DESIGN AND DEVELOPMENT OF COLLISION AVOIDANCE STRATEGY FOR DIFFERENTIAL DRIVE MOBILE ROBOT

NG SING YEE

UNIVERSITI SAINS MALAYSIA
2018

DESIGN AND DEVELOPMENT OF COLLISION AVOIDANCE STRATEGY FOR DIFFERENTIAL DRIVE MOBILE ROBOT

by

NG SING YEE

Thesis submitted in partial fulfilment of the
requirements for the degree of
Bachelor of Engineering (Electronic Engineering)

JUNE 2018

ACKNOWLEDGEMENT

Firstly, I wish to express my sincerest gratitude and thanks to Dr. Nur Syazreen Ahmad, my thesis advisor, and project supervisor, for her continuous guidance and advice to complete my final year project. Dr. Nur Syazreen Ahmad gave me many comments and advices throughout the progress of the project so that the project can be completed in time. Besides that, she was patient while she mentored me on how to implement and execute the project. Without her guidance, this project could not have been completed in time and good manner.

Moreover, I would like to offer my sincere appreciation to School of Electrical and Electronic Engineering for providing funds to expose me to a more practical final year project. The hard work of the technicians and staff who help students to order and collect the components is deeply appreciated.

I would like to thank my examiner, En Mohd Nazri Mahmud for examining this thesis. During the pre-viva section, the comments and discussions given by him are useful, which lead to the improvements in the overall idea of this project.

Last but not least, I wish to express my gratitude to my family for the unbelievable amount of support and love. Especially, I would like to thank my father and mother for always supporting my choices in life.

TABLE OF CONTENTS

CHAPTER 3 - METHODOLOGY 36

CHAPTER 4 - RESULT AND DISCUSSION 58

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS/ACRONYMS

ANN	Artificial Neural Networks
APF	Artificial Potential Field
DAQ	Data acquisition
DC	Direct Current
DDMR	Differential-Drive Mobile Robots
DWA	Dynamic Window Approach
FL	Fuzzy Logic
GUI	Graphical User Interface
HIS	Hybrid Intelligent System
ICC	Instantaneous Center of Curvature
ICR	Instantaneous Center of Rotation
IR	Infrared Sensor
LIDAR	Light Detection and Ranging
MATLAB	Matrix Laboratory
PIR	Passive Infrared Sensor
PWM	Pulse Width Modulation
VFF	Virtual Force Field
VFH	Vector Field Histogram algorithm
WMR	Wheeled Mobile Robots

REKA BENTUK DAN PEMBANGUNAN STRATEGI PENGGUNAAN COLLISION UNTUK ROBOT MOBILE DRIVE BERBEZA

ABSTRAK

Robot mudah alih autonomi telah dipertimbangkan untuk banyak aplikasi perkhidmatan seperti pembersih rumah pintar dan sistem penghantaran tanpa pemandu. Walau bagaimanapun, untuk beberapa tugas yang tertentu, robot mudah alih mesti dapat mengelakkan rintangan dan boleh bergerak dengan cekap dari titik permulaan ke titik matlamat. Dalam kes sedemikian, teknik mengelakkan perlanggaran yang baik diperlukan di mana jarak antara robot dan halangan mesti disimpan tanpa sifar. Dalam projek ini, strategi mengelakkan perlanggaran direka dan dibangunkan untuk robot bergerak mudah alih yang berlainan, yang dibina menggunakan mikrokontroler ATmega 328p. Dua algoritma, iaitu Medan Potensi Buatan (APF) dan Bug 2 digabungkan ke dalam model dengan sensor ultrasonik untuk mengesan dan mengelakkan rintangan. Untuk strategi perancangan jalur, kaedah mati yang diedarkan dibangunkan untuk mengira kelajuan dan kawalan kedudukan robot manakala pengawal berkompresi proporsional yang diskret (PI) digunakan untuk mengawal halaju kedua-dua roda. Untuk menilai prestasi kaedah yang dicadangkan, Antara Muka Pengguna Grafis MATLAB (GUI) dibuat untuk merekod jalan yang disasarkan dan sebenar robot. Dalam karya ini, ditunjukkan bahawa kedua-dua algoritma menyediakan strategi mengelakkan perlanggaran yang baik dengan ralat maksimum hanya 5cm.

