Study

An Inertial Measurement Unit(IMU) is used to collect angular velocity and linear acceleration data which is sent to the main processor. Inside IMU housing contains two separate sensors which is accelerometer and angular rate sensor triad. Both sensor will generate three analog signals output describing the accelerations and angular rate along each of its axes. MPU 6050 triple axis accelerometer and gyro breakout board is used to collect the data on the moving robot. The information from the sensor is then returned to the main processor via a I2C communications interface.

A Rotary Encoder is used to translate linear motion in to digital signal. It is used to determine the speed, distance and position of the robot while carry out measurement. The information will then be send though the center processing unit to the computer.

Visual C# language is used to describe the information of flatness and distance to user. It provided a way for interaction between user and the Visual Studio(VS).

1.5 Summary

In this project, there are five chapter in this project to describe and clarify the flow for this project. In first chapter, it includes the background information and objective of this project, relevant solution and method to solve the problem. In chapter two, literature review included the fundamental theory of the material and element used in this project. It also includes the review on the previous work from journal article, book and other sources. Comparison between previous work and current project will give better overview on knowing the method used in previous work and advantages of this method. In chapter 3, methodology describe the flow of the project and method used to accomplish the target output. In chapter 4 cover the actual results get from this project and discussion on finding. Lastly, chapter five will conclude overall result from this project.

CHAPTER 2

LITERATURE REVIEW

This chapter summaries prior works related to design an autonomous robot for flatness inspection system. It will cover the background and details of flatness inspection system. It also summarizes the usability of hardware and software that will going to be utilize to this project. Beside that this chapter will summarizes and discuss the past related research of flatness inspection system.

2.1 Introduction

Not all the highway road has the same flatness, and sometimes improper flatness can cause problem to road user. One of the major problem is accumulation of puddles during raining time. This puddles endanger the user where it decreased the fiction efficiency between the road and the vehicle tyres. Which will determine the loss control of vehicle skidding on the wet surface. As technologies evolved and instrument such as flatness measurement sensor, positioning devices etc. become affordable and well-known, an autonomous robot for flatness measurement inspection system is not no more a complicated project.

To solve the existing problem, an accurate flatness measurement inspection system is needed. With the autonomous robot that can carry out measurement inspection system on the road, this can ease the workload of the road management team. Hence more human resource and time can be reduced.

Yayan Prima Nugraha, Dwi Hanto, et al (2015) proposed a flatness measurement system that consisting of multiple sensors to determine whether railroads are flat [1]. The measurement system provided information about translational and rotational shifts from original position and angle in particular locations. The magnitudes of the shifts are obtained from IMU sensor that consist of accelerometer, magnetometer, gyroscope, air pressure and GPS. However, some sensor like magnetometer, air pressure and GPS are not necessary for my project that measure flatness of road.

Wahyudi, Ngatelan, et al (2015) proposed a multi-sensor IMU sensor to measure the angular rate and acceleration in three axes of the land vehicle navigation control system [2]. A sensor with high sensitivity has a short range of measurement, so to optimize the sensitivities of all sensors, a multi-sensor system will be applied in wide range of motion. This project proposed idea of optimize the sensitivity of all sensor is very useful as a reference to improve the accuracy of the data.

Ruben Usamentiaga, Julio Molleda, et al (2015) proposed a flatness measurement system using two laser stripes to remove the effects of vibrations [3]. The method used to measure the flatness is by projection of laser stripes on the steel strip. The lengths of the laser stripes on the strips fibers will be extract and further process and compute to flatness. The advantage of this method is easy to maintain, low-cost components and provide accurate results. The main drawback of this method is only measure the flatness of moving object.

Seong-Og Shin, Donghan Kim, et al (2014) proposed a project for controlling mobile robot using IMU and EMG Sensor-Based Gesture Recognition [4]. The proposed system can control the mobile robot by recognizing every gesture from the user. The body gesture is recognized using IMU sensor, where different direction of force acceleration and orientation recognized as different gesture. Although the project focus on Sensor-Based gesture recognition system, but it used mostly the theory of IMU sensor for collecting data from change of acceleration and orientation of the moving object.

Korrakot Surakul, Sucha Smanchat, et al (2016) proposed a project that used to detect accident by using device consists of inertial measurement unit (IMU) and also a 3G cellular module [5]. In this accident detection project, the IMU and odometry will be used to detect accident and the data of accident coordinate will be send out through cellular network to shown the location on map. This method is useful for flatness measurement with using of IMU sensor module to detect the orientation of the object itself.

Nana O. Abankwa, Steven J. Jhonston, et al (2015) proposed a project of measurement system on the vessel's motion by using inertial measurement unit (IMU) [6]. The data collected will be send through wireless method to the Raspberry Pi, this method is useful as a references to flatness measurement project. Besides, the method of transfer data over wireless method is useful and can be reference in the oncoming project.

Kovacheva, M, E. Stoimenov, P. Yakimov, et al (2014) proposed a research to study the basic characteristics and behaviour of the incremental encoders [7]. In this research, a digital circuit is design to generate the output signal from incremental encoder, the simulation allows to study the basic characteristics and behaviour of the incremental encoders. This research study the behavior and also the output waveform of the encoder gives references to this flatness measurement project as encoder is used to measurement displacement.

Arinata Fatchun Iimiawan, Dito Wijanarka, et al (2014) proposed a speed measurement for incremental rotary encoder using multi stage moving average method [8]. Classical theoretical algorithms which include frequency counting and period counting algorithm can reduce measurement error and increase the measurement accuracy for rotary incremental encoder is very useful for application in speed and displacement measurement.

Wang, Yu-Duo, and Li Bo, et al (2013) proposed a research to study the tools that are useful in handling mathematical operations and design user interface for developer [9]. Visual Studio IDE offers some function in Visual Basic that can handle complicated mathematics operations in scientific research and application design. This research is useful in this flatness measurement project, the method to handle the mathematical data for graph processing and tools to design user interface is one of the references in this project.

Sven Amann, Sebastian Proksch, Sarah Nadi, et al (2016) proposed a research on the Integrated Development Environments (IDEs) in order to understand how it is useful to the developers [10]. In this research, it is important to study how much time is developer spend on Visual Studio IDE and it assistance tools with code executions. This research is useful as the developer tools that been used can be references when choosing the tools to create graphical user interface (GUI) in this flatness measurement project.

2.2 Introduction of Inertial Measurement Unit (IMU) Sensor

Based on the journal article appear in 2015 International Conference on Automation, Cognitive Science, Optics, Micro Electronic- Mechanical System, and Information Technology (ICACOMIT), an Inertial Measurement Unit(IMU) is one of the unit in the electronic module that will collects both acceleration data and angular velocity which will then sent to the main processor [1]. Inside the electronic module of IMU, it actually contains of two sensors which are accelerometer and gyroscopes.

An accelerometer is very useful for sensing the vibration or orientation of an object. The acceleration measurement can be divided into two type which is static and dynamic acceleration. A static forces of acceleration is due to the gravitational pull of freefall object which measure in meters per second squared (m/s^2) or in G-forces (g). At any surface on the earth, an accelerometer at rest will indicate approximately 1 g upwards, because acceleration acting in upwards direction is relative to the local inertial frame. In outer space, an accelerometer will read only zero during any type of free fall. An analog accelerometer will produce a continuous voltage proportional to acceleration. While dynamic forces of acceleration are measured based on movement and vibration of the object itself. Accelerometer generates three analog signals along three axes x, y, z among it six's surface. The force can act in direction x+ or x- which means forward and backwards, with the same conditions goes for axes y and axes z. Hence it will be able to measure acceleration among all six surface.

A gyroscope is very useful to measure or maintain orientation. Unlike the accelerometer, a gyroscope will not be affected by gravitational force. Due to not affected by any linear acceleration based on vibration, a gyroscope is able to maintain its level of effectiveness and measure the rate of rotation around a particular axis. Gyroscope is used to sense rotation and measure angular velocity of the object itself. The measurement unit of angular velocity are degrees per second ($°/s$) or revolutions per second (RPS). Typically, a triple axis gyroscope can measure rotation around three axes which are x, y, z. But limitations of gyroscope are it often used on objects that are not spinning at a very high speed. Figure 2.1 shows IMU sensor measure angular velocity with three orthogonal gyroscopes and measure forces with three orthogonal accelerometers.

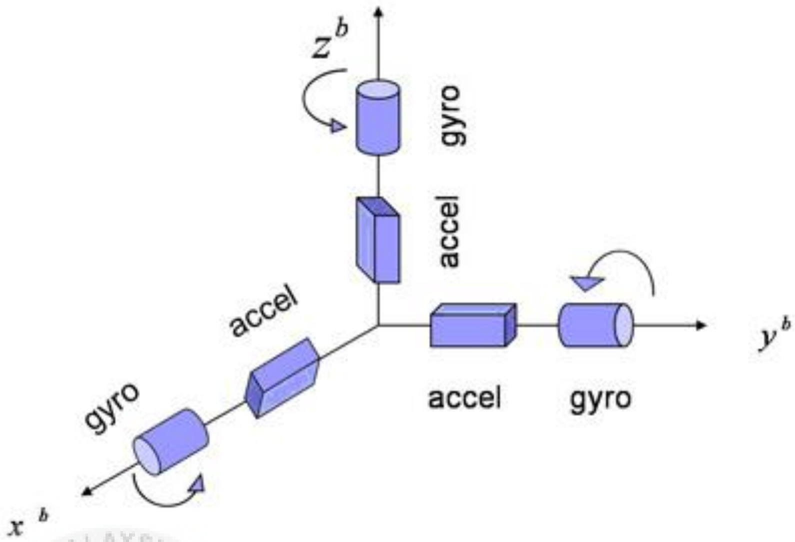

Figure 2.1: Conventional Inertial Measurement Unit.

2.3 Introduction of Rotary Encoder

Based on journal article appears in Microelectronics Proceedings – MEIL 2014, 2014 29th International Conference, a rotary encoder or sometimes called shaft encoder, is electro-mechanical devices that is used for sensing in myriad applications to converts angular positions of a shaft to analog or digital code. There are two type of rotary encoder which are absolute and incremental encoders. These rotary encoders normally used for tracking the motor shaft rotation to generate motion information and digital position.

Primarily, an absolute encoder is used to indicate the current of speed and position of the shaft. It made up of two disc with concentric rings with offset markers. One disc is fixed to central shaft, while the other is set to move freely. When the disc turns, the markers along the track of the absolute encoders will change position on the fixed disc. After that, a unique binary code is produced based on each configuration along the disc of the absolute rotary encoder. The output of absolute encoder is in binary form, so if you want to transform it into different output options, they have to be send to somewhere in a language that the system can understand. One of the advantage of absolute encoder is that it can maintain positions information even if the power source is removed from the system.

Incremental encoder is used to sense the motion of the shaft in order to get information from it, which give excellent speed and distance feedback. For every rotation of the incremental encoder, it gives a specified amount of pulses every one rotation of the encoder. For the output of the incremental encoder, it can be a single line of pulses which is an “A” channel or two lines of pulses which are channel “A” and “B”. A single channel output is used to detect motion only while dual channel output is used to detect motion and direction. For two lines of pulses, it is called quadrature outputs as they are 90 degrees phasing between the two signals. Each channel A and B produce square waves in quadrature with different of waves, it can be decoded and the coding will show either clockwise or counter-clockwise rotation. Compare to absolute encoders, it only involved few sensors in the system, so it is more simple and also inexpensive. Advantage of incremental encoder is that it can be used in light duty application up to a heavy duty which require higher temperature, shock and vibration application. Disadvantage of incremental encoder is that they can lose resolution at high speed due to output frequency limitation.

2.4 Peripheral Interface Controller (PIC)

Cited by Myke Predko from book titled Programming and Customizing the PIC Microcontroller 3rd Edition, for 8-bit microcontroller of PIC MCU, there are 4 families that we can choose from it for various of applications. The differences between these four families PIC is that they all have different processor architecture built into the chip itself, function of the sophistication of the processor give many peripheral functions to the chips. So if the sophisticated peripheral functions in the chips is advanced compare to other PIC, the processor is more capable to be used.

It is important to notice that the mid-range processor architecture of microcontroller made from the Microchip are used in various application or project. This is due to the widest range of peripheral enhancements for the mid-range PIC MCU families. Because of the good diversity in memory sizes, features and peripherals, it is very famous for various application that need the solution from PIC microcontroller. Microchip has made the mid-range PIC microcontroller an advanced version of low end PIC microcontroller architecture as they had enhance is it by adding more registers that are available to be interrupted. Mid-range PIC microcontroller also have the advantages from adding numbers of advanced input and output peripheral devices compare to the low-end microcontroller.

2.4.1 PIC18 Devices

From all these PIC families of microcontroller, PIC 18 family are very useful and suitable for various kind of application because it is an enhanced type of processor that make it more capable compare to the other PIC microcontroller among mid-range family. There are many advantages that choosing the PIC 18 processor, which includes: 4K of file and hardware registers, extended oscillator choices, one megabyte of instructions available to be address in program memory and enhanced ICD capabilities.

PIC 18 processor has 16-bit instruction word and instruction set which make can share the same source code with other mid-range devices. Beside that, it compatibility makes it more easy when work with other mid-range or even low-end devices where it can share the code or programming tricks between the architecture. By increasing the memory access and also the oscillator options, the capability of PIC 18 had been improved when read and write for the stack.

2.4.2 Analog to Digital Convertor (ADC)

In real life, many existing electrical signals around us are originally in analog form. These electrical signal come from variety of sensor like example temperature, pressure, light or force. The output voltage of these sensors are normally varies to the sensitivity of the sensor itself. For examples in a temperature sensor, the output voltage varies according to the temperature, so to be able to measure temperature, it is necessary to measure the voltage first. But most of the computer or microcontroller are digital in nature, they can only differentiate between HIGH or LOW level from input pins. To be able to measure voltage directly from microcontroller unit, PIC 18F4550 have an Analog to Digital Convertor (ADC) built-in in the microchip.

One of the most important specification of ADCs is the resolution, it specifies how accurately the ADC can measure the analog input signals. The ADCs of PIC 18F4550 is 10 bit. If the reference voltage of ADC is 0 to 5V, then a 10 bit ADC will break it in 1024 divisions so it can measure up to 5/1024 V = 4.88mV.

The reference voltage of PIC 18F4550 specifies the minimum and maximum voltage range of analog input. Minimum voltage represent Vref- and maximum voltage represent Vref+. If input signal Vref- is applied to analog input channel, the result of conversion is 0 and if input signal Vref+ is applied to the input channel, the result will be 1023. PIN4 and PIN5 of the PIC 18F4550 are Vref- and Vref+ input pins. Sometimes, ADC module is connected to several channels via a multiplexer. The function of the multiplexer is to connect any available channels with the input of the ADC. This allows user to connect many analog signals to the MCU. There are 13 analog input channels for PIC 18F4550 which is named as AN0, AN1 etc.

Acquisition time is the time that internal holding capacitor needed to fully charged and become equal to the applied voltage from the selected input channel. Inside PIC 18F4550, the ADC provides a programmable acquisition time where it is possible to setup the acquisition time. The acquisition can be set if it is over a period of time, the input channel is disconnected from the source and conversion begin. There are several factor that will influence the acquisition time like source impedance, Vdd of system and temperature.

ADC clock is the clock source needed to do its conversion for the ADC. The time period of the ADC clock is called TAD which is the time required to generate 1 bit of conversion. ADC requires 11 TAD to do 10 bit conversion where it can be derived from the CPU clock by a suitable division factor.

2.5 Reviewing on Previous Work

Reviewing on previous work give more idea and sources of references when developing a new project. The idea on how to progress a project or research give better understanding on organize the flow when designing and developing a project. Some practical example and method is more relevant and helpful when developing a project.

2.5.1 Previous Work related to Flatness Inspection System

Reviewing from this journal article appear in 2015 International Conference on Automation, Cognitive Science, Optics, Micro Electronic- Mechanical System, and Information Technology (ICACOMIT), this project focus on develop and design flatness measurement system primarily for railroads transportation safety issues [1]. In this journal article, the method used to measure the flatness on railway is by using Inertial Measurement Unit(IMU) sensor. It is used to measure the translational and rotational position and angle of location on the railways.

The Graphical User Interface(GUI) in this journal article is pair with LabVIEW software to display the data collected from the sensors which includes angle, position and the location of the railways. An accelerometer sensor is used to detect the translational movement of the train when moving along the railways. A gyroscopes sensor is used to detect the rotational movement of the train when moving along the railway. It will provide the magnitude of the angular velocity on the railways itself. Measurement collected from the translational and rotational movement are use to determine the flatness of the railroad. A magnetometer sensor is used to determine the deviations of directions on the earth's surface coordination. To detect the exact location of railroad, a GPS is used to generate a database for recording data of current location. To be able to store the data when in offline mode, a SD Memory Card and a data logger is connected directly connected to the embedded board. The data logger after that will display all the results by using Matlab software. Figure 2.2 show how the overall system being developed, input from sensor system, implementation of data acquisitions and also integration of data logger.

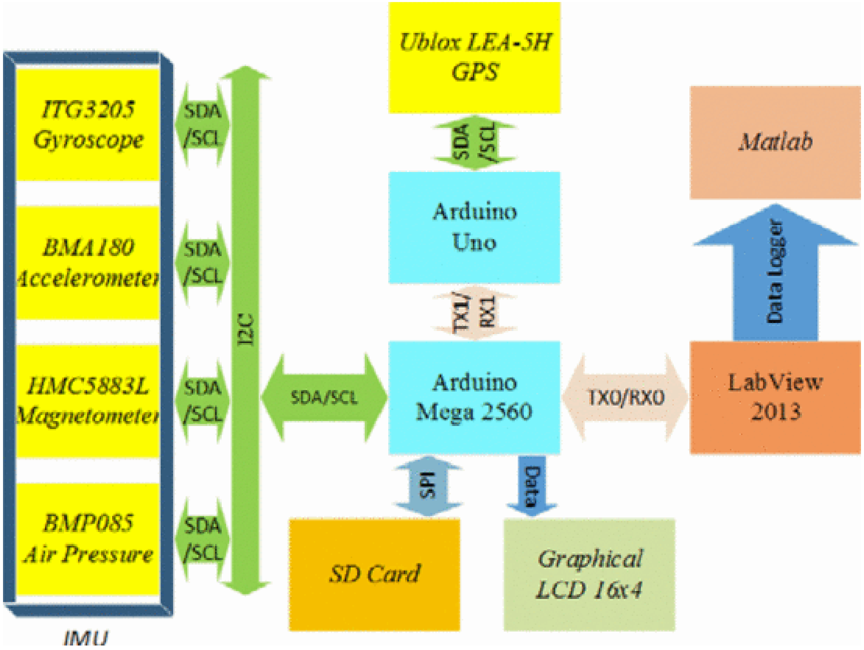

Figure 2.2: Block diagram of overall system.

From the reviewing the result of this article, it display the measurement data of three translational acceleration from the accelerometer with Cartesian axis of "X", "Y" and also "Z". The measurement from the translational acceleration is in units of "g" which is acceleration with refer to the center of the earth's gravity. In figure 2.3, it describe the information of the train is relatively not constant when moving along the railroad. It is due to the flatness of the railroad is not proper and constant with an average angle.

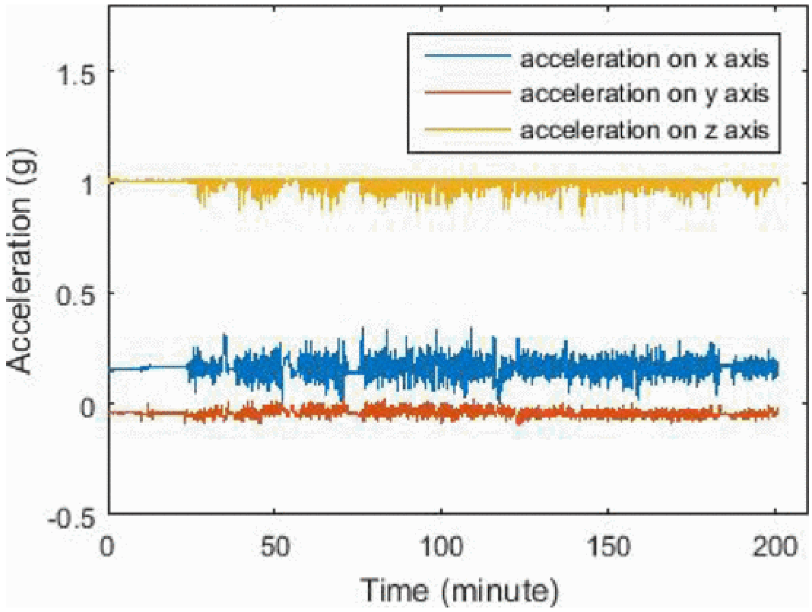

Figure 2.3: Acceleration measurement of accelerometer on railroad.

In figure 2.4, it give the information on how the train change in positions when moving on railroad. Same like the translational measurement, it also give three measurement on X, Y, Z axis, but is in positions rotational direction. Both the measurement from translational and rotational movement are firmly required for the flatness analysis. The measurement indicate and describe how the movement of the train is influenced when moving on the railway with different flatness from point to point. The result describes the flatness of the railroads with different result for each time and also positions. A GPS system is also use to send the information about the altitude of the train. It is important that GPS is very useful to measure location coordinate data and also determine the occurrence of unevenness coordinate of the railroad.