DESIGN AND DEVELOPMENT OF COLLISION AVOIDANCE STRATEGY FOR DIFFERENTIAL DRIVE MOBILE ROBOT

ABSTRACT

Autonomous mobile robots have been considered for many service applications such as intelligent household cleaners and unmanned delivery systems. However, for some specific tasks, a mobile robot must be able to avoid obstacles and move efficiently from a starting point to a goal point. In such a case, a good collision avoidance technique is required where the distance between the robot and the obstacle must be kept non-zero. In this project, a collision avoidance strategy is designed and developed for a differential drive mobile robot, which is built using ATmega 328p microcontroller. Two algorithms, namely Artificial Potential Filed (APF) and Bug 2 are integrated into the model with an ultrasonic sensor to detect and avoid the obstacles. For path planning strategy, the dead-reckoning method is developed to calculate the speed and position control of the robot while discrete proportional-integral (PI) controllers are used to regulate the velocities of both wheels. In order to evaluate the performance of the proposed methods, a MATLAB Graphical User Interface (GUI) is created to plot the targeted and real path of the robot. In this work, it is shown that both algorithms provide good collision avoidance strategy with a maximum error of only 5cm.

CHAPTER 1

INTRODUCTION

1.1 Research Background

A mobile robot is an automatic machine that moves to accomplish a task in a given environment and recognizes its surrounding environment with multiple sensors[1]. There are three types of mobile robots that can be classified according to their locomotion which is wheeled, legged, and caterpillar track. From these three types of mobile robot, wheeled mobile robots (WMR) are most famous in service and industrial robotics, particularly when flexible motion capabilities are required for reasonably smooth grounds and surfaces[2]. The most common drive for the mobile robot are differential drive, synchronous drive, tricycle or car-like drive, and also omnidirectional steering[2]. A mobile robot is very complicated in dynamics and mathematical statics model, electronics control theory, and manufacturing[3]. In this research, full attention will be focused on collision avoidance strategy. This is due to collision avoidance strategy is one of the key issues to successful applications of mobile robot systems.

Estimation of the position of the robot with respect to the external world is fundamental to navigation. The current autonomous mobile robot focuses on the obstacle avoidance whose objective to provide a collision-free navigation in an unknown environment. There are many control strategies in collision avoidance, such as Vector Field Histogram, Dynamic Window Approach, Bug 2 algorithm, artificial potential field (APF) [4], Vector Field Histogram algorithm (VFH)[5], Hybrid Intelligent System (HIS) based on Fuzzy Logic (FL) and Artificial Neural Networks (ANN)[6]. Although the algorithm mentioned above are widely used in an autonomous mobile robot to prevent a collision, there are still other issues that may affect the performance of the mobile robot.

Based on [7], the complexity of the algorithm cannot be applied to a large number of obstacles and thereby lowering the efficiency. These restrictions motivate researchers to make some improvement on the collision avoidance. In order to build a low-cost mobile robot with ease calculation, artificial potential field (APF) algorithm and Bug 2 algorithm are applied in this work. Also, an obstacle avoiding robot model uses an ultrasonic sensor mounted on servo motor to detect the obstacle in front in a different angle.

Path planning is being categorized into global path planning and the local path planning. Global path planning of the mobile robot is to reach the destination using mapping method. A map will be created using different way with the presence of the obstacle in a known environment. On the other hand, local path planning of mobile robots is to determine the position and direction with respect to knowing the locations in an unknown environment[8]. In order to build up a mobile robot which can reach the destination in an unknown environment, local path planning is applied. As a result, the mobile robot can reach the destination without colliding with any obstacle. The most common and basic way of performing path planning is through dead-reckoning method. Dead reckoning obtains the relative position from the initial starting point using the encoders that attached to the motors and wheels of the mobile robot[9]. The position and the direction of the mobile robot can be calculated by this angular rate and this method is known as Odometry based on [1, 8, 9]. With the differentiate drive of a mobile robot, the speed of both wheels can be obtained in closed loop system to minimize the systematic error occur. Thus, the mobile robot can move from starting point to the desired goal point and avoid all obstacles.

1.2 Problem Statement

Nowadays, many people are inclining more and more towards using robotic technologies to ease some of their daily work. Real-time collision avoidance is one of the key issues to successful applications of mobile robot systems. There are many strategies for different types of sensors proposed in the literature that can be implemented to detect and avoid obstacles. For instance, the work in [10] focuses on collision avoidance using IR or PIR sensor to detect obstacles. The sensitivity of IR sensors towards light intensity, however, may cause some inaccurate measurements [11]. Besides that, from previous work in [12], eight ultrasonic sensors are used to detect obstacles in different direction. However, this may cause the interference between ultrasonic sensors occur.