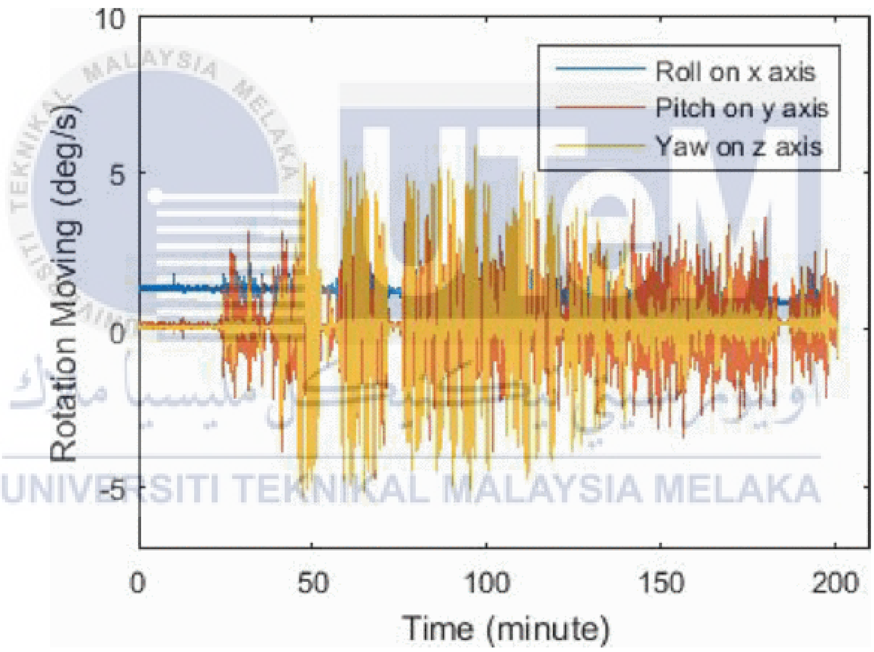

Figure 2.4: Rotational measurement of gyroscope on railway.

In conclusion, this research is more focused on how to design an instrumentation system to measure physical quantities that had shifts in positions. Reviewing from this journal article, the method used this project which are IMU sensor with accelerometer and gyroscope is very suitable and relevant for my project. The method used to measure the flatness of the railway is suitable as a source when designing an instrumentation system to measure the flatness of the highway road. For the graphical user interface(GUI), it is suitable to be used in my project because of it is able to work offline when transferring data and information from the main processor.

The method used to store the data by directly connected a SD Card to the embedded board is relevant to my project due to large memory size has to be used to store the data.

Reviewing from the article appears in 2015 2nd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), the project in this article focus on designing of multi-sensor IMU for land vehicle [2]. In this project, Inertial Measurement Unit(IMU) is used to measure the angular rate and acceleration along three axis of the land vehicle. For land vehicle, it is more likely to focus on the wide range of acceleration in x axis, with another angular rate in Z axis than the other two axis. But taking the advantage of high sensitivity sensor will decrease it range of measurement. So multi-sensor system is used to apply in wide range of motion in order to optimise the sensitivities of all sensor. When operating, microcontroller received acceleration data from x axis and angular rate from z axis. IMU sensor also has a good linearity of measurement in acceleration and also angular rate.

For a land vehicle, it has six Degree of Freedom(DOF), from both translational and rotational along the land vehicle axes. An acceleration sensor is used to detect the translational motions and angular rate sensors is used to detect the rotational motions of the land vehicle. Figure 2.5 show the wide range of acceleration in x axis with proportional to time. Figure 2.6 show the wide range of angular rate in z axis with proportional to time.

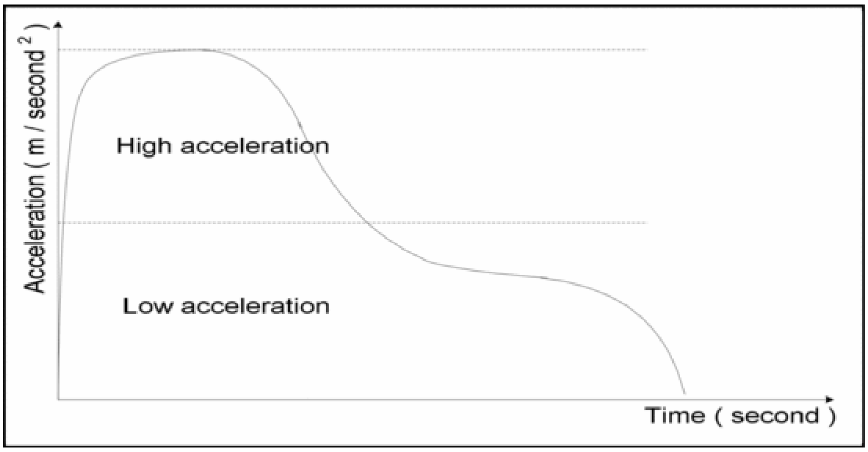

Figure 2.5: Acceleration level.

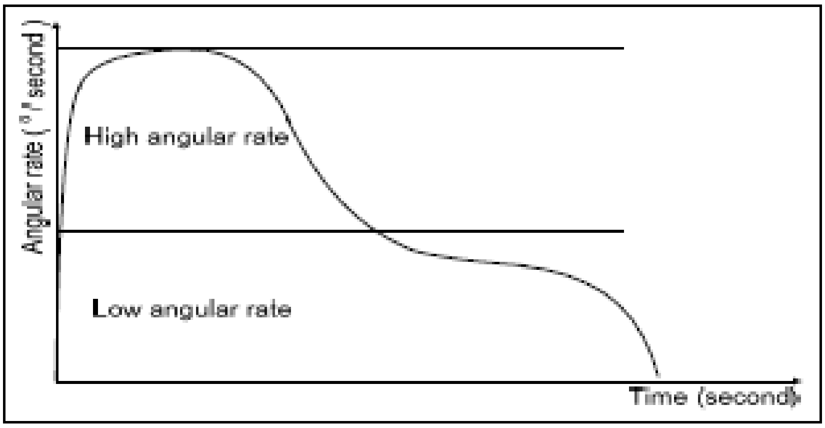

Figure 2.6: Angular rate level.

To design a multi-sensor IMU, it requires two types of gyroscope which are LPR503AL and LPR530AL and an accelerometer of MMA7361L. The two type of gyroscopes LPR503AL and LPR530AL are 2-axis gyroscope sensor with angular velocity of 30 degree plus minus and 1-axis gyroscope sensor with angular velocity of 300 degree plus minus. The sensor is capable to operate with voltage of a range from 2.7V to 3.6V and operate under temperature range between -40 degree to +125 degree. The accelerometer MMA7361L has ability of signal conditioning, a low pass filter, and g-select options which have two sensitivities option between 800 mV/g and 206 mV/g.

An IMU sensor consist of 4 accelerometers and 4 gyroscopes where 2 gyroscopes are reserved for z-axis and 2 accelerometers are reserved for x-axis. The microcontroller will received the outputs of 4 accelerometer and 4 gyroscopes via port A and port B. The output from the sensors are filtered by an analog low pass filter in order to reduce it noise. Microcontroller then process the sensors output to digital data to obtain 6 DOF data. Figure 2.7 show the design of the IMU.

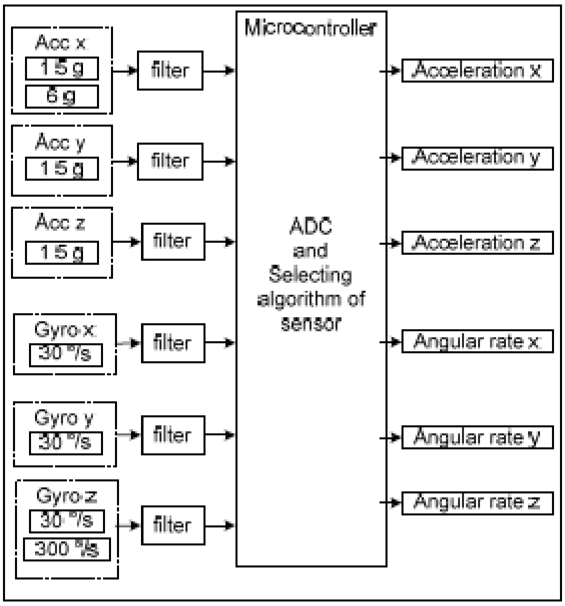

Figure 2.7: Design of IMU.

Calibration should be carry out before apply to the land vehicle. To carry out the calibration, a three-axis motion simulator model ST-3176-TC-10 is used due to it high accuracy positions and rate system. It I primarily designed for testing and calibrate high performances inertial guidance system and inertial grade sensors. The first axis with roll axis has maximum rate of 1000 degree per second. The second axis with pitch axis has maximum rate of 600 degrees per second. While third axis with yaw axis has maximum rate of 400 degrees per second. Calibration is carry out under room temperature with installed in chamber of standard device. Setup process of gyroscope and accelerometer calibration have two steps which are calculate scale factors and run test.

For designing of the software, a Selecting the Sensor Data(SSD) algorithms is used for acceleration and angular rate with higher sensitivity are shown as flowchart in figure 2.8 and figure 2.9 Microcontroller is programmed to read all the acceleration and angular rate data from the sensors. It is more accurate of measurement results as data were taken from sensor with high sensitivities.

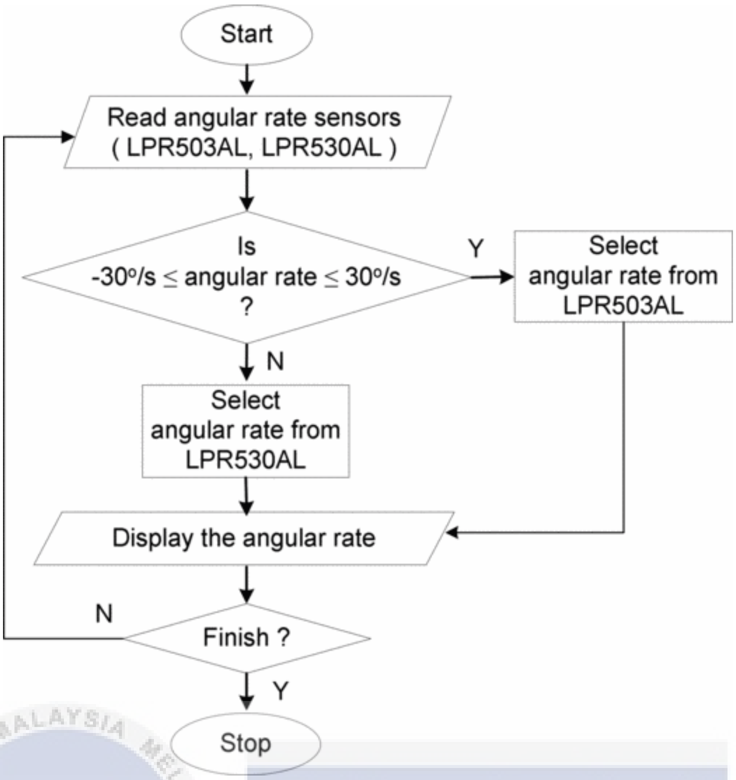

Figure 2.8: Flowchart of selecting angular rate data.

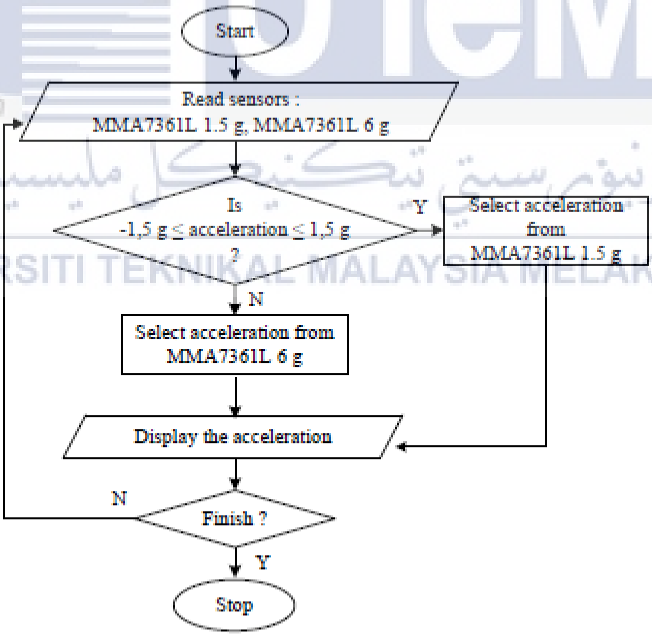

Figure 2.9: Flowchart of selecting acceleration data.

Reviewing the result from this journal article, testing of SSD algorithm is carry out with two type of acceleration. The first one is with MAA736AL 1.5g that work in limited value of acceleration of g value, while the other one MMA7361L 6g is still operating even out of the range between 1g to -1g. SSD algorithm will select a data with higher sensitivities, when acceleration is more than 1.5g or less than -1.5g, SSD algorithm select data from MMA7361L 6g. MMA7361L 1.5g is used to sense the normal drive while MMA7361L 6g is used to sense acceleration or sudden brake of the driver. Figure 2.10 show the result from this two type of acceleration, MMA7361L 6g is longer sensing range than the MAA736AL 1.5g.

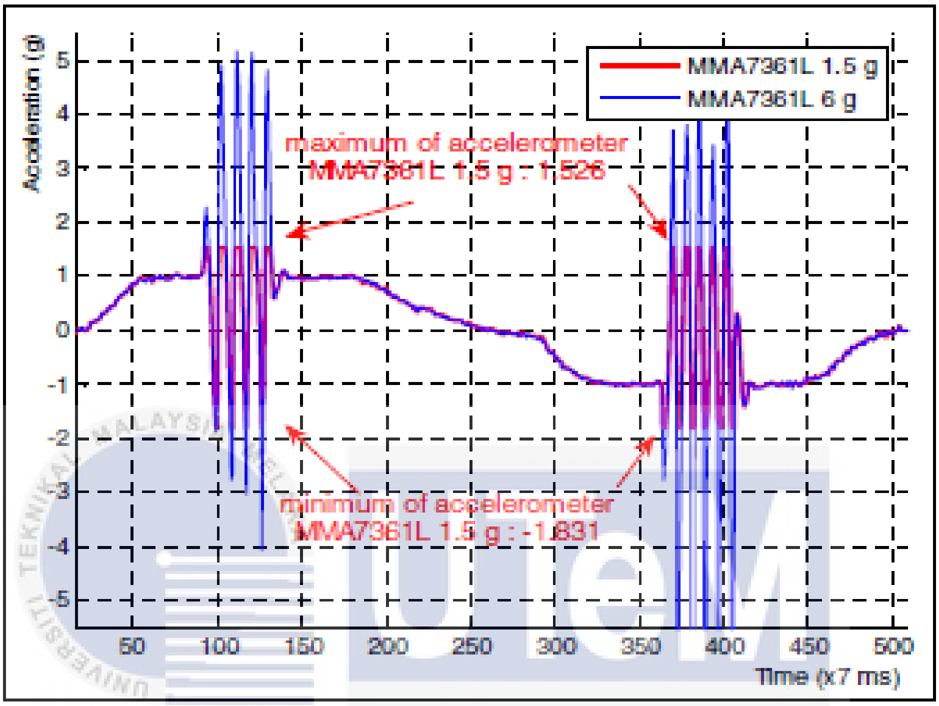

Figure 2.10 Acceleration on the test of SDD algorithm.

For the SSD algorithm of angular rate, two type of data is collected from LPR503AL and LPR530AL. The IMU then is rotate in clockwise and counter clockwise with certain range of angular velocity until there two type sensor reach minimum and maximum limit. LPR503AL have limited sensing range of angular rate, while the other LPR530AL still be able to detect a certain range of angular rate even though LPR503AL has been cut. SSD algorithm select the angular rate data from LPR503AL if its range is between -30˚/s to 30˚/s, if within range between -300˚/s to 300˚/s it will select the angular rate data from LPR530AL. LPR503AL used to sense normal drive of land vehicle, while LPR530AL used to detect suddenly rotates steering of the land vehicle. Figure 2.11 show the minimum and maximum angular rate of LPR503AL and LPR530AL.

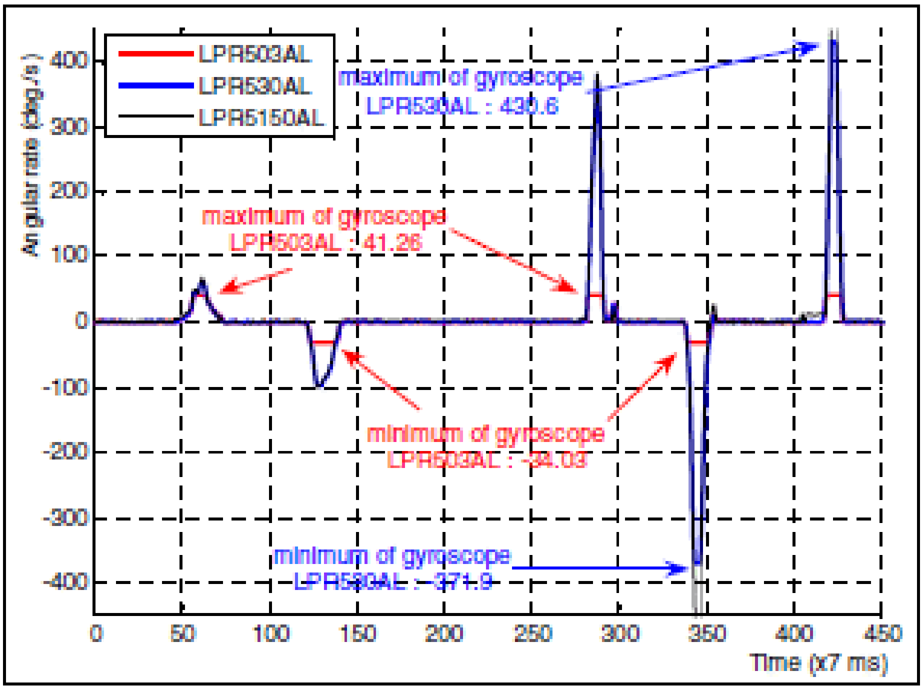

Figure 2.11: Angular rate on the test of SSD algorithm.

In conclusion, method from this journal article which is SSD algorithms method to test certain acceleration and angular rate is suitable and relevant for my project road flatness inspection system. The advantage of SSD algorithm selecting high sensitivities data from accelerometer and gyroscope will give and provide information of which one is the most suitable type acceleration for certain type of sensing range. One the other hand, it provides method of calibration process where real time error could me reduce by calculate the scale factors and run test on the sensor. The method of designing software is suitable as SSD algorithm is used to select the sensors with higher sensitivities, in order to obtain more accurate data results.

Reviewing from the journal article appears in Industry Applications, Sept 2015, IEEE Transactions on, it proposed the flatness measurement would be laser light-sectioning sensors [3]. The method used in this project is based on projection of laser stripes onto the steel strip while the steel strip rolling through the path. The flatness information come from extraction of laser stripes about the lengths of the strip fibers. This flatness measurement method has advantage such as low cost, easy to maintain which provides accurate results. But the disadvantage is that it will affected by vibrations which will cause the flatness result become inaccurate. A solution is proposed to overcome the problem which is using a second laser stripe where repeating measurement are able remove vibrations. To approach the experiment, combine the laser strips is needed to produce a vibration-free result.

The first method is measure flatness using one laser stripe based on 3-D reconstruction techniques. First, laser stripe is projected onto the steel strip with perpendicular to the movement of the object. Then, a machine vision application comoute height profiles and translate the coordinates into length units using a calibrated map had been set previously. The steel strip is repeatedly scanned and the movement is relative to the laser stripe. The movement of repeating scanning produce the results can be seen in Figure 2.12 Flatness is measured from considering the strips as multiple adjacent longitudinal fibers. If the fibers have different length, the system will generate different flatness information.

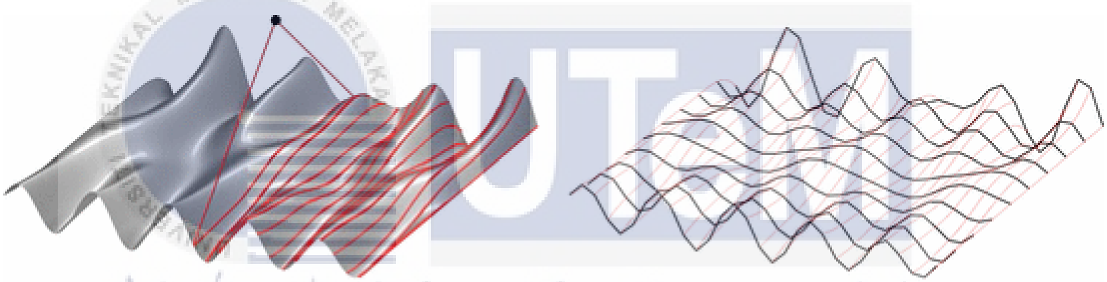

Figure 2.12: Flatness measurement based on noncontact techniques.

The second method is measure flatness by using two laser stripes as shown in figure 2.13 First, two laser stripes are projected on the strip and first image is acquired as shown in figure 2.13(a) from the projection. After that when the strip is moving forward, another new image is acquired as shown in figure 2.13(b). So the new image acquired by the laser strip on right is same position as the first image acquired by the laser strip on left. If the shape of the object between these two images is difference, then it is caused by the vibrations. Hence, redundant information is suitable to be used to estimate and remove vibrations.

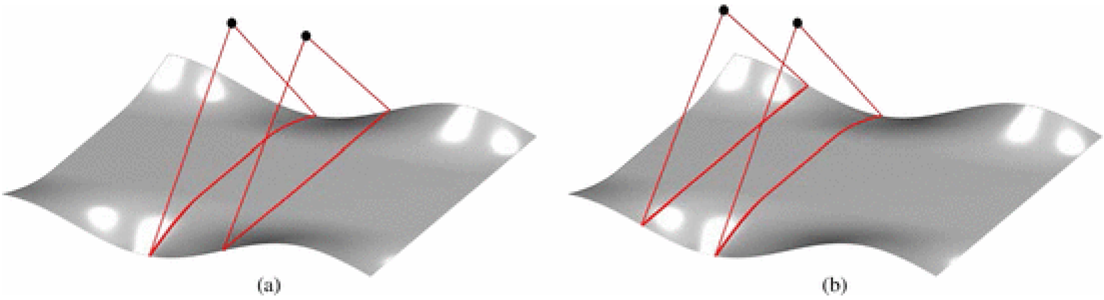

Figure 2.13: Rebundant information using laser stripes. (a) First image. (b) Second image with same positions of projected laser stripe.

An experiment is conducted on two different surfaces which is flat surface shown in figure 2.14(a) and curved surface shown in figure 2.14(b) with projections of two laser stripes and a camera. The camera equipped with interference filter that only light in the scene that emitted at a particular frequency will be capture by the camera. The images acquired by camera is the information of laser projection where figure 2.14(c) and 2.14(d) corresponding to flat and curved surface. After that the image captured by the camera is then extracted and the coordinates of the laser stripes is translated to world unit which is in millimetres. Then a previously calibrated map is used to translate the image coordinates to the world coordinates. This approach is intended to estimate and remove the vibrations by using laser stripes.

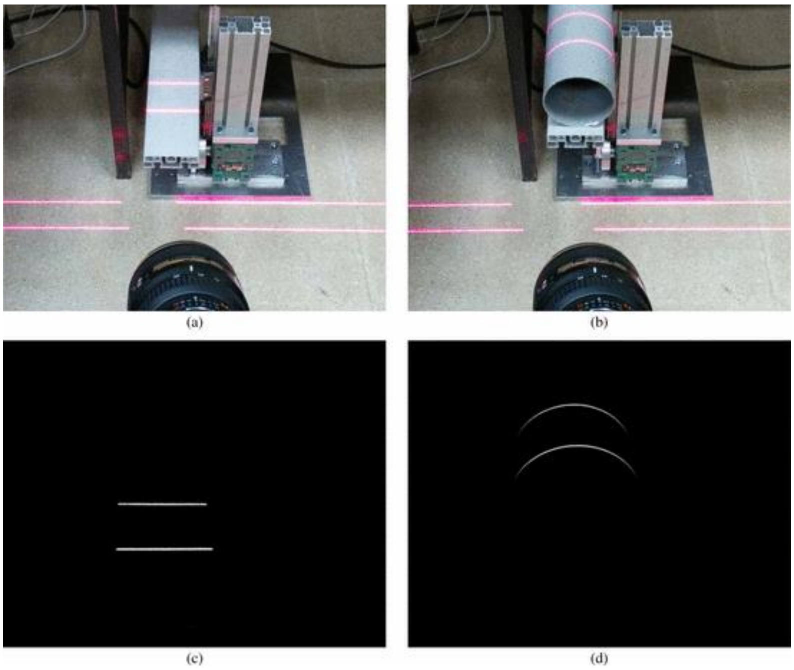

Figure 2.14: Images from prototype. (a) Camera and laser on flat surface. (b) Camera and laser on flat surface. (c) Image acquired by the camera from the flat surface. (d) Image acquired by the camera from the curved surface.

In conclusion, after reviewing this journal article, the method used in this project which is measure flatness using two laser stripes to remove the effects of vibrations is one of the suitable method to measure flatness. This method is easy to maintain, provides accurate results and low-cost component but having the disadvantage of difficulty carry out mechanical prototype. This method is used on the application of fixed position flatness measurement which is not relevant to be used as method of measure the flatness of the road. IMU sensor is more suitable due to it can measure orientation of the moving object continuously.

Reviewing from the journal article appears in Broadband and Wireless Computing, Communication and Applications(BWCCA), 2014 Ninth International Conference on, it stated that relationship between human and robot had been developed with many type of methods [4]. One of this method is speech recognition with gesture-based interaction, it is a system that control mobile robot with recognizing gesture from the user. The system use hidden Markov model(HMM) with inertial measurement unit and a electromyography(EMG) sensor. HHM is a rich formula system that not just applied on gesture recognition but also use for human robot interaction(HRI) with effectively. HMM is then used to generate a familiar interaction that to be recognize from the user to the mobile robot. Mobile robot is controlled by the user gesture according to the incoming EMG command signal via Bluetooth. Lastly, HMM is also a method for determining the accuracy of each posture from the user.

The gesture recognition system had been divided into three real-time categories which is measure the values of roll, pitch, yaw by using IMU sensor. Euler angle is measure in degrees, with continuously input signal from 3-axis sensors. The recognized gesture can be divided in to four gestures: move forward, move backwards, turn right and turn left. The first gesture is to rotate wrist in counter clockwise direction to indicate turn left gesture. The second gesture is to rotate wrist in clockwise direction to indicate turn right gesture. The third gesture is to drop the arm down to indicate forward gesture. The forth gesture is to raise the arm up to indicate backward gesture. The recognized gestures are relatively simple that can be used by everyone to control the motion of mobile robot when each gesture is taken. While EMG is used to implement the movement of the muscle of inner arm. EMG is used to recognize the levator scapulae muscle movement where “GO” and “START’ commands are given out. The first gesture is to set “START” commend where it is recognized as start to control the mobile robot according to the 3-axis data from IMU. While the second gesture is to set “STOP” commend to be recognized as change the current status of mobile robot to standby mode and also stop receiving data from IMU sensors. Figure 2.15 show four gesture to be recognized by using 3-axis IMU sensor.

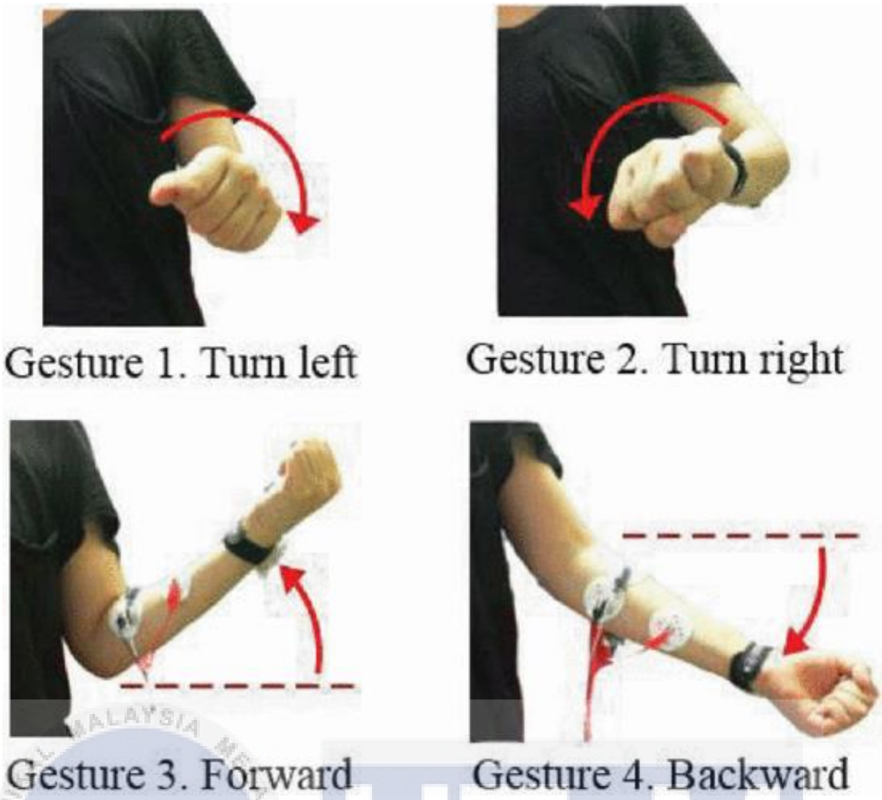

Figure 2.15: 3D accelerometer gesture performance.

The overall structure of this proposed system is to receive the signal from sensor, processed the data into gesture information, lastly is to transfer the data to mobile robot for controlling use. EMG is use to detect the signal by using sensor electrode following the movement of the arm muscle. IMU sensor then process the gesture movement with angular value as input data. HMM then is used to classified each gesture motion that to be used by mobile robot to perform the same determined gesture. The EMG signal have to be processed before the IMU signal as it decided to start or stop the mobile robot gesture.

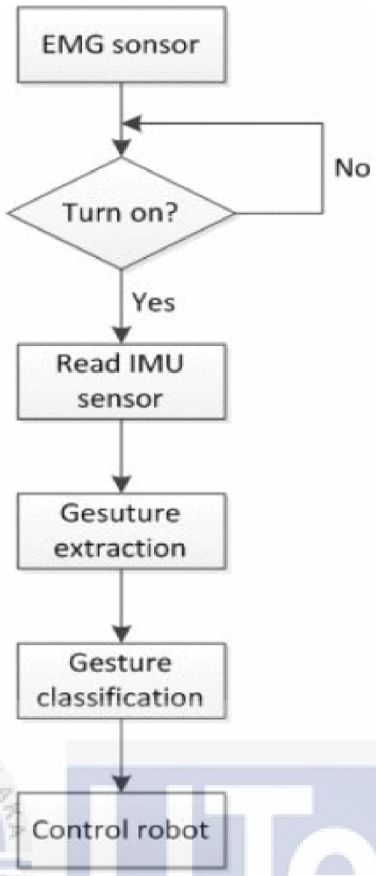

Figure 2.16: Flow chart of proposed system.

The experiments result is displayed with using MATLAB software. Microcontroller that been chosen to convert EMG analog signal to digital signal is Arduino UNO. Aduino first receive the signal from EMG, then was send to the PC via a serial communication and then converted to be displayed on the MATLAB. The input data is set at 1kHz and 128 samples of EMG signal as the threshold value in order to activate gesture motion. When microcontroller detected the force from the EMG sensor is greater than the threshold value, the system will started to recognized user gesture. In figure 2.17, the first graph result show the 3-axis IMU sensor value, the second graph show the result of yaw-axis value, while the third graph show the raw data of EMG sensor with voltage versus real-time. For every 10 milisecond, IMU sensor measured the arm force if it is greater than the threshold value.

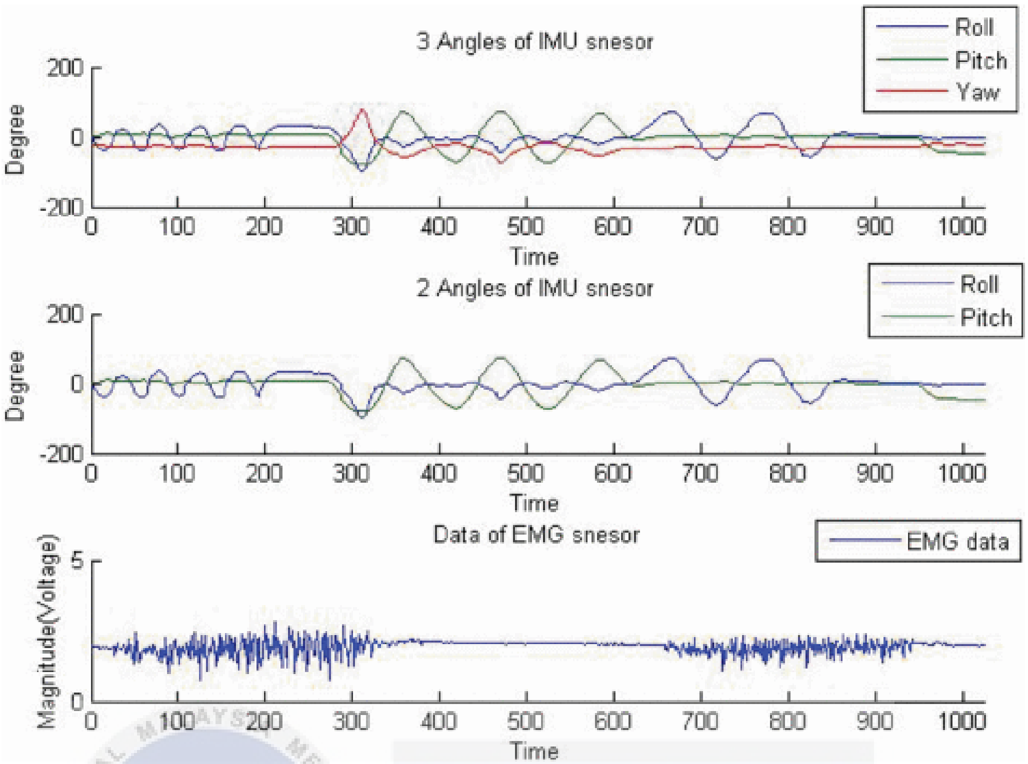

Figure 2.17: IMU sensor results.

In conclusion, after reviewing the project from this journal article, the method used to sense the gesture by using the 3-axis IMU sensor is very suitable and closely related to my project for road flatness inspection system. The method of how the IMU sensor sense and detect the motion from the arm by recognizing different angular value is related to how to measure the flatness of the road. While the HMM method used to classify the type of gesture that to be implement is somehow related to how to categorize the condition and flatness level on the road. The result of this gesture recognized system can be one of the reference when processing the data from the 3-axis IMU sensor. The results of 3 angles: roll, pitch and yaw are closely related due to it is developed from the fundamental theory of a 3-axis IMU sensor.

Reviewing from the journal article appears in 13th International Joint Conference On Computer Science and Software Engineering (2016), it stated that the use of device to detect the accident by using IMU sensor combine with the 3G cellular module [5]. In this project, IMU sensor is used to detect the accident and the collected data will be send out through cellular network in order to indicate the location of the accident in the map. The location of the accident is located by using GPS (Global Position System).

In this project, IMU sensor which consist of accelerometer and gyroscope is used to measure the velocity, orientation and gravitational forces of the car. The purpose of using IMU sensor is to detect the moving speed and the balance of the car. The abnormal reading from the IMU sensor will indicate the condition of the car, hence determine whether the car involved in accident. IMU sensor measure the data in three axis which are X, Y and Z, this data will then be processed to indicate the current velocity and movement of the car. Whenever there is accident occur to the car, the IMU sensor will show an unusual accelerations reading which indicate accident occurred. Also, if accident occurred the velocity of the car is relatively high and it tend to be a serious accident.

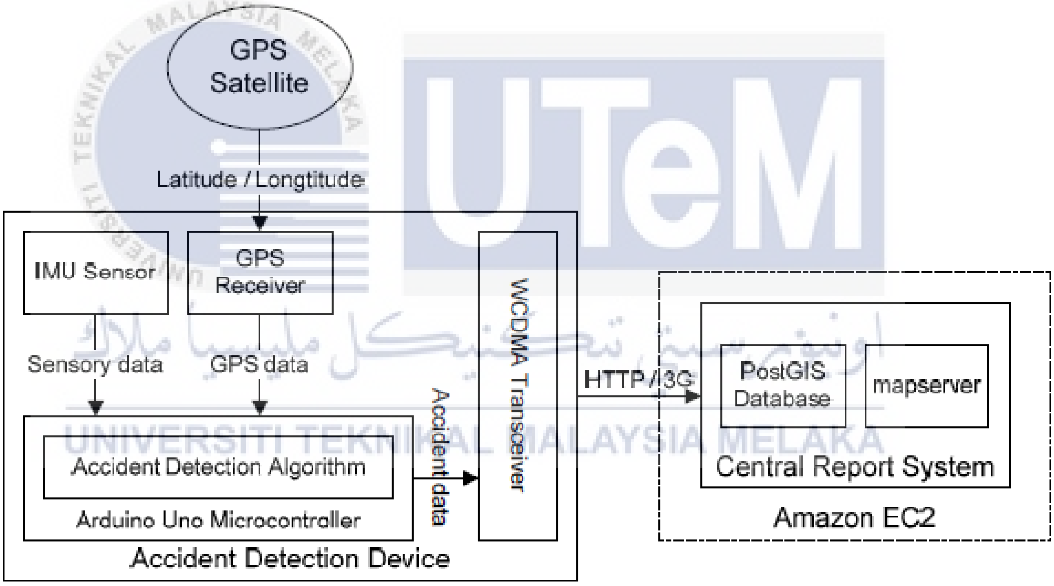

Figure 2.18: System overview

Figure 2.18 shows the design of the system overview to detect the accident of the car. Arduino UNO microcontroller is used as the central processor to process the input data from IMU sensor and GPS module. After that, the information of the car will be send out by using WCDMA transceiver to indicate the location of the car. On the other side, a report system is receiving the data and store the data in database.

In conclusion, after reviewing the project from this journal article, the method used to detect the accident by using IMU sensor and method to report the location of the accident by using wireless transmission is very useful in this flatness measurement project as the way to implement the IMU sensor to detect the accelerations of the car to determine accident. Besides, the to reduce the noise from the IMU sensor, Kalman's filter is used but it cannot completely eliminate all the noise of the data.

2.5.2 Previous Work related to Speed and Distance Measurement

Reviewing this journal article appears in Microelectronics Proceedings – MEIL 2014, 2014 29th International Conference, it explains the physicals implementation by using VHDL and development of behavioural model of rotary incremental encoder [7]. A digital circuit is design to generate the output signal from incremental encoder, the simulation allows to study the basic characteristics and behaviour of the incremental encoders. Result of output signals waveform between the physical model and simulation are being compare together.

Encoder is a mechanical device that that detect the coded pattern on a rotating disk and convert it to digital output signal like an electrical transducer. The operation of an incremental encoder is to generate a repeating waveform that is used to monitoring the motion of the rotating disk. A series of square wave will be produce when it began to rotates. Resolution on the encoder is depend on how many number of square wave cycles are produce per on turn of shaft. The number of the pulse in the encoder is the number of tracks of opaque lines on the disc itself. An incremental encoder usually has two channels (A & B) that are offset to one of each other by a cycle of 90 electrical degrees. The signals pattern allows user to determine the speed and also direction of the rotation. The relationship between Channel A and B explain the direction by determining the channel inputs. If channel A leads channel B, it is counter clockwise rotation. If channel B lead channel A, it shows the input shaft turning direction is clockwise rotation. Figure 2.19 shows the relationship of the encoder output signals. For a turning disc, the sensing on the opaque line on the disc give generate signal either raise or fall of the output square wave.

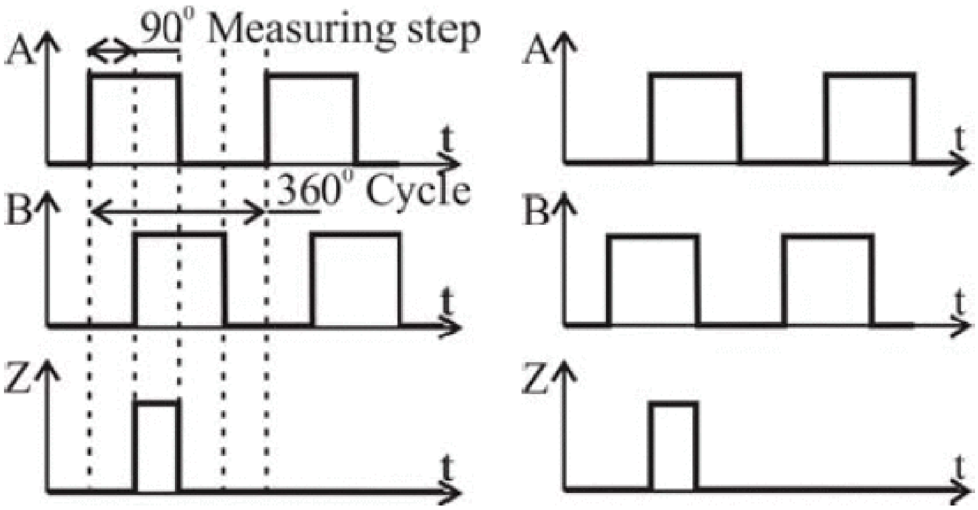

Figure 2.19: Output signals relationship.

Real time simulation is carry out with a proper electric circuit that can produces output signals to represent the behaviour of the incremental rotary encoder. In the circuit design, an advanced CMOS combinational and sequential logic are included. The speed of the rotation is determined by using digital stimulus DSTM3 to adjust and editing the frequency of output signals A and B. The D flip-flop acting as a frequency divider and act as a main part of the circuit that generate signals. XOR gate after that will produce signal with 90 electrical degree phase shift by normal output of flip-flop. The signal from the output of the flip-flop is inverted so it will lag the output signal of XOR gate. If the output of XOR gate id produce signal A, then the other part in the circuit will be produce the signal B and change the direction of the rotation. To determine the relationship between signals A and signals B, input of the REF was applied with an external logic signal. To complete the set of the signals, another signal Z also needed for the rotary encoder. The circuit will continuously produce pulse for every predefined outputs of A and B. The output of the counter will decide the number of cycles of A and B signals per every one turn.