There are many considerations when building an autonomous mobile robot such as the cost, accuracy of the sensors, efficiency of the actuators and environmental issues. The hardware and software design also play an important role to increase its functionality for a given task while minimizing the noise and disturbance from the surrounding.

In order to implement a collision avoidance strategy in a robot, the path planning technique and obstacle avoidance algorithm is the most crucial parts of the design, other than the choice of the sensor and its location on the robot. This is to ensure the performance of the mobile robot can be maximized. The data acquisition system is also important to evaluate the suitability and performance of the proposed collision avoidance strategy.

1.3 Research Objectives

- To implement the dead-reckoning method for speed and position control of the differential drive mobile robot.
- To design and develop suitable artificial potential field (APF) and Bug algorithms for collision avoidance strategy of the robot.
- To develop a data acquisition system via a graphical user interface for performance evaluation of the experimental results.

1.4 Scope of Research

The scope of this work is limited to a differential drive mobile robot which is controlled by ATmega 328p microcontroller. All the algorithms are synthesized via model-based technique in Simulink. As for the obstacle detection subsystem, only one ultrasonic sensor and one servo motor are used, and all the data are recorded wirelessly in MATLAB. The types of obstacle used are limited to the static ones, with the flat surface of the rectangular box. In addition, the rectangular box must be at least with height 13cm, length 9 cm, and width 9cm so that the ultrasonic sensor can detect the obstacle. If the obstacle is too smaller, it will become a blind spot for the robot. Besides that, the experiments are conducted on the floor with ceramic tile. This reduces the frictionless between the robot and the floor.

1.5 Report Organization

There are five chapters in this report including this chapter. The rest of the report is organized as follows:

Chapter 2 covers the literature review where previous works are discussed and analyzed. Related studies involving collision avoidance strategies are the main interest of this chapter.

Chapter 3 discusses the methodology used in this study. The hardware implementation of this project, including the list of components and the schematic diagram are explained in detail. Besides, the software implementation of this project is also presented in this chapter. The theory for each algorithm is explained clearly including the calculation formula.

Chapter 4 describes the result and discussion for this project. This chapter shows the result of implementation the dead-reckoning method and the two strategies for collision avoidance in the robot. The comparison between two algorithms is made and discussed in detail.

Finally, Chapter 5 presents the conclusion of this project. This chapter includes the limitation of this robot and the future works to improve it.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is to present a detailed background information and the related works done by researchers. There is plenty of significant research have been conducted on developing a mobile robot with the collision avoidance strategy. As mentioned in Chapter 1, a differential drive mobile robot is built with two wheels and a castor. This concept is obtained from researchers, and the reason will be explained in section 2.2. While section 2.3 will focus on the sensor fusion that is applied in collision avoidance strategy to detect obstacles. Sensor fusion technology is one of the important factors for good performance in obstacle detection. All the algorithms for collision avoidance strategies will be explained and compared in section 2.4 after the research. Lastly, a summary will be concluded in section 2.5 after going through the previous studies done by others.

2.2 Wheel Mobile Robot (WMR)

2.2.1 Definition

Wheel mobile robot (WMR) is the combination of various computation (software) and physical (hardware) components. Bi-wheel type robot, caterpillar type robot, and omnidirectional robot are the examples of the WMR as shown in *Figure 1*. The Bi-wheel type robot is smooth in motion but it has the risk of slipping. Hence, a roller-ball is used to make the robot more stable. The caterpillar type robot has exact straight motion, it takes time to change the direction. The omnidirectional robot has free motion with a complex structure in design.

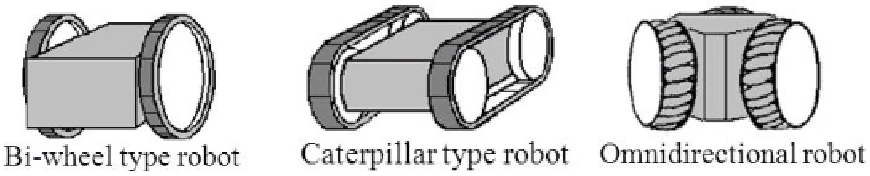

Figure 1 : Example for WMR [13]

2.2.2 Classification of Wheels

There are many types of the wheel can be used to be the main steering wheel in motion. For example, fixed wheel, centered orientable wheel, off-centered orientable wheel (castor wheel) and Swedish wheel. It is obvious that there is a restriction to the robot mobility for the fixed wheel, centered orientable wheel and off-centered orientable wheel [13].

<u>Fixed Wheel</u>

From *Figure 2*, point P cannot move in the direction perpendicular to the plane of the wheel.

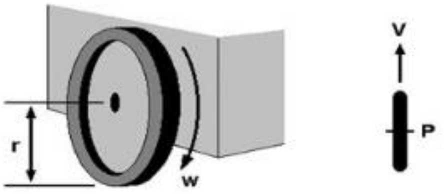

Figure 2 : Fixed wheel [13]

<u>Centered Orientable Wheel</u>

Figure 3 shows the centered oriented wheel. If the wheel requires moving to 45 degrees to the left, the wheel need to change the position of t and rotate the w then only can move.

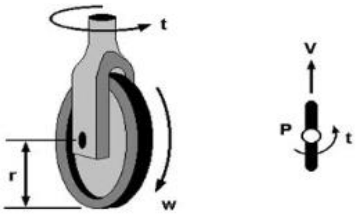

Figure 3 : Centered oriented wheel [13]

Off-Centered Orientable Wheel

If the off-centered orientable wheel display in *Figure 4* requires moving to 45 degrees to the left, the wheel need to change the position of t and rotate the w then only can move.

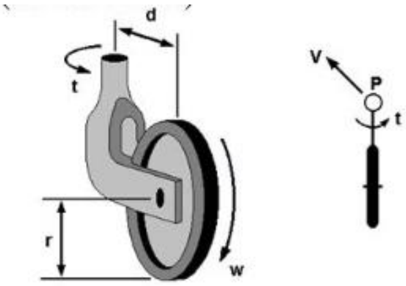

Figure 4 : Off-centered orientable wheel [13]

Swedish Wheel / Omnidirectional Property

The Swedish wheel as shown in *Figure 5* contains omnidirectional property. This property allows the robot to rotate and translate at the same time.

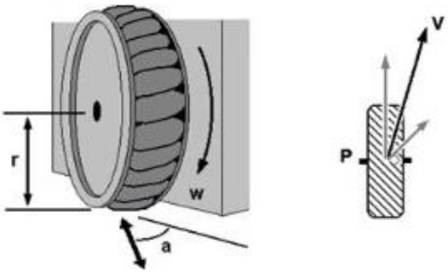

Figure 5 : Swedish wheel [13]

2.2.3 Locomotion

Locomotion is the process of causing an autonomous robot to move from one point to another point[14]. There are two keywords that play an important role in locomotion of mobile robot which is the Instantaneous center of rotation (ICR) and Instantaneous center of curvature (ICC). ICC is the point where the robot rotates while ICR is the point around which each wheel of the robot makes a circular course [13, 15]. ICR changes over time as a function of the individual wheel velocities. In order to analyze the degree of freedom of mobile robots, ICR needs to be determined for each wheel on the robot [15].

2.2.3.1 Degree of Freedom

There are two types of a mobile robot which are holonomic robots and non-holonomic robots. If the controllable degree of freedom is less than the total degree of freedom, it can be considered as a non-holonomic drive.

The degree of mobility, δ_m is defined by the degree of freedom of the robot motion. A straight line is drawn perpendicular to the center of the wheel [15]. From *Figure 6,* the top left robot does not have ICR so the degree of mobility is 0. The top right in *Figure 6* has only one degree if mobility which is rotated to the left side. Next, the bottom left of the *Figure 6* has 2 degree of mobility which is forward and backward. Lastly, the bottom right of the *Figure 6* has 3 degree of mobility which can move in three directions.