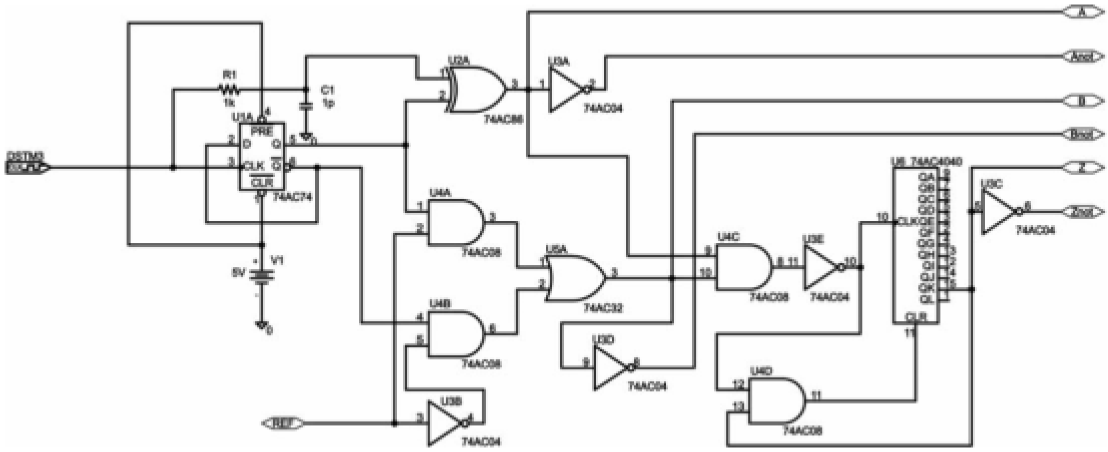

Figure 2.20: Behavioral model electric circuit.

To get the result, a standard digital four channel oscilloscope is used to measure the physical model. The input clock signal set at frequency of 10kHz and amplitude of signal with 3.3V. Figure 2.21 shows the four output channels, A(CH3), B(CH2), Z(CH4), Z_INV(CH1) when signal is set with 1. It shows that A is leading B with shifting of 90 degrees where indicate it is rotate in counter clockwise direction. If signal B is leading signal A, its indicate the disc is rotate in clockwise direction.

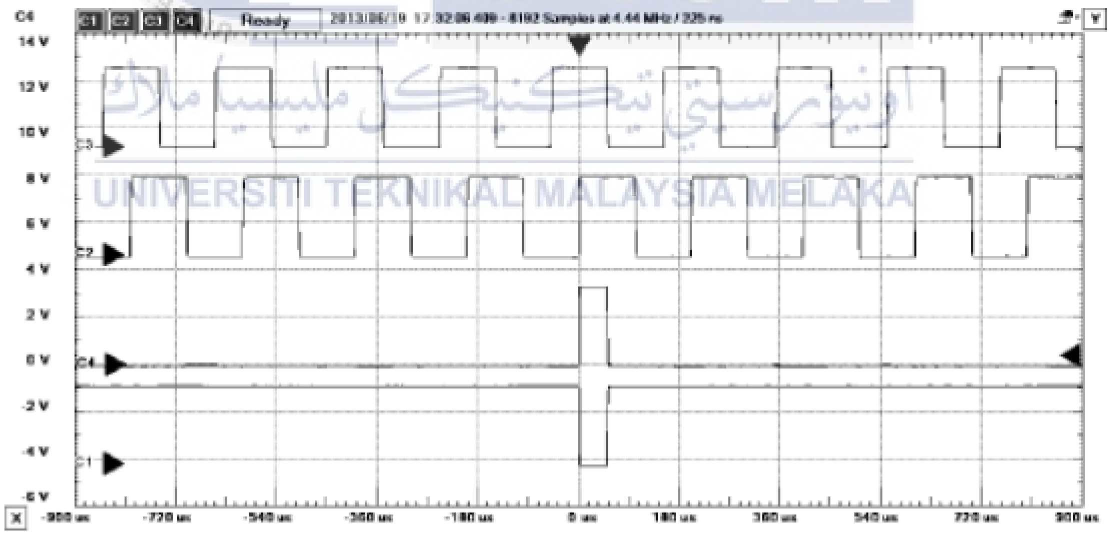

Figure 2.21: Output signals simulating CCW rotation direction.

In conclusion, after reviewing this journal article the method used to simulate the incremental rotary encoder is suitable and relevant for the project of road flatness inspection system. The theory and operation on how the outputs are produced from input pulse is suitable as a references for the purpose of speed and distance measurement for road flatness inspection where it can be used detect the location of the robot. The method used to measure the output of the encoder is also as a method that can be used to do calibration when apply in real application.

Reviewing this journal article appears in Electrical Engineering and Computer Science(ICEECS), 2014 International Conference on, it stated an easy speed measurement for incremental rotary encoder using multi stage moving average method [8]. Rotary encoder was used to measure displacement angle transducer where the information is provided by two pulse from output channel A and B, it will be then transmitted to the control system. User are able to measure the displacement angle from this information and calculate the speed of the rotation. Classical theoretical algorithm is used to calculate the speed of the rotation but have disadvantage over low and high speed. For low speed rotation, there are huge measurement error for frequency counting algorithm. Same with the high speed rotation, there are huge measurement error for period counting algorithm. So, a combination of both these two algorithms can achieve a better speed accuracy in speed measurement. A filter is needed to minimize the inaccuracy of speed measurement which cause the failure in FOC. Another moving average method is also used to reduce the noise.

For method used in this journal article, a multi stage moving average method was proposed. A speed transducer must be able to operate with a huge range of speed range, but there is measurement error in both low speed and high speed that have to minimized, so a scheduling mechanism is needed to achieve a smooth transition between frequency counting and period counting algorithms. For both algorithms, they have the same equation to obtain speed, so it can be simplified into an equation (1).

$$\omega = \frac{delta \cdot \varphi}{null \cdot T_s} \qquad (1).$$

The advantages of using this mechanism is that now the controller does not need to decide whether to use period or frequency counting algorithm to calculate the speed.

When there is no encoder pulse(delta) detected, the sampling period(Ts) controller will wait until there is encoder pulse again. To reduce the error from calculation, an average filter method is proposed to calculate the mean value of instantaneous speed, which written in equation (2).

$$\overline{\omega} = \frac{\omega_j + \omega_{j-1} + \cdots + \omega_{j-(i-1)}}{i} \qquad (2).$$

Beside using moving average filter method, an application of two stages moving average filter also be used to produce a better result than the single stage moving average.

For simulation results in a low speed region, comparisons are made from single stage moving average, two stages moving average and also combine of these two moving average. As seen in figure 2.22 and figure 2.23, measurement error of two stages moving average is much lower compare to the single stages moving average method. Figure 2.24 is the combination of single stage and two stages moving average in low speed region.

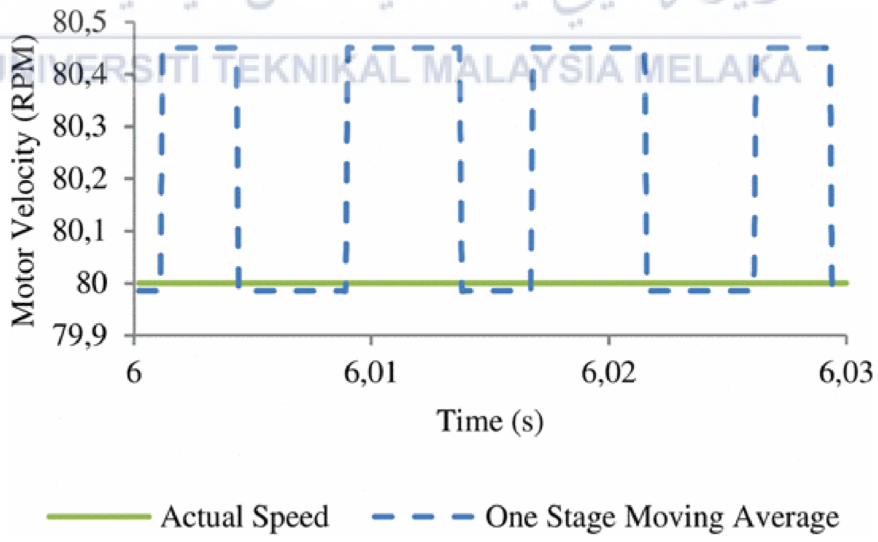

Figure 2.22: Simulation result for single stage moving average measurement in low speed region.

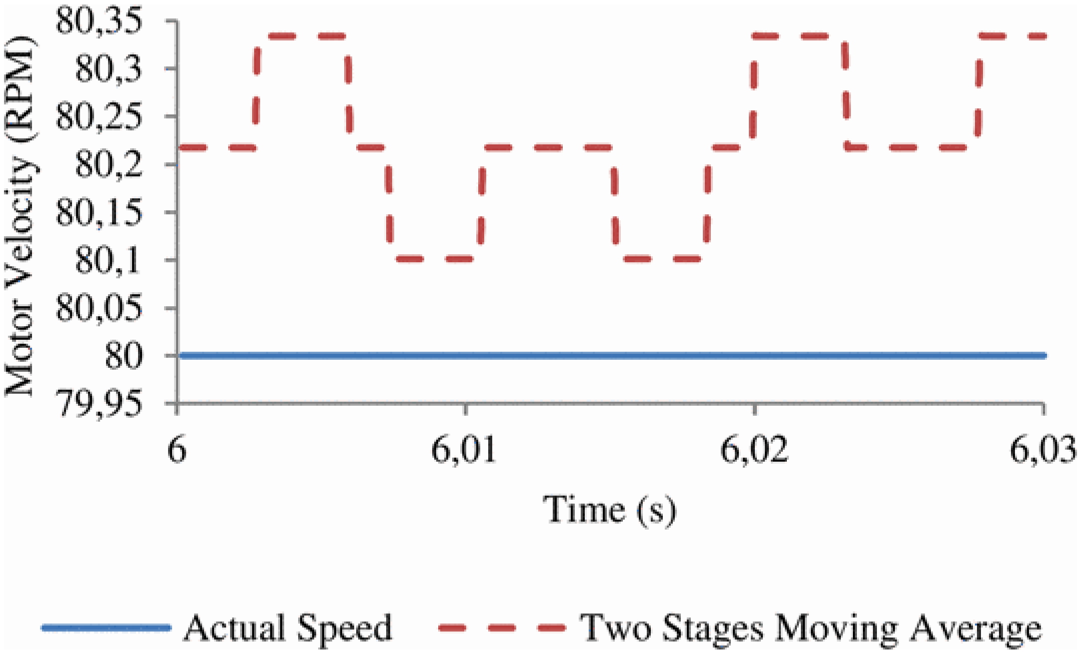

Figure 2.23: Simulation result for two stage moving average measurement in low speed region.

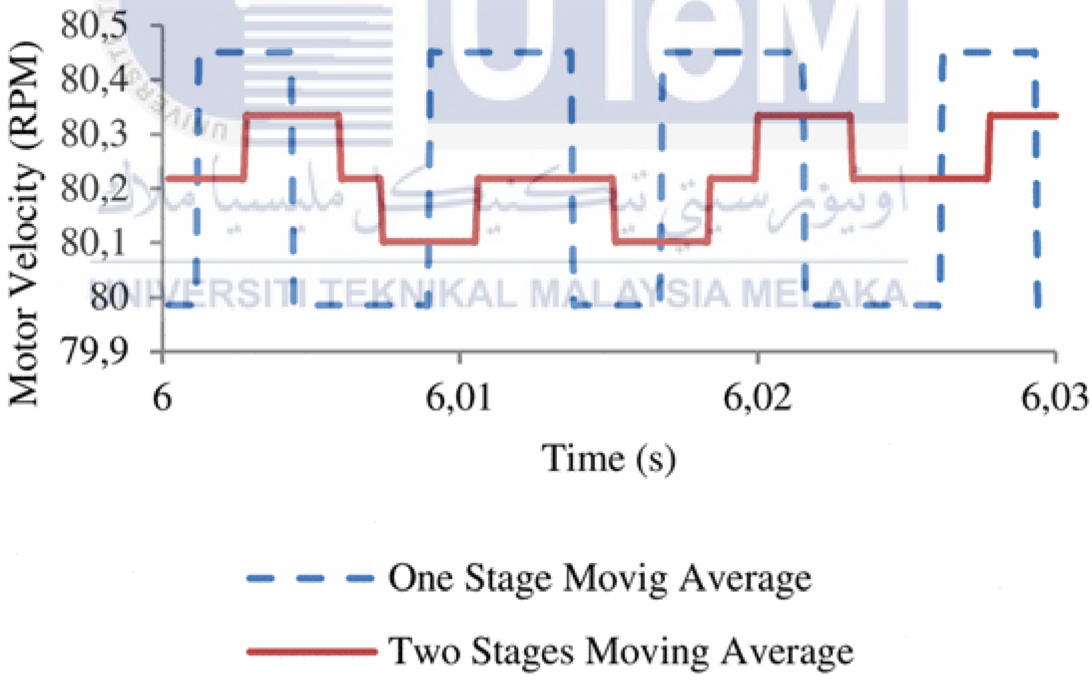

Figure 2.24: Comparison between single stages and two stages moving average in low speed region.

In conclusion, the method used to reduce the measurement error which use in this simulation is very useful for purpose of distance measurement in my project. The combination of frequency counting algorithm and period counting algorithm is a good method to increase the measurement accuracy for rotary incremental encoder. On the other hand, moving average method can be expanded to a multi moving average method, with this advances method more noise can be reduced. Because of only low speed mode is involve in my project, so the result of single stages and two stages moving average are more suitable and relevant references than the high speed region.

2.5.3 Previous Work on creating Graphical User Interface

Reviewing the journal article appear in Computational Intelligence and Communication Networks (CICN), 2013 5th International Conference on, it stated that some function in Visual Basic can handle complicated mathematics operations in scientific research and application design [9]. The integration of software MATLAB can also handle some complicated engineering software. This two software can be used to perform implementation of data statistic and FFT. Programmers are able to use this program to perform connections between dynamic link library(DLL) and object due to simplicity and procedure operation relatively easy. For MATLAB software, version 6.5 was launched by Mathworks Company, was added some powerful scientific calculating tools to perform data calculating and graph processing. These function includes digital signal processing, matrix operation, data integration. So for the Visual Basic 6.0, it is more to uses of researcher to design user interface, while for MATLAB 6.5 is used for programmer's arithmetic with fast development. Table 1.0 shows a listed function included in DDE.

Table 1.0: DDE Requesting Functions.

Function	Description
Execute	Receiving the string returned after MATLAB server executes command
GetCharArray	Receiving the data dimension come from MATLAB server
PutCharArray	Sending the matrix to MATLAB server

GetFullMatrix	Receiving the matrix come from MATLAB server
PutFullMatrix	Sending the matrix to MATLAB server
MaximizeCommandWindow	Displaying MATLAB server windows in Windows applications program
MinimizeCommandWindow	Displaying the minimized MATLAB server windows in Windows application program
Quit	Quitting from MATLAB server

In conclusion, the software Visual Basic 6.0 and MATLAB 6.5 are very simple and widely available for all programmer. But between these two software, there are some differences that allow programmer to choose for some program requirement with specific uses. For Visual Basic 6.0, it is for programmer who wants to develop interface for their research with more simple way. Visual Basic 6.0 is more suitable and relevant for my project measurement of road flatness inspection due to Visual Basic C++ 6.0 is more concision and perfect, while programming method to develop interface is relatively simple and excellence.

Reviewing the journal article appears in 23rd International Conference on Software Analysis, Evolution, and Reengineering (2016), it proposed a research to study the tools that are useful in handling mathematical operations and design user interface for developer [10]. Visual Studio IDE offers some function in Visual Basic that can handle complicated mathematics operations in scientific research and application design. An analysis was carried out to obtain the average time developer spend on Visual Studio IDE. Besides, the research also including the analysis on the useful tool that used by the developer and how they use it in non-industrial usage.

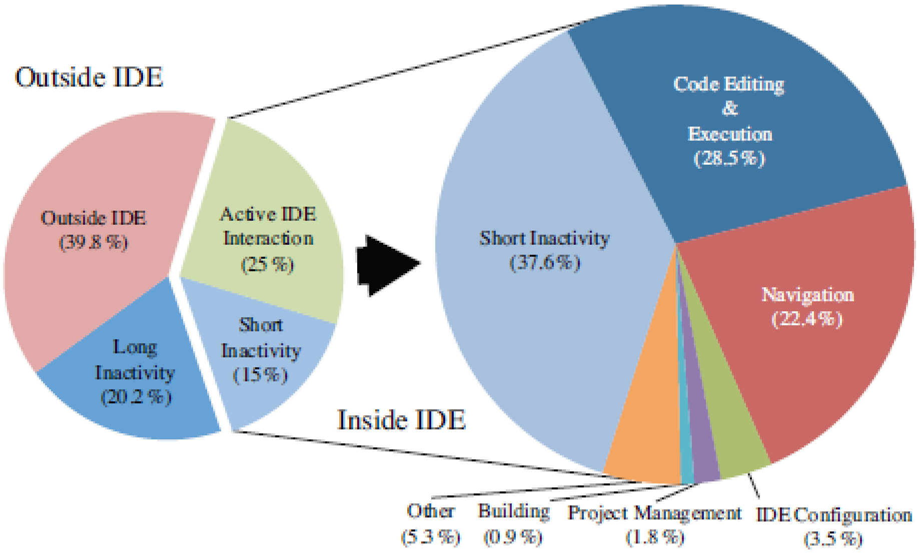

Figure 2.25: Developer's Time Budget

In figure 2.5, it shows the time of developer spend on Visual Studio IDE and also the IDE tools usage on each activities. Developer wound used C# language in editing coding and also the execution on the application. The time of developer who use C# language is higher compare to the Java language developer. The reason is the C# have more usage in code editing and also execution in the Visual Studios IDE. The research shows that the most frequently tools used by the developer is debugger and followed by searchers. The usage of debugger is to commands usage in coding line while for searchers is to search the textual and code that are mostly used by the developer.

In conclusion, the tools that are useful in handling mathematical operations and design user interface for developer is a references in this flatness measurement project when there is need of create a graphical user interface (GUI) to display the collected data for better monitoring the flatness of the road.

2.6 Summary

This chapter has discussed and covered the equipment and hardware that are necessary for this project and how it going to be implemented. Furthermore, this chapter has discussed the main equipment that are necessary for a flatness inspection system. Previous work that were related to this project also been discussed.

CHAPTER 3

METHODOLOGY

In this chapter, the system design for the autonomous robot for flatness inspection will be clearly explain with the simulation and flow chart. The method that will be use is present in flow chart form to clarify the overall general strategy will be taken on this project. In this part, all the important element of the task will be cover to clarify the specific goal of this project. The system design to accomplish the specific task will also be discussed in this part. Other than that, hardware equipment and development of programming will be clearly explain to clarify the connection between software and hardware of whole system. Lastly, the field of application and weakness of this project will also be discussed.

3.1 Introduction

In methodology, it includes finding an appropriate title for the project and research through the journal or article. Next, there are planning on a project design and equipment that is necessary, project's hardware and software implementation, flowchart of overall progress and report writing.

3.2 Overview of System

In this part, the operation of the whole system for this project will be discussed. The block diagram as shown in Figure 3.1 is the flow of the system. The block diagram described the input and output of the system.

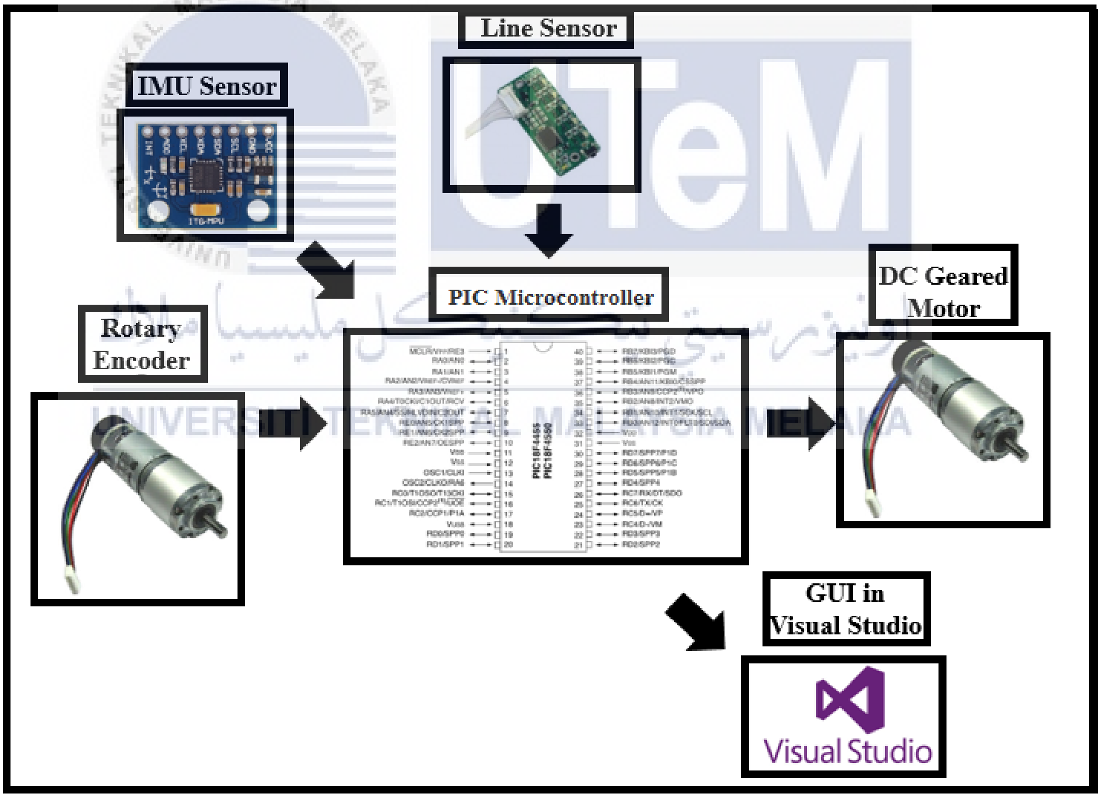

Figure 3.1: Block diagram for flatness inspection system.

The block diagram started with the autonomous robot measure the flatness of the road and send to the PIC 18F4550 microcontroller. After microcontroller processed the analog signal to digital signal, it will be send to the computer via serial communication by using UART module. After that the flatness information will be handle by using Visual Studio 2015 software. Graphical User Interface (GUI) is created in Visual Studio 2015 to display the flatness information in 2D view of flatness versus distance.

3.2.1 Flowchart of the project flow.

The flowchart represented the flow and the technique used to demonstrate the progression to accomplish the target have been set for this project. Figure 3.2 below is the diagram of the methodology flow chart that will be undertaking to demonstrate the project.

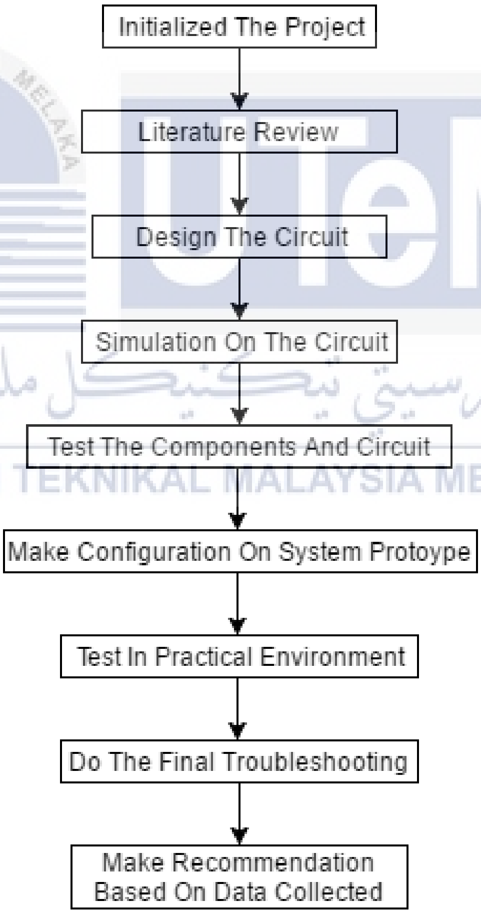

Figure 3.2: Flowchart of project flow.

3.2.2 Flowchart of Overall Progress

Flowchart of overall progress described the flow of the project from fundamental input element to desired output with complete information. A progress flowchart is a picture that shows the separate steps of a process in sequential order. The input and output of every step or process have to be well positioned in order to synchronized the whole system of the project. Figure 3.3 is the flowchart of the overall progress.

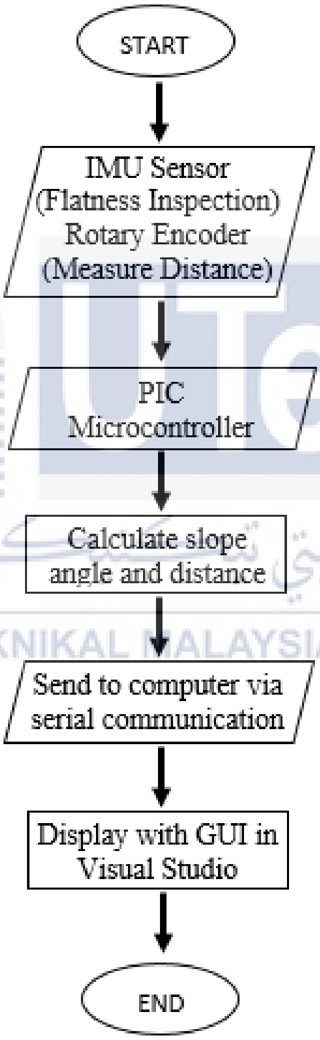

Figure 3.3: Flowchart of overall progress.

3.3 Project implementation

There is numerous strategy that can be taken to document the project's tasks to enhance the upcoming studies. Within these strategy, it primarily response for accomplish the target goals and gain awareness on ideal result and output of the project. On the other hand, it reminds the associated target date and status of the project within the progress flow. There are few stages before the task assessment:

1. Project planning
2. List of project task
3. Review and choose device
4. Experimental testing
5. Report writing

3.3.1. Project Planning

Project planning is undertaking to arrange the needed step and procedure to accomplish specific task like a timetable as reference for every finished progress. At first, the task arrangement had to be characterized and fitting the strategies based on the target goal on this project. In this project, the arranging stage are divided into few parts includes accumulation of the information, review the equipment information and programming necessity.

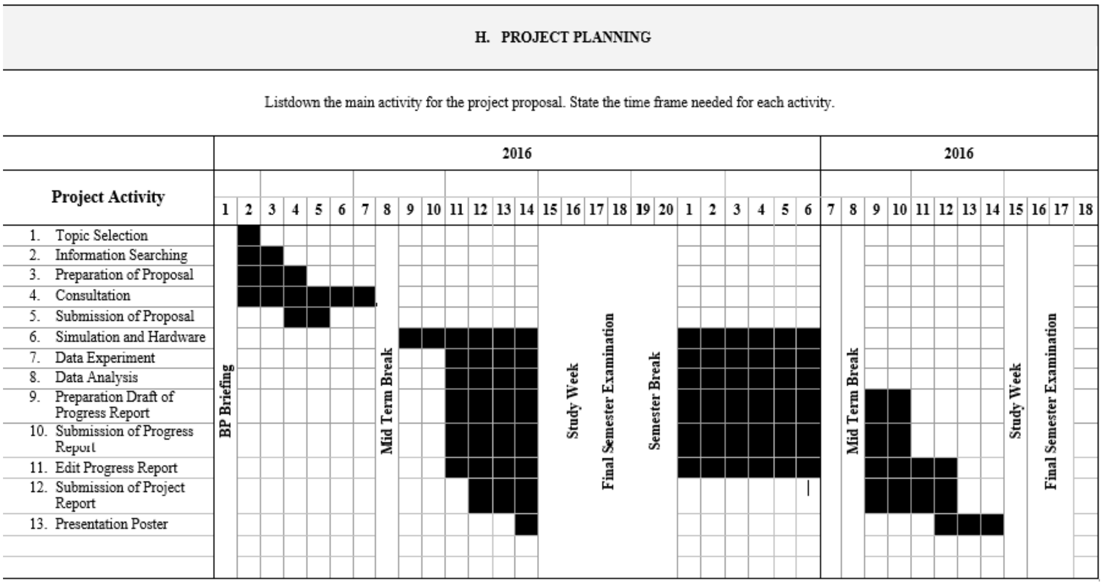

Figure 3.4: Gantt chart.

3.3.2. Data Collection

Data collection is a process of collect and measuring information. It is a step to be undertaking at the beginning of the study on the variable that related and interested, it also enabled one to answer the research question and evaluate the outcomes of project. All the information and material for this project are collected from many sources such as references books and journal article. The sources where gathered come from library, internet and also journal.

3.4 Hardware Development

The PIC 18F4550 were used as a microcontroller in this project. All the pins on this microcontroller and connections with other peripherals will be discussed in this section. Other peripherals include Inertial Measurement Unit (IMU) sensor, Rotary Encoder, LCD screen, motors and LED. It responsible to process the analog information received from IMU sensor and rotary encoder to another digital form information. The processed information is then transfer to computer via Serial Communication, a Graphical User Interface(GUI) is created in Visual Studio to present the information in 2D graph of angle versus distances.

3.4.1. Electronic Hardware

PIC 18F4550 microcontroller is one of the PIC 18 series family microcontroller made by Microchip manufacturer. PIC 18F4550 is one of the famous microcontroller nowadays due to good diversity in memory sizes, features and peripherals. PIC 18F4550 have 40 pin DIP with 35 input/output pins with individual direction control. PIC 18F4550 consist build-in Analog-to-Digital Convertor with up to 10-bit for thirteen Channel, External Clock Modes with up to 48MHz, 16 kBytes OnBoard Flash Program Memory, USB V2.0 Compliant with up to 12 Mb/s at full speed and Secondary Oscillator clock input up to 32kHz. This microcontroller can transfer or receive data from a computer via USB cable.

3.4.2. IMU Sensor and Rotary Encoder Implementation

IMU sensor works by collects both acceleration and angular velocity data. Accelerometer measures the forces of acceleration in 3 dimensions with refers to gravitational pull. Accelerometer generate three analog signals along 3-axis which are X, Y and Z, it generates continuous voltage with proportional to the acceleration. Accelerometer will measure force act by the gravity when robot moving on the road surface of difference flat rate, the measurement unit is meters per second squared (m/s^2) or in G-forces (g). Gyroscopes measure the orientation of the object body but will not be affected by the gravitational force. It measures the rotation and angular velocity making it suitable be used for inspection on road flatness. Gyroscopes measure change of angular rate when the autonomous robot moving on the highway road. The measurement unit of angular velocity are degrees per second (˚/s). After accelerometer and gyroscopes collects the data of the flatness of the road, IMU unit will send the data to the microcontroller for further process to digital information. Figure 3.5 shows IMU sensor measure angular velocity with three orthogonal gyroscopes and measure forces with three orthogonal accelerometers.

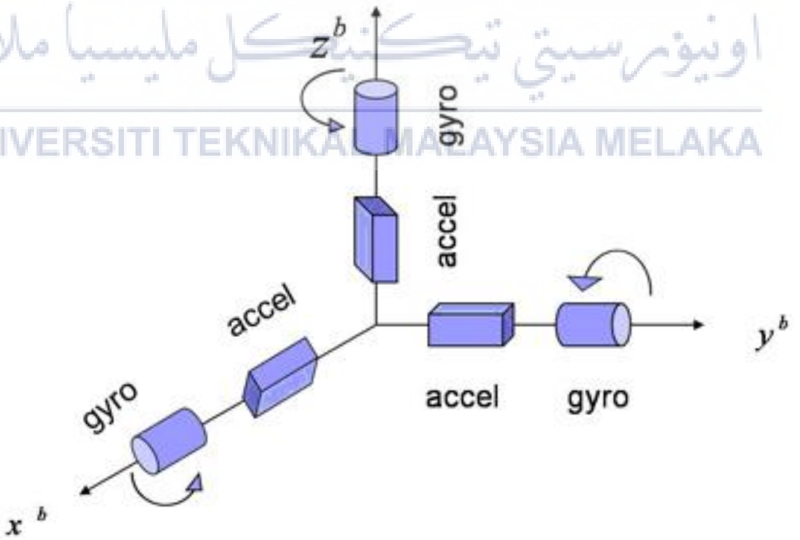

Figure 3.5: Conventional Inertial Measurement Unit.

Rotary encoder is used to measure the direction of rotation and also the distance travelled by the autonomous robot. Rotary encoder works by sensing the opaque segments that block the light when rotating. For every opaque segments block the light, rotary encoder will generate pulses, and this pulses will produce square wave pulses, which will then be interpreted into motion and linear position of the rotating shaft. The pulses send to the microcontroller will then be calculated to amount of displacement travelled. Figure 3.6 shows the output waveform of channel A and channel B in clockwise direction.

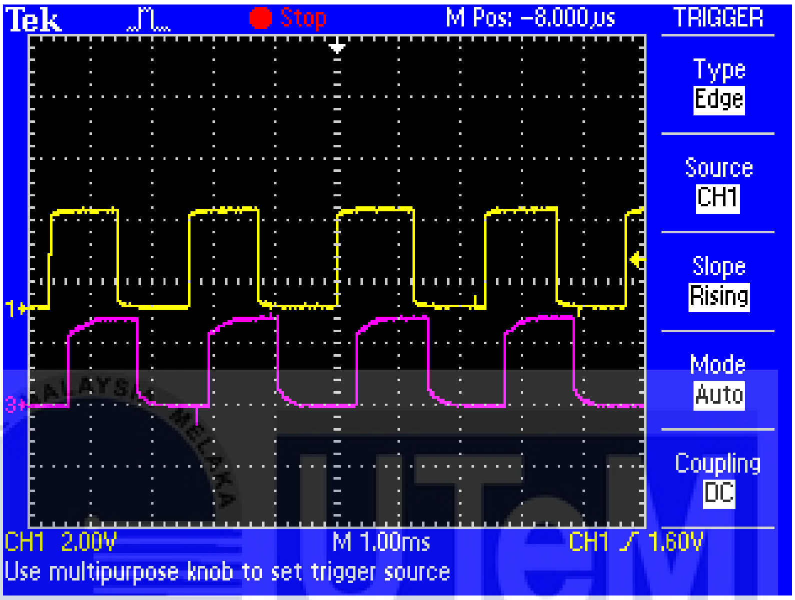

Figure 3.6: Output waveform of rotary encoder.

3.4.3. Hardware Circuit

Figure 3.7 below shows the basic hardware circuit that constructed for simulation by using Proteus software. In the circuit, the microcontroller used is PIC 18F4550. The circuit consist of vital parts includes power supply circuit, clock circuit, reset circuit, 3 potentiometer circuit and a motor encoder circuit. Power supply circuit produce two type of DC output voltage which is 12V and 5V to microcontroller and motor encoder. Clock circuit used for system coordination to synchronize the whole circuit while reset circuit used for reset microcontroller to initial stage. Three potentiometer circuit generate analog signal represent the input from IMU sensor. The motor encoder generated square wave form for every pulse of rotating shaft.

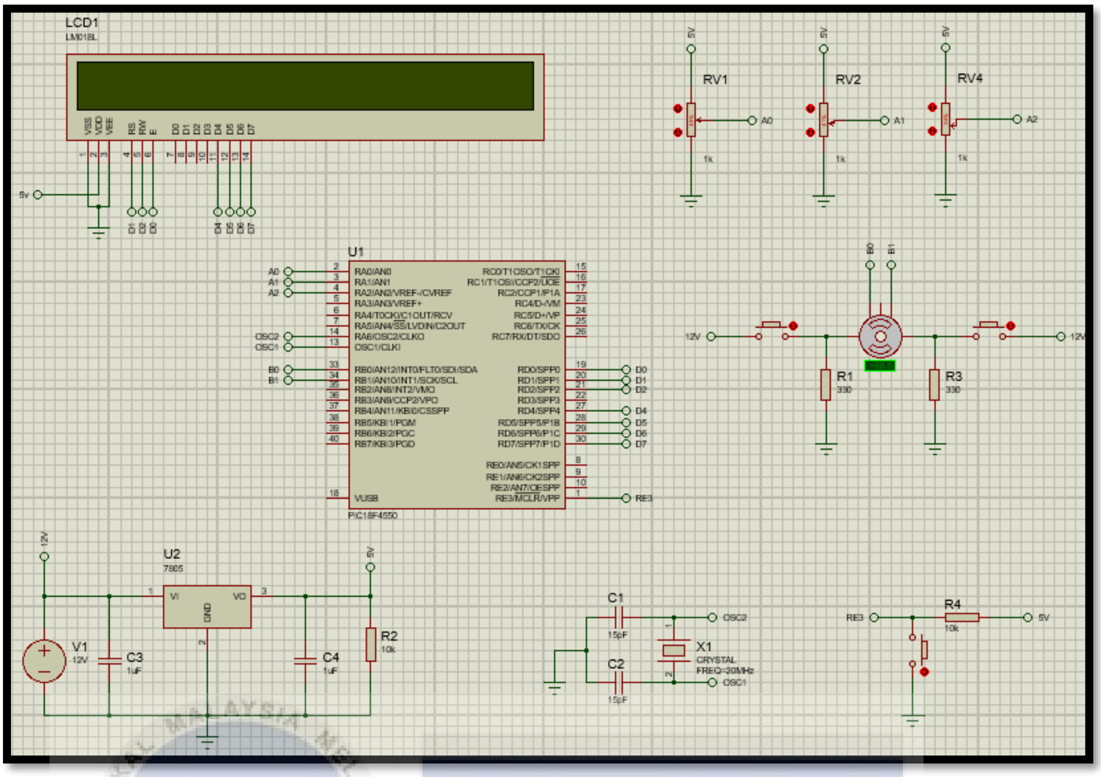

Figure 3.7: Hardware Circuit created using Proteus.

Figure 3.8 below show the hardware circuit connection of the project. The robot is control by microcontroller PIC 18F4550, the robot will move according to the black line which determined by auto-calibrating line sensor. Two planetary DC geared motor are used as moving part of the robot, speed of the motors controlled by pulse width modulation technique from dual motor controller module powered by 12V input voltage. MPU 6050 triple axis accelerometer and gyro breakout board is use to sense the flatness of the road, where the information will then be send to the microcontroller via I2C communication. The distance travelled by the robot is determined by the two channel hall effect encoder using interrupt interface to the microcontroller. Processed information of flatness and distance are send to the PC via serial communication by using UART module.

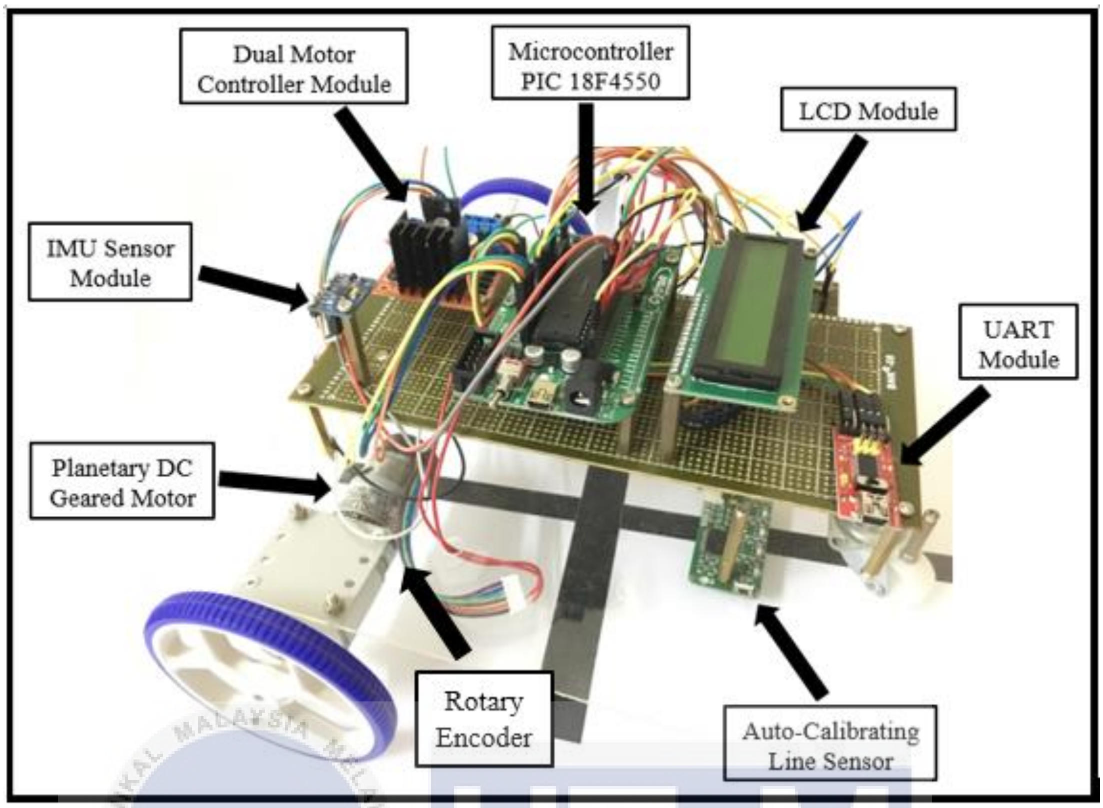

Figure 3.8: Hardware Circuit of Project.

3.5 Program for Hardware

In this section, some program was used to run and enable the communication between each hardware parts. The main software used in this project is the Visual Studio 2015, where it is used to create graphical user interface (GUI) for data analysis between flatness and location of the road.

3.5.1. CCS C Compiler and PIC Kit2

A CCS C Compiler software is used to develop a program code in high level language to control the microcontroller PIC 18F4550. This Compiler software generate coding in hexadecimal form that will be transfer into the microcontroller. While the other software PIC Kit2 will be used as platform for transferring the code into the microcontroller by using ICSP port as a communication path.

3.5.2. Visual Studio 2015

Software visual studio 2015 is use to create graphical user interface to handle the data collected from the IMU sensor and rotary encoder. The data transfer from microcontroller to the computer will be use to plot a 2D graph to illustrate the condition on the highway road. The 2D graph plotted with distance on x-axis versus flatness on y-axis. First is to decide the type of control use to create the graphic where line charts are the most suitable one for this project. Then is to set up the coordinate system for the control, distance is added on the horizontal axes and flatness is added on the vertical axes to illustrate the change of flatness over distance travelled by the robot. After that is add division marks and labels to the axes and also the titles of this project to the graphic. And finally the data collected from microcontroller are used to draw the graphic on the control. Figure 3.9 show the 2D graph of flatness versus distance created for purpose of flatness measurement.

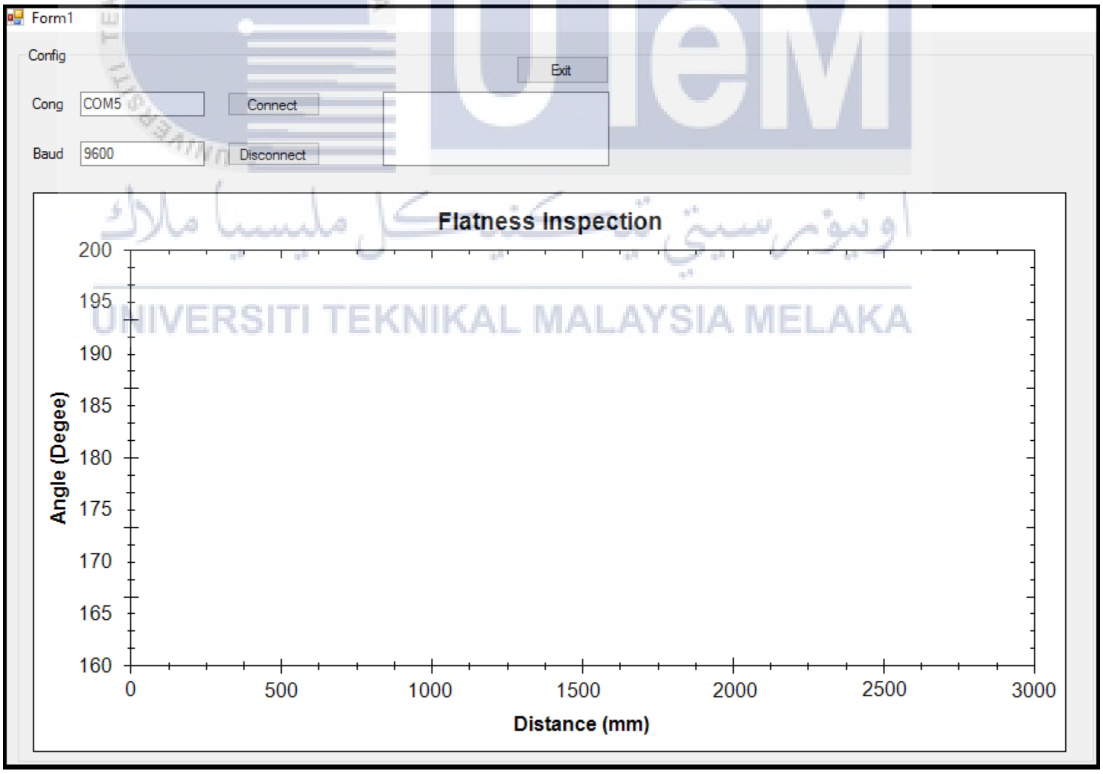

Figure 3.9: 2D graph flatness(degree) versus distance(mm).

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter will elaborate and discuss the result of this project and also the schematic diagram of the project. Every details include hardware and software result are further discussed and explained in this chapter.

4.1. Introduction

In this chapter, analyzes were carried out on the flatness and distance measurement result to determine its accuracy. The robot is set to run through three surface with different flatness angle to test the accuracy of the IMU sensor. In this project, the autonomous robot was set to run through three different flatness surface which are going up slope, run on flat surface and finally going down slope. Since there is only change on one axis of angle, then only one axis out of three axis of angular velocity was measured and used to plot the graph of flatness versus distance. The runway divided into three parts with each part having different length to test the accuracy of the encoder. Distance was measured with refer to relationship between the encoder output pulses and the circumference of the wheel. A graphical user interface (GUI) was created in Visual Studio to handle the information from the IMU sensor and encoder as shown in Figure 4.1. The graph of flatness angle versus real time travelled distance was used to describe the flatness angle at some instant point of location on the runway.

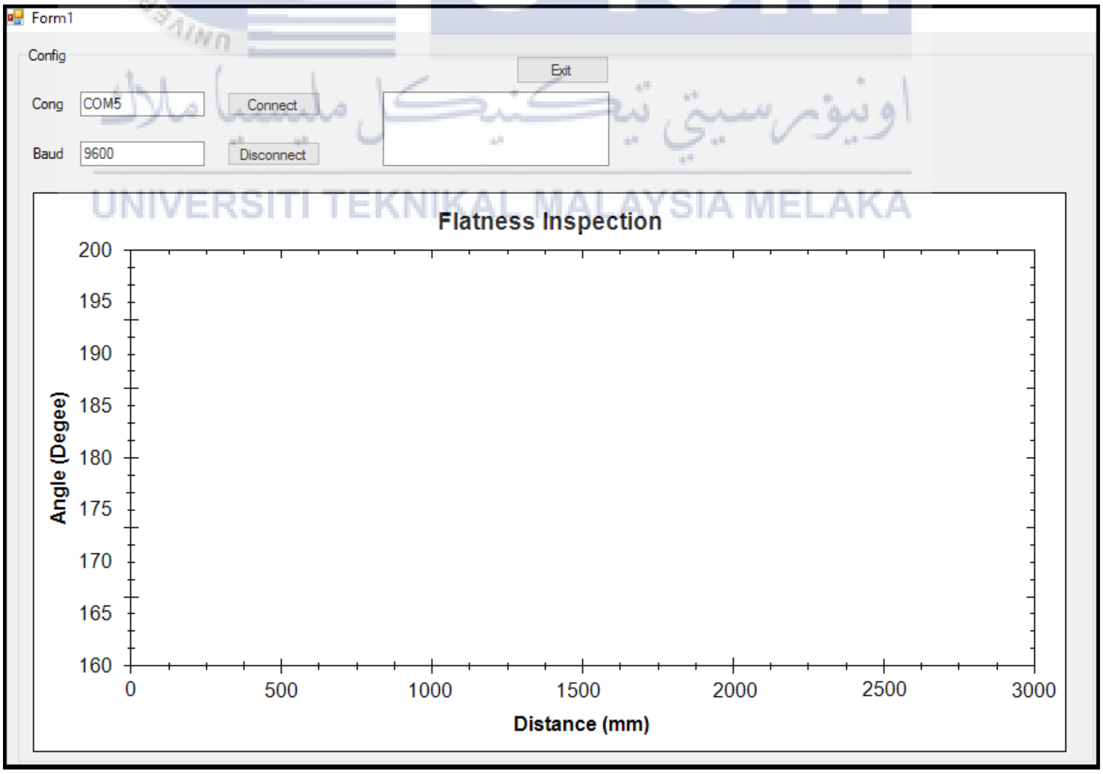

Figure 4.1: GUI in Visual Studio 2015.

4.2. Results

a) The below figure shows the actual dimension of the runway.

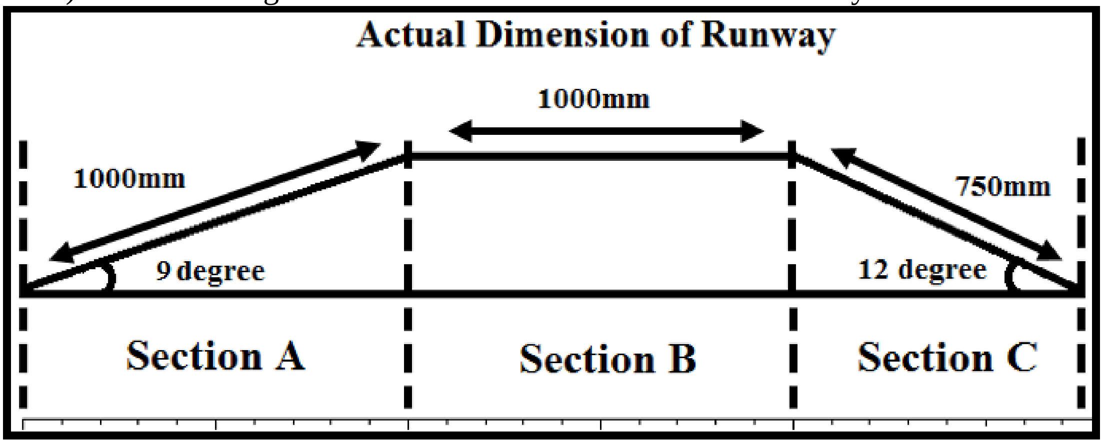

Figure 4.2: Actual dimension of runway.

b) The below table shows the distance measurement results compare to the preset distance of the runway which obtained by using rotary encoder.

Table 2.0: Comparison of distance measurement.

Runway Distance (mm)	Measurement Distance (mm)	Error (mm)
500	496	4.0
1000	996	4.0
1500	1492	8.0
2000	1985	15.0
2500	2471	29.0

c) The below figures shows the flatness measurement graph with DC motor speed set at 50% duty cycle.

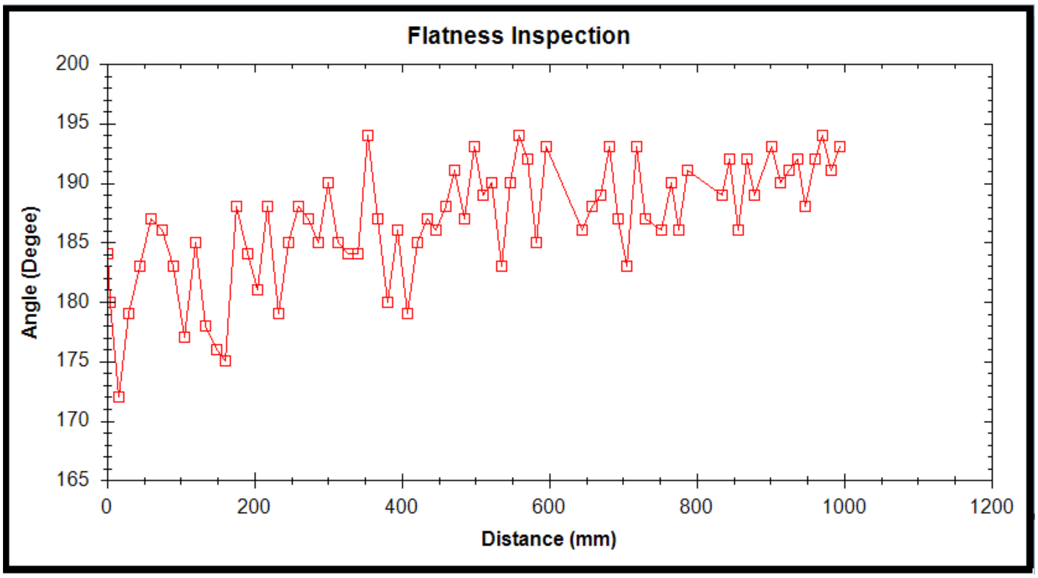

Figure 4.3: Flatness measurement on section A with 50% duty cycle.

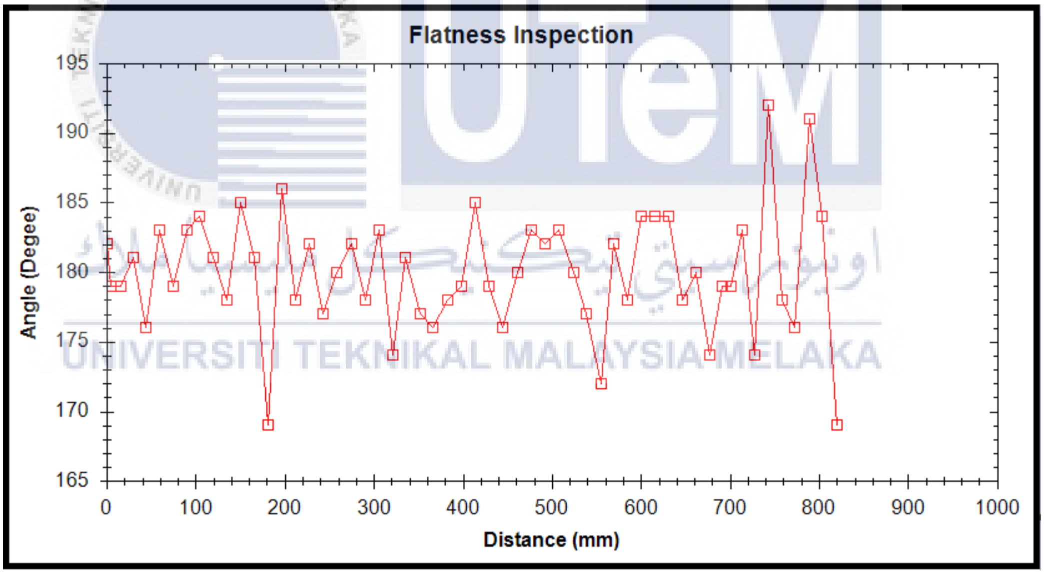

Figure 4.4: Flatness measurement on section B with 50% duty cycle.

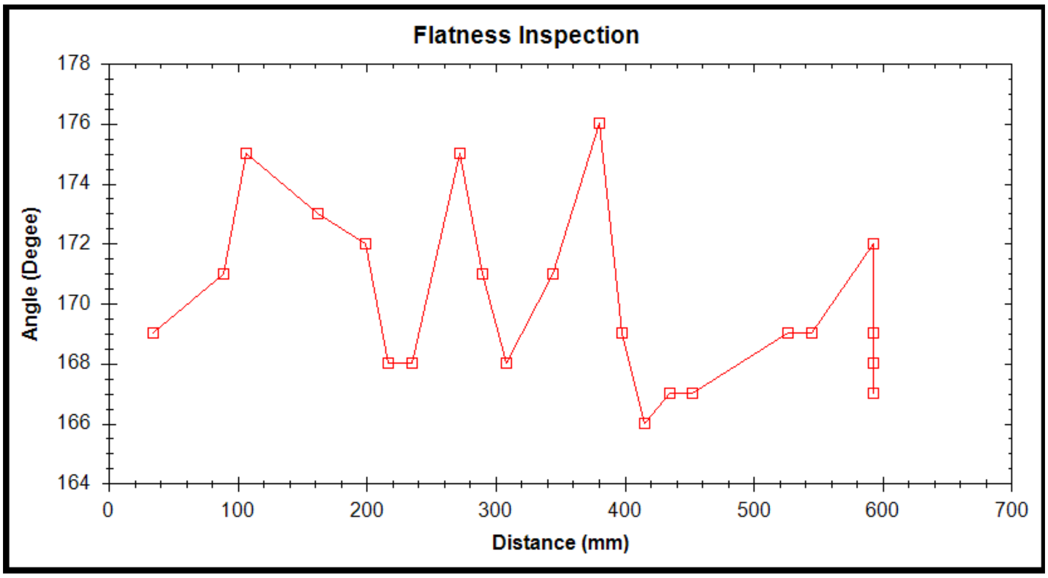

Figure 4.5: Flatness measurement on section C with 50% duty cycle.

d) The below figures shows the flatness measurement graph with DC motor speed set at 60% duty cycle.

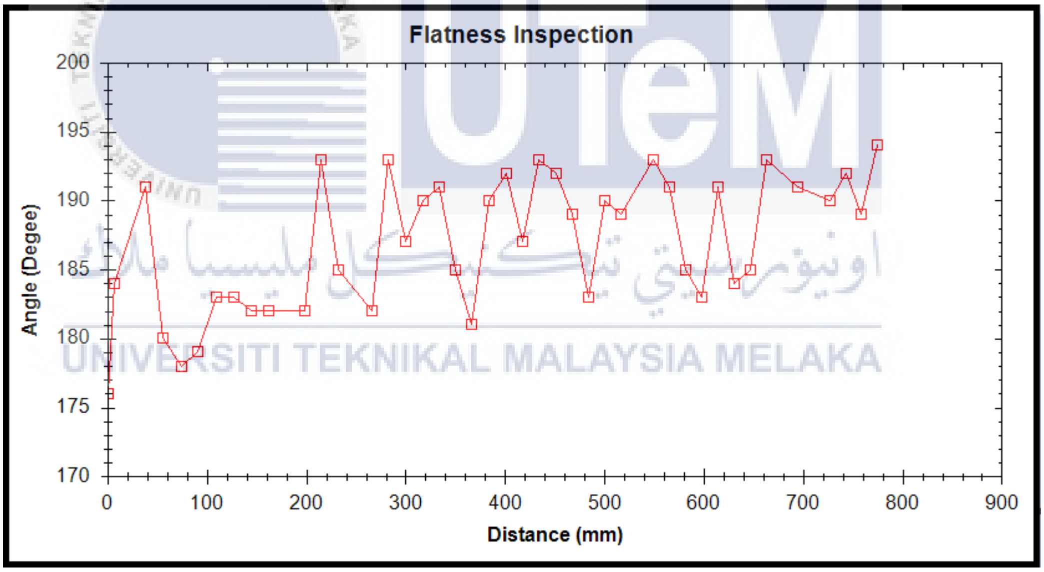

Figure 4.6: Flatness measurement on section A with 60% duty cycle.

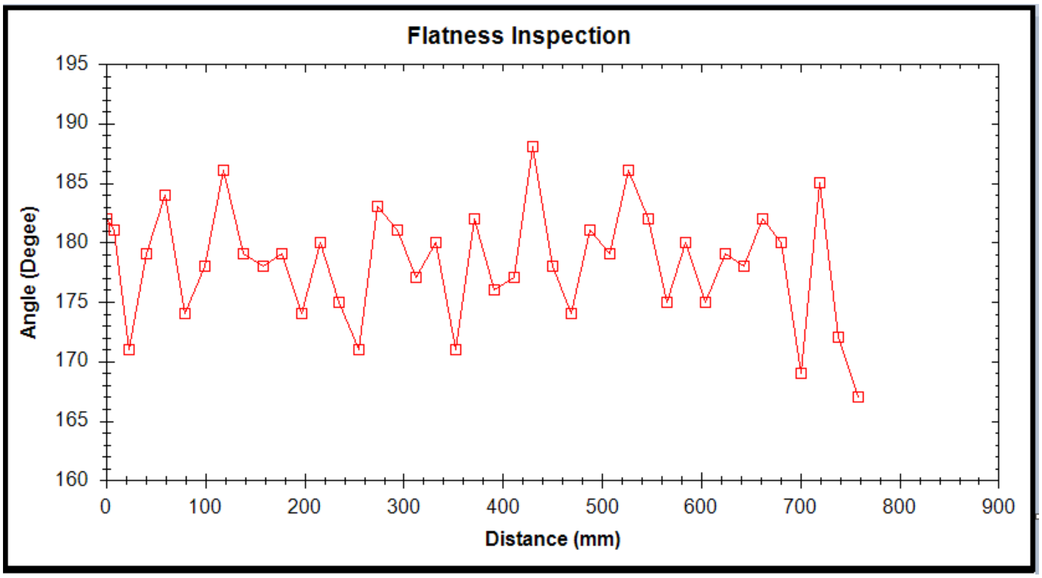

Figure 4.7: Flatness measurement on section B with 60% duty cycle.

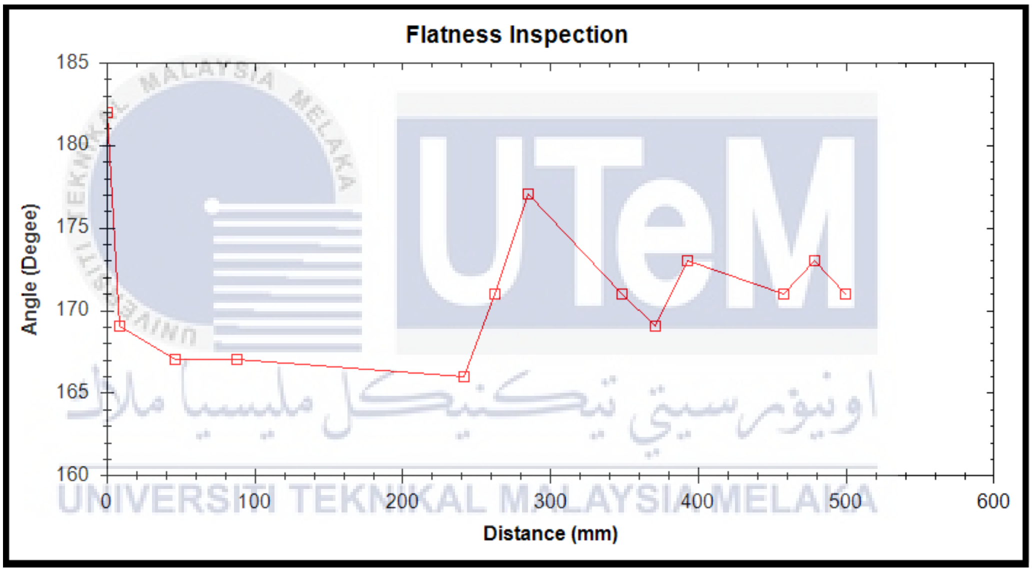

Figure 4.8: Flatness measurement on section C with 60% duty cycle.

e) The below figures shows the flatness measurement graph with DC motor speed set at 70% duty cycle.

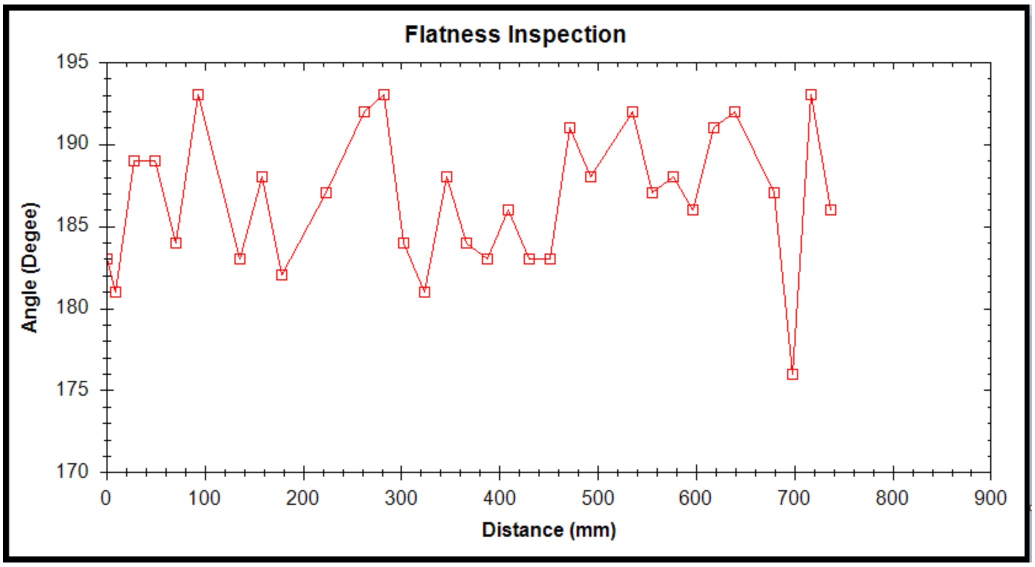

Figure 4.9: Flatness measurement on section A with 70% duty cycle.

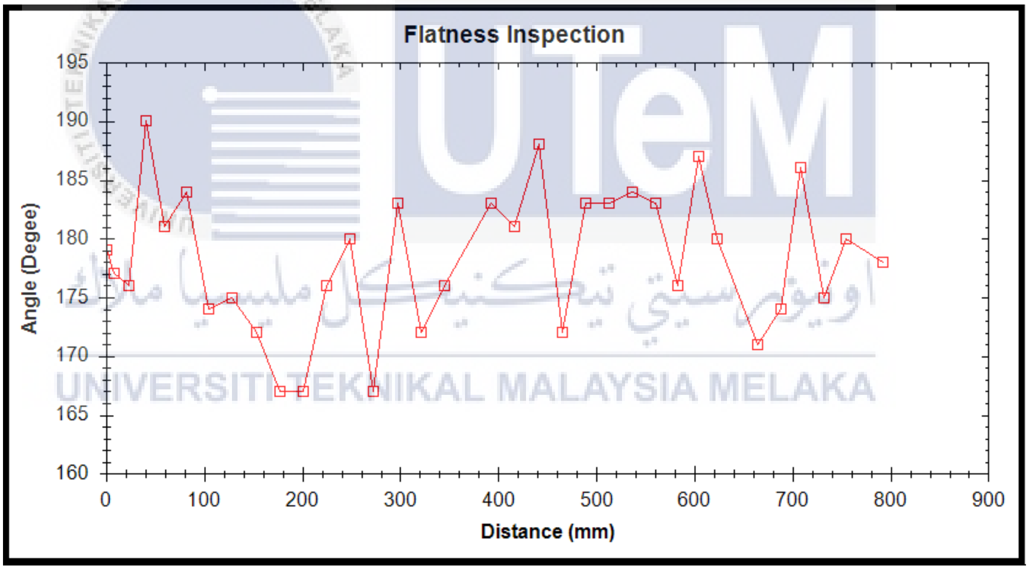

Figure 4.10: Flatness measurement on section B with 70% duty cycle.

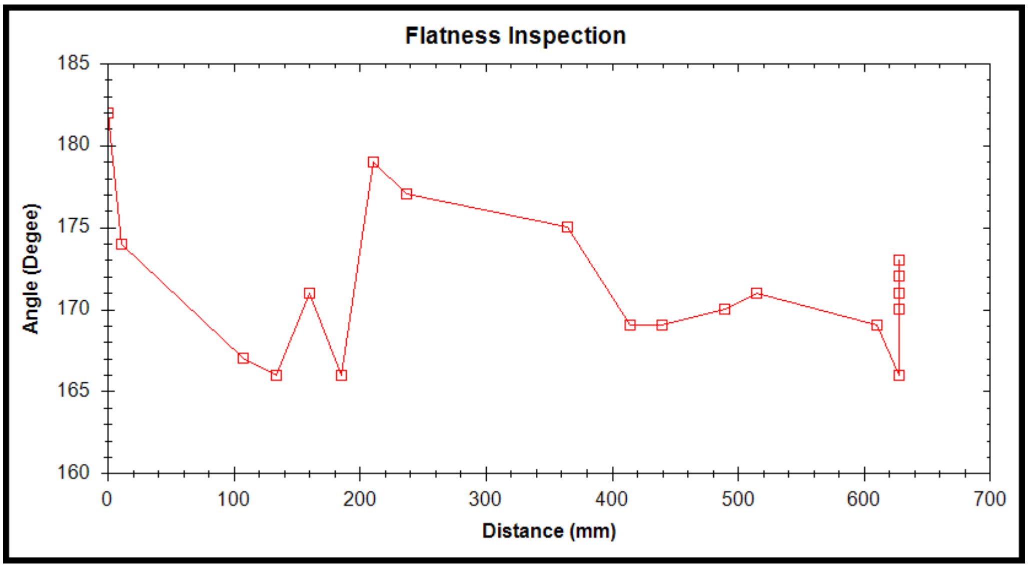

Figure 4.11: Flatness measurement on section C with 70% duty cycle.

f) The below figure shows the flatness measurement graph of running on full path way of preset runway.

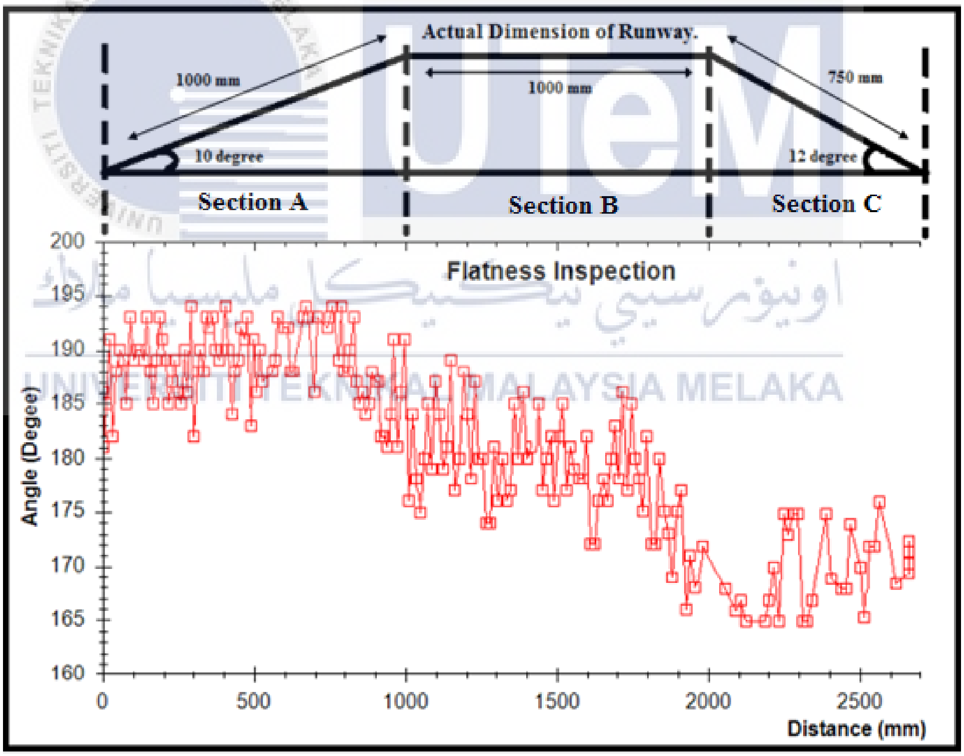

Figure 4.12: Flatness measurement of full path way of preset runway.

4.3. Discussion

Rotary encoder measure distance according to the rotation of the wheel, the rotary encoder used in this project has 700 pulses per every rotation. For every certain degree of rotation, pulses were produced with square wave output. For every rising and falling edge indicated the pulses that will be taken for distance calculation purpose. The rotary encoder has 700 pulses per rotation, for every pulses produced were equal to 0.38147mm travelled by the robot. Table 2 shows the measurement results compare to the preset distance of the runway which obtained by using rotary encoder. For running on 500mm preset distance, the measurement distance obtained is 496mm distance which have error of 4mm compare to the preset distance. For running on 1000mm preset distance, the obtained measurement distance is 996mm which have error of 4mm compare to the preset distance. For running on 1500mm preset distance, the obtained measurement distance is 1492mm which have error of 8mm compare to the preset distance. For running on 2000mm preset distance, the obtained measurement distance is 1985mm which have error of 15mm compare to the preset distance. For running on 2500mm preset distance, the obtained measurement distance is 2471mm which have error of 29mm compare to the preset distance. From the result of the table, the percentage of differences increase linearly with distance, this measurement error may due to the calculation formula constant that is not accurate enough although the constant value had been rounded up to five decimal places. Another factor that affected the accuracy of the distance measurement is the minimum startup space needed by the auto-calibrating line sensor, infrared proximity sensor need minimum of 15mm on the black line to start operate.

IMU sensor was used to measure the flatness angle of the preset runway, in this project only single axis of angle had been measured due to the runway was set with going up slope or down slope only. For the flatness measurement graph with DC motor speed set at duty cycle 50%, 60% and 70% when moving on section A, it shows that the noise will increase with the speed of the robot. Flatness measurement in figure 4.3 shows that the measurement is more accurate within 190 ˚ compare to the flatness measurement in figure 4.4, among these three figures, figure 4.5 have the biggest fluctuation. Same goes to the flatness measurement graph when moving on section B, it shows that the noise will increase with the speed of the robot. Flatness measurement in figure 4.6 shows that the measurement is more accurate within 180 ˚ compare to the flatness measurement in figure 4.7, among these three figures, figure 4.8 have biggest fluctuation. For the flatness measurement graph with DC motor speed set at duty cycle 50%, 60% and 70% when moving on section C, it shows that the noises are almost same at all speeds, the result is not accurate enough to show the flatness angle is on 168˚ level and this may due to the robot going down the slope with greater velocity and causes bigger fluctuation. From the result graph of flatness measurement, it shows the noises will increase linearly with the speed of the DC motor. This may due to the high frequency vibration of the DC motor or the wheels had affected the accuracy of the IMU sensor.

Figure 4.12 shows the comparison of dimension between a preset runway and measured data by the autonomous robot. The full preset runway covers three different part where section A is going up slope of about 189˚ with 1000 mm in length, section B is flat surface of about 180˚ with 1000 mm in length and section C is going down slope of about 168˚ with 750 mm in length. The robot was started at running up a slope of about 9˚ from nominal level, inside the graph shows that the dotted line was plot among 189˚ level between 0 mm to 1000 mm distance. Then the robot will run on a flat surface and the data inside the graph shows that the dotted line was plot among 180˚ level between 1001 mm to 2000 mm distance. Lastly the robot was moving down the slope of about 12˚, inside the graph shows that the dotted line was plot among 168˚ level between 2001 mm to 2750 mm distance. Although the dotted line in the graph indicate the flatness condition which are almost same as the actual dimension of the runway, but there are noises that affected the accuracy of the flatness angle and caused fluctuation. These noise only happened when the autonomous robot is moving on the runway, this may due to the interruption of high frequency vibration that produced from the DC geared motor or the wheels. Another factor that causes fluctuation on result is speed of the motor, an analysis of different speed of motor with 50%, 60% and 70% PWM duty cycle was set to test the noise on the result. The result shows that the higher the speed of the motor, more noise is produce by DC motor and interrupt the flatness angle accuracy. The distance measured by the autonomous robot was 2700mm which was slightly different compare to the actual dimension of runway with

2750mm in total length. This measurement error is due to the calculation formula value had been rounded up to five decimal places, which will lead to the apparent measurement error for a long distances measurement. After all, the flatness inspection system was still able to measure the flatness and distance of the runway with approximately same as the actual dimension of the runway.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

In this project, an autonomous robot for flatness inspection system was created to achieve the objective as stated before. Information of flatness inspection system was obtained in this project. The overall achievement of the objectives in this project will be concluded and there are few suggestions that can be implement for future work so that this flatness inspection system can be improved.

5.2. Conclusion

In conclusion, the objectives stated in this project was successfully achieved with an autonomous robot for flatness inspection system was created to measure the flatness of the road. Also, the intelligent mobile robot is able to obtain the distance and location of the road which are under standard.

Furthermore, the graphical user interface (GUI) created in Visual Studio 2015 software was able to process the collected data and display it in graphical method way for better monitoring and analysis on the flatness condition of the road. The collected data from the sensor of the robot were successfully transfer to the computer from PIC 18F4550 microcontroller via serial communication during the operation. The IMU sensor and rotary encoder were successfully measured the flatness angle and distance travelled by the autonomous robot accurately.

The graph of flatness angle (degree) versus distance (mm) in the GUI created in software Visual Studio 2015 was able to display and show the flatness dimension at every single location on the runway. This enable the user to monitor the flatness condition on the road with a better and faster way. With intelligent mobile robot carry out road monitoring job, it can ease the road management team to save more human resources and time. Some measurement error occurred in this project was able to be identified and few suggestion was given out to improve the system in future work.

5.3. Recommendations

In this project, there are some factors that affected the result's accuracy in this flatness inspection system. Hence, few improvement suggestions have been suggested to improve the system in order to increase the accuracy and ability of this system. Below are the improvements that can be applied to this flatness inspection system:

i. Add anti-vibration mount between IMU sensor module and the robot to absorb the high frequencies noise from the motor.
ii. Configure the digital low pass filter setting to remove the noise from affecting the signal of the IMU sensor.
iii. Calibrate the measurement error by readjust the calculation constant value in order to get accurate measurement data.
iv. Change serial communication method to Bluetooth wireless connection to increase the monitoring range between the intelligent mobile robot and computer.

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APPENDICES

I) Source Code of program for Microcontroller

Main program of CCS C compiler

```
#include <18F4550.h>
#fuses
HS,NOWDT,NOPROTECT,NOLVP,NODEBUG,USBDIV,PLL3,CPUDIV1,VREG
EN
#use delay(clock=20M)
#use RS232(baud=9600, xmit=PIN_C6, rcv=PIN_C7, PARITY=N, BITS=8,
STOP=1)
#use fast_io(B)
#include <stdlib.h>
#include <stdio.h>

#define MPU_SDA PIN_E0
#define MPU_SCL PIN_E1
#use I2C(master, sda=MPU_SDA, scl=MPU_SCL)
#use TIMER(TIMER=1, TICK=1ms, BITS=16, NOISR)

#define LCD_RS_PIN PIN_D0
#define LCD_RW_PIN PIN_D1
#define LCD_ENABLE_PIN PIN_D2
#define LCD_DATA4 PIN_D4
#define LCD_DATA5 PIN_D5
#define LCD_DATA6 PIN_D6
#define LCD_DATA7 PIN_D7

#include <lcd.c>
#include "MPU6050.c"
#include "math.h"
#include "Filter.h"
#define RAD_TO_DEG 180/PI

#define IN1  PIN_A1
#define IN2  PIN_A2
```

```
#define IN3  PIN_A3
#define IN4  PIN_A4
#define IN5  PIN_A5

typedef struct
{
 struct
 {
  signed int16 X;
  signed int16 Y;
  signed int16 Z;
 }Accel;

 struct
 {
  signed int16 X;
  signed int16 Y;
  signed int16 Z;
 }Gyro;
}MPU6050;

int32 count =0;
int32 dis=0;
char buf1 [7];
char buf2 [7];

#INT_EXT
void EXT_ISR(void)
{
   count++;
   dis=(count*0.38147);
}

void main()
{
   SIGNED int16 accX,accY, accZ;
   SIGNED int16 gyroX,gyroY,gyroZ;
   DOUBLE accXangle,accYangle;
   DOUBLE gyroXangle,gyroYangle;
   DOUBLE kalAngleX,kalAngleY;
   UNSIGNED int16 timer;
   int32 DAT;
   int counter=0;
```

```
lcd_init ();
Mpu6050_Init () ;
printf(lcd_putc,"Flatness\nInspection");
delay_ms (500) ;

  port_b_pullups(0x01);
  delay_us(10);
  ext_int_edge(L_to_H);
  clear_interrupt(INT_EXT);
  enable_interrupts(INT_EXT);
  enable_interrupts(GLOBAL);

  set_tris_b(0x0F);
  set_tris_a(0xFF);
  set_tris_c(0x00);

  output_b(0x00);
  output_a(0x00);
  output_c(0x00);

  setup_ccp1(CCP_PWM);
  setup_ccp2(CCP_PWM);

  setup_timer_2(T2_DIV_BY_4,254,1);

while(true)
{
  if(!input(PIN_A0))
  {
    while(counter<5)
    {

if((input(IN1))&&(input(IN2))&&(input(IN3))&&(input(IN4))&&(input(IN5)))
        {
          set_pwm1_duty(0);
          set_pwm2_duty(0);
          output_LOW(PIN_B4);
          output_LOW(PIN_B5);
          output_LOW(PIN_B6);
          output_LOW(PIN_B7);
          delay_us(1);
```

```
      counter+=1;

      lcd_gotoxy (1, 1) ;
      printf(lcd_putc,"\fDistance=%ldmm", dis);


while((input(IN1))&&(input(IN2))&&(input(IN3))&&(input(IN4))&&(input(IN5)))
      {
      }
    }

    else if(input(IN1))
    {
      output_HIGH(PIN_B4);
      output_LOW(PIN_B5);
      output_LOW(PIN_B6);
      output_LOW(PIN_B7);
      set_pwm1_duty(0);
      set_pwm2_duty(120);
      delay_us(1);
    }

    else if(input(IN2))
    {
      output_HIGH(PIN_B4);
      output_LOW(PIN_B5);
      output_HIGH(PIN_B6);
      output_LOW(PIN_B7);
      set_pwm1_duty(100);
      set_pwm2_duty(110);
      delay_us(1);
    }

    else if(input(IN3))
    {
      output_HIGH(PIN_B4);
      output_LOW(PIN_B5);
      output_HIGH(PIN_B6);
      output_LOW(PIN_B7);
      set_pwm1_duty(110);
      set_pwm2_duty(110);
      delay_us(1);
    }
```

```
else if(input(IN4))
{
  output_HIGH(PIN_B4);
  output_LOW(PIN_B5);
  output_HIGH(PIN_B6);
  output_LOW(PIN_B7);
  set_pwm1_duty(110);
  set_pwm2_duty(100);
  delay_us(1);
}

else if(input(IN5))
{
  output_LOW(PIN_B4);
  output_LOW(PIN_B5);
  output_HIGH(PIN_B6);
  output_LOW(PIN_B7);
  set_pwm1_duty(120);
  set_pwm2_duty(0);
  delay_us(1);
}

else
{
  set_pwm1_duty(0);
  set_pwm2_duty(0);
  output_LOW(PIN_B4);
  output_LOW(PIN_B5);
  output_LOW(PIN_B6);
  output_LOW(PIN_B7);
  delay_us(10);
}

accX = Mpu6050_GetData (MPU6050_RA_ACCEL_XOUT_H);
accY = Mpu6050_GetData (MPU6050_RA_ACCEL_YOUT_H);
accZ = Mpu6050_GetData (MPU6050_RA_ACCEL_ZOUT_H);
gyroX = Mpu6050_GetData(MPU6050_RA_GYRO_XOUT_H);
gyroY = Mpu6050_GetData(MPU6050_RA_GYRO_YOUT_H);
gyroZ = Mpu6050_GetData(MPU6050_RA_GYRO_ZOUT_H);

set_ticks(0);
accXangle = (atan2 (accY, accZ) + PI) * RAD_TO_DEG;
```

```
      DOUBLE gyroXrate = (double) gyroX;
      gyroXangle += gyroXrate * ( (DOUBLE) (get_ticks () - timer)  / 1000);
      kalAngleX = kalmanCalculate (accXangle, gyroXrate, (get_ticks()-timer));
      timer = get_ticks ();

      DAT=(int)kalAngleX;

      itoa(Dat,10,buf1);
      itoa(dis,10,buf2);

      printf("%s%s\n", buf1, buf2);
      delay_ms(100);
    }
  }

  else
  {
  }

 }
}
```

II) Source code in Visual Studio 2015

Main program

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;
using ZedGraph;

namespace WindowsFormsApplication1
{

    public partial class Form1 : Form
    {
        string DataFromCOM;
        double[] x = new double[500];
        double[] y = new double[500];
        int i;

        PointPairList listPointsOne = new PointPairList();

        public Form1()
        {
            InitializeComponent();
        }

        private void button3_Click(object sender, EventArgs e)
        {
            Application.Exit();
        }

        private void button2_Click(object sender, EventArgs e)
        {
            if (serialPort1.IsOpen == false) return;
            serialPort1.Close();
            button1.Enabled = true;
            button2.Enabled = false;
```

```
        }

        private void button1_Click(object sender, EventArgs e)
        {
            serialPort1.Close();
            serialPort1.PortName = textBox1.Text;
            serialPort1.BaudRate = Convert.ToInt32(textBox2.Text);
            serialPort1.DataBits = 8;
            serialPort1.Parity = System.IO.Ports.Parity.None;
            serialPort1.StopBits = System.IO.Ports.StopBits.One;
            if (serialPort1.IsOpen) return;
            serialPort1.Open();
            button1.Enabled = false;
            button2.Enabled = true;
            timer1.Enabled = true;
        }

        private void serialPort1_DataReceived(object sender,
System.IO.Ports.SerialDataReceivedEventArgs e)
        {

            while (serialPort1.BytesToRead > 0)
            {

                DataFromCOM = serialPort1.ReadLine();

                string newstring1 = DataFromCOM.Substring(0, 3);
                string newstring2 = DataFromCOM.Substring(3);

                int yDAT = Convert.ToInt32(newstring1);
                int xDAT = Convert.ToInt32(newstring2);

              if (yDAT < 195)
              {
                if (yDAT > 165)
                {
                  i++;
                  i = (i + 1) % 500;
                  x[i] = xDAT;
                  y[i] = yDAT;

                  listPointsOne.Add(xDAT, yDAT);
                }
```

```
            }
        }

    }

    private void timer1_Tick(object sender, EventArgs e)
    {
        textBox3.Text = DataFromCOM;
        z1.GraphPane.CurveList.Clear();
        z1.GraphPane.AddCurve(null, listPointsOne, Color.Red,SymbolType.None);
        z1.AxisChange();
        z1.Invalidate();
    }

    private void Form1_Load(object sender, EventArgs e)
    {
        timer1.Enabled = false;
        z1.IsShowPointValues = true;
        z1.GraphPane.Title.Text = "Flatness Inspection";
        z1.GraphPane.YAxis.Title.Text = "Angle (Degee)";
        z1.GraphPane.XAxis.Title.Text = "Distance (mm)";

        i = 0;

    }
}
```

III) Data sheet and user manual

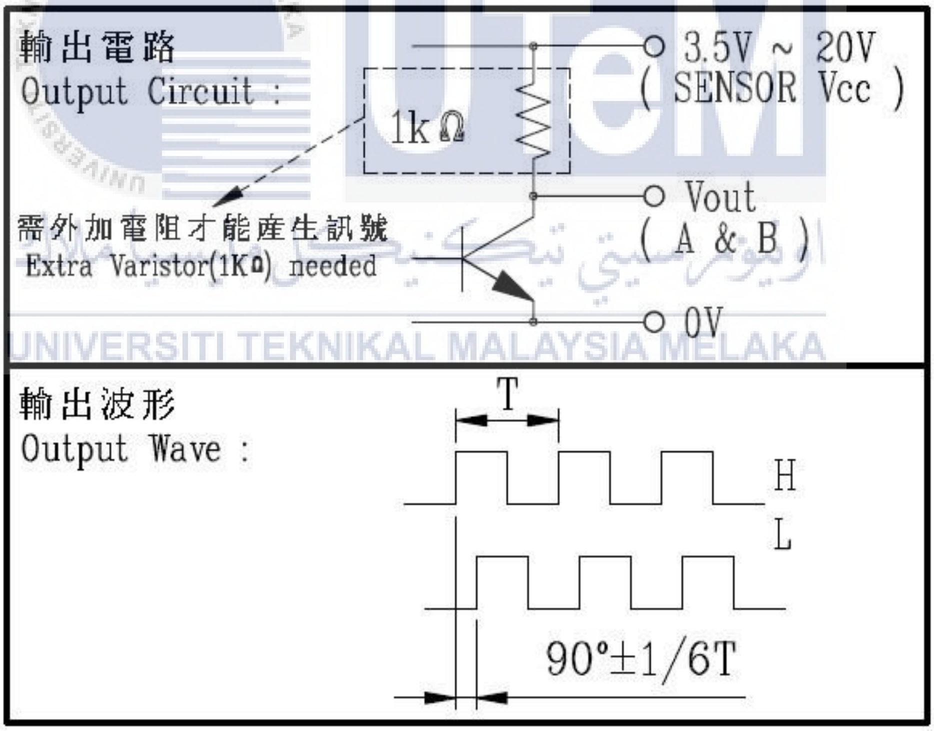
IG32E-Two Channel Hall Effect Encoder

Two Channel Encoder
Connections :

1. Black : −MOTOR
2. Red : +MOTOR
3. Brown : HALL SENSOR Vcc
4. Green : HALL SENSOR GND
5. Blue : HALL SENSOR A Vout
6. Purple : HALL SENSOR B Vout

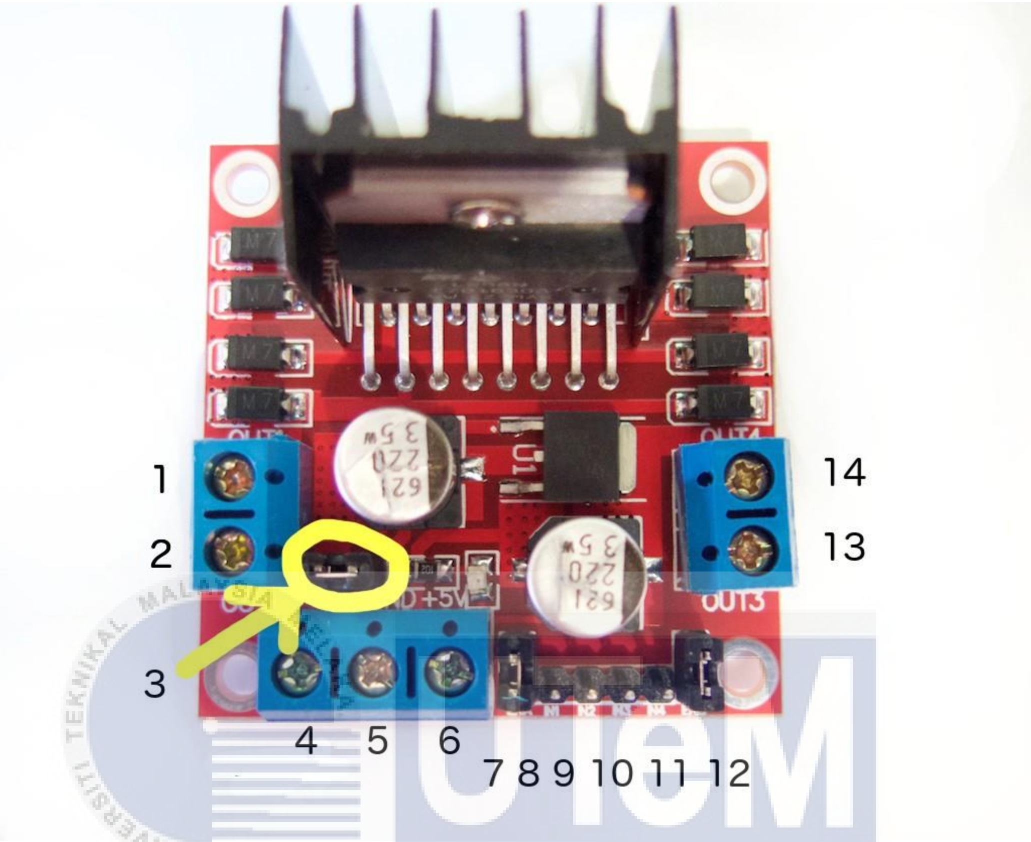
ELECTRICAL CHARACTERISTICS

規格特性 CHARACTERISTICS	代號 SYMBOL	測試條件 TEST CONDITIONS	極小 MIN.	基準 REF.	最大 MAX.	單位 UNITS
輸入電壓 Supply Voltage	Vcc	---	3.5	−	20	V
輸出飽和電壓 Output Saturation Voltage	Vce(sat)	Vcc=14V ; Ic=20mA	−	300	700	mV
輸出漏電電流 Output Leakage Current	Icex	Vce=14V ; Vcc=14V	−	< 0.1	10	μV
輸入電流 Supply Current	Ice	Vcc=20V Output open	−	5	10	mA
輸出上升時間 Output Rise Time	t_r	Vcc=14V ; R_L=820Ω; C_L=20pF	−	0.3	1.5	μS
輸出下降時間 Output Fall Time	t_f	Vcc=14V ; R_L=820Ω; C_L=20pF	−	0.3	1.5	μS



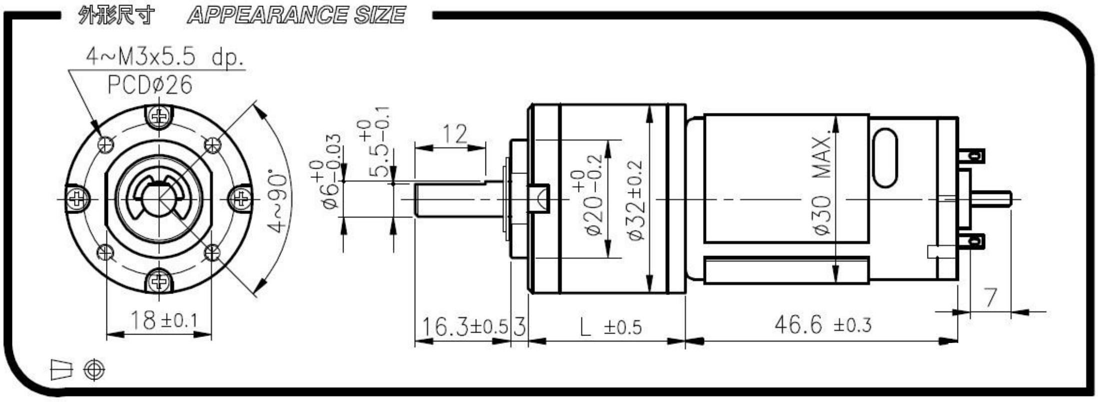
L298V Dual Motor Controller Module 2A

Module pinouts



1. DC motor 1 “+” or stepper motor A+
2. DC motor 1 “-“ or stepper motor A-
3. 12V jumper – remove this if using a supply voltage greater than 12V DC.
4. Connect your motor supply voltage here, maximum of 35V DC.
5. GND
6. 5V output if 12V jumper in place, ideal for powering Arduino (etc)
7. DC motor 1 enable jumper.Connect to PWM output for DC motor speed control.
8. IN1
9. IN2
10. IN3
11. IN4
12. DC motor 2 enable jumper.Connect to PWM output for DC motor speed control.
13. DC motor 2 “+” or stepper motor B+
14. DC motor 2 “-“ or stepper motor B-

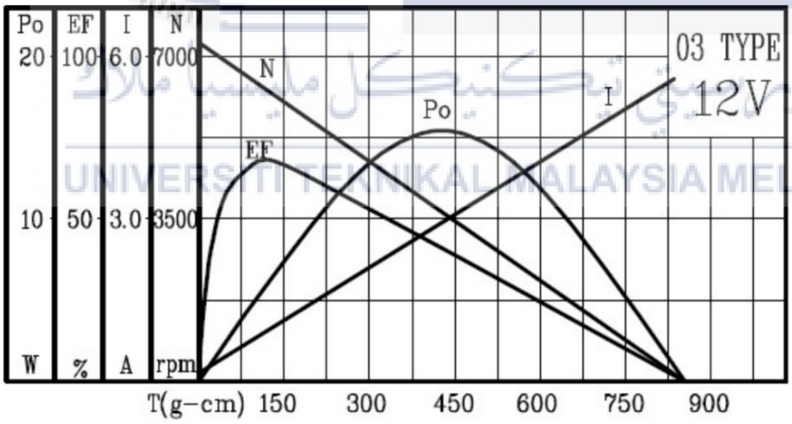
Planetary DC Geared Motor Technical Data



Motor Data

Voltage (V)	12
Rated Torque (g.cm)	110
Rated Speed (RPM)	5950
Rated Current (mA)	≤ 900
No Load Speed (RPM)	7300
No Load Current (mA)	≤ 150

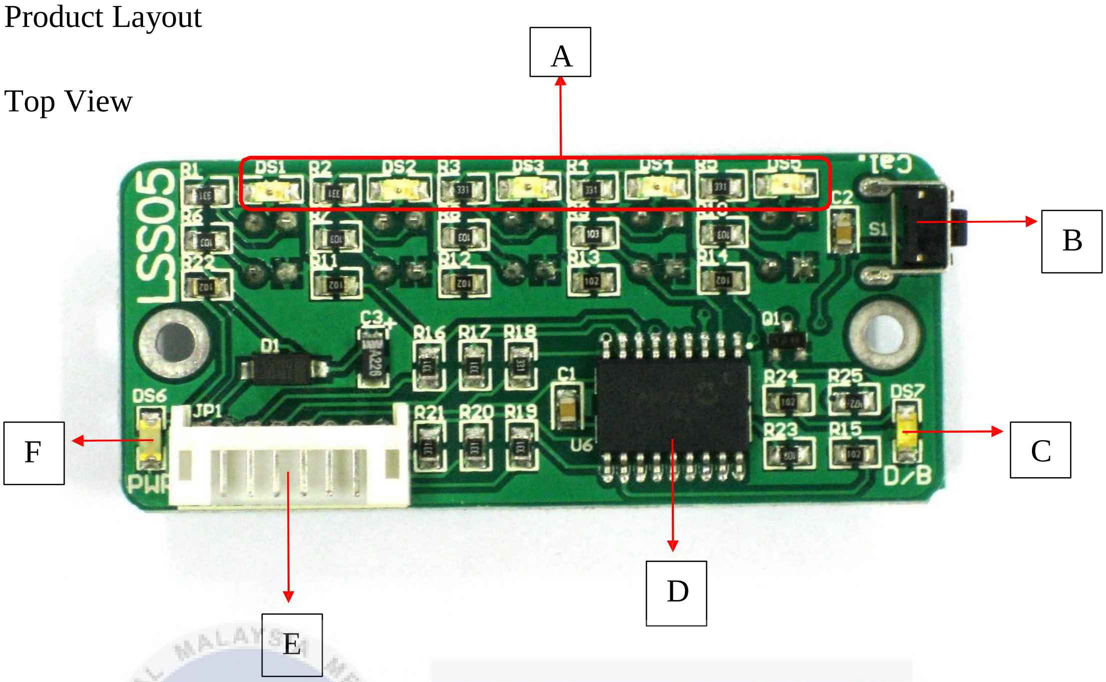
Motor Characteristic



Auto-Calibrating Line Sensor

Product Layout

Top View



A - Sensor indicator LEDs (red) will light up showing that it detects line.

B - Calibration button is used to enter different modes. Press once to enter the calibration mode. Press twice to set the line sensor bar into dark line following mode and press 3 times to set the line sensor bar into bright line mode.

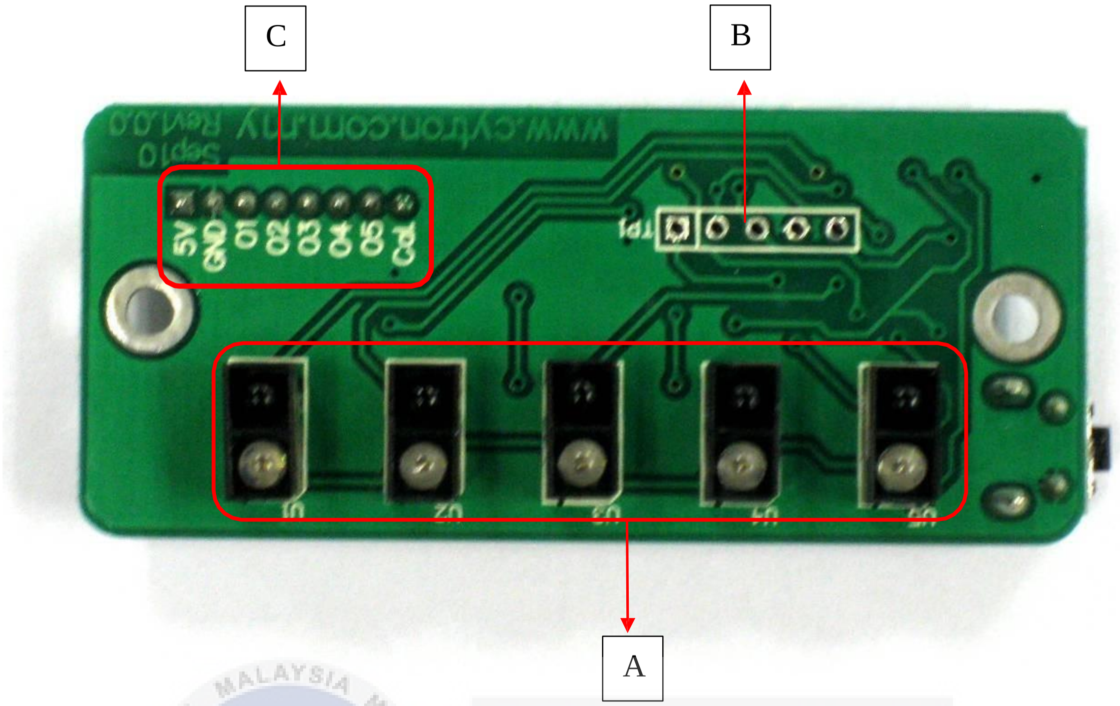
C - Mode indicator LED (orange) is for indication of the mode. LED will light up if LSS05 is in bright line detection mode. Otherwise, it is off.

D - PIC16F819 PIC microcontroller for data processing.

E - Power and output signal connector.

F - Power indicator LED (green) showing the board is supplied with power. Maximum input power is 5V.

Bottom View



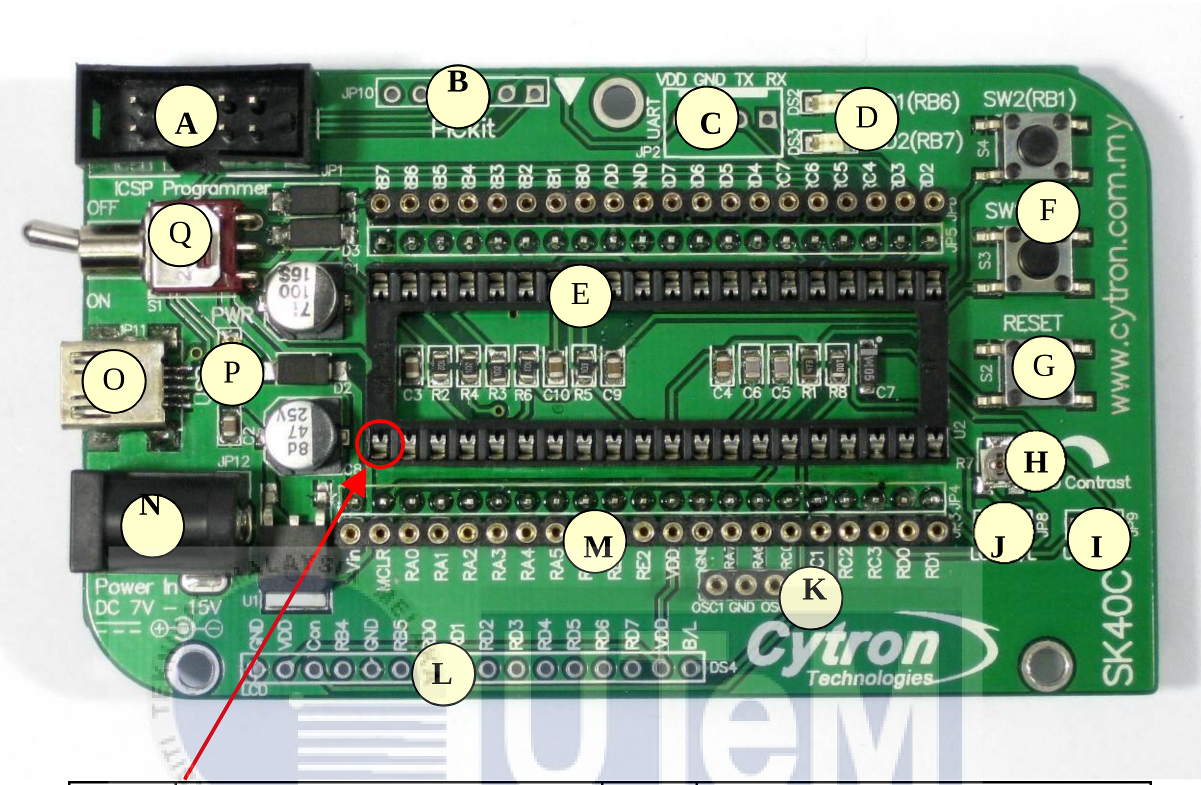
A - Pairs of IR sensor which consist IR transmitter and IR receiver.

B - It is reserved for Manufacturing Test Point. Please **DO NOT** short or connect wire to any of these pins.

C - Input/output signal label showing the Power (5V, GND), output signal pins (O1-O5) and calibration signal (Cal.).

SK40C 40 Pins PIC Start-Up Kit Board Layout

Top View



Label	Function	Label	Function
A	Connector for UIC00A/B Programmer	**J**	JP8 for LCD Backlight
B	JP10 for PICkit	**K**	Turn pin for crystal
C	UART Connector	**L**	LCD Display
D	LED Indicator	**M**	Header pin and turn pin
E	40 pin IC socket for PIC MCU	**N**	DC power adaptor socket
F	Programmable Push Button	**O**	USB Connector
G	Reset button	**P**	Power indicator LED
H	LCD contrast	**Q**	Toggle Switch for power supply
I	JP9 for USB		