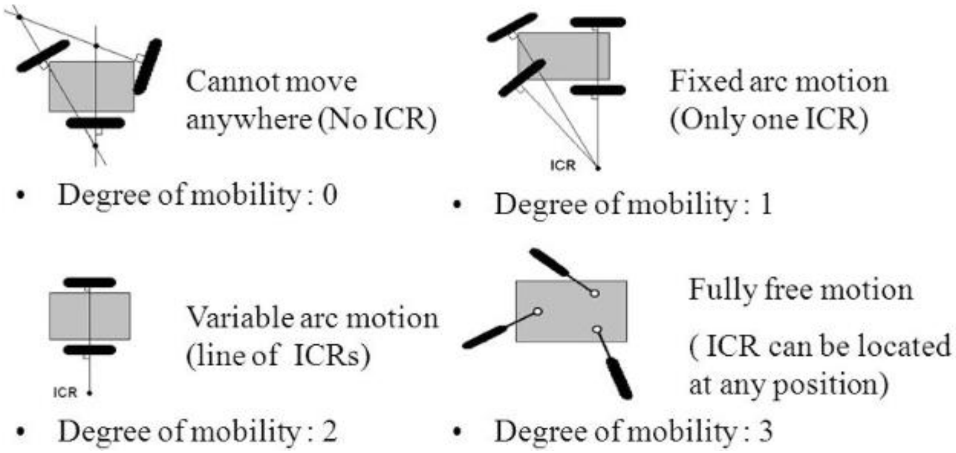

Figure 6 : Degree of mobility [15]

The degree of Steerability, δ_s is the number of independent DOF that can be controlled in mobile robots. The number of centered orientable wheels that can be steered independently in order to steer the robot [15]. From *Figure 7*, when no centered orientable wheels the degree of steerability is equal to zero. When one centered orientable wheel, two mutually dependent centered orientable front wheels will make the degree of steerability become one. On the other hands, when two mutually independent centered orientable rear wheels combine with one centered orientable front wheel, the degree of steerability become two.

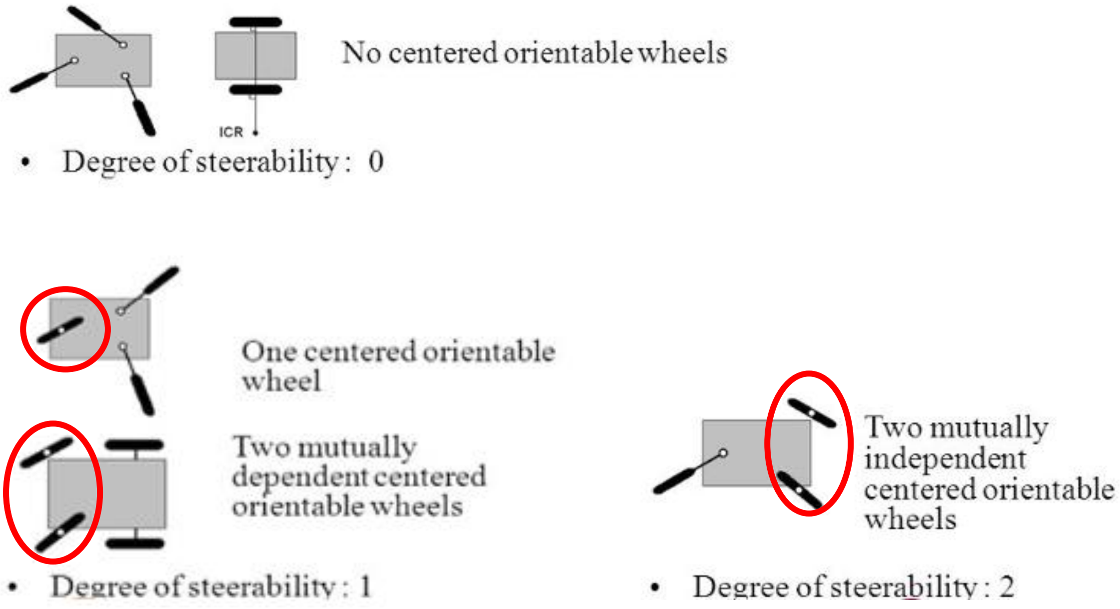

Figure 7 : Degree of Steerability [15]

The degree of Maneuverability, δ_M is the overall degree of freedom that a robot can manipulate. The formula is as shown in below.

$$\delta_M = \delta_m + \delta_S$$

From *Figure 8* , omnidirectional drive robot has the same number of between degree of mobility and degree of maneuverability which is 3 due to no centered oriental wheel. Differential drive robot also has the same number of between degree of mobility and degree of maneuverability which is 2 due to the same reason. Two robots with the same degree of maneuverability are not necessarily equal such as omnidirectional and Omni-steer drive robot. For any robot which has 2 degrees of maneuverability, the ICR is always constrained to lie to a line. Then, for any robot which has 3 degrees of maneuverability, the ICR is not constrained and can be set to any point on the plane[15].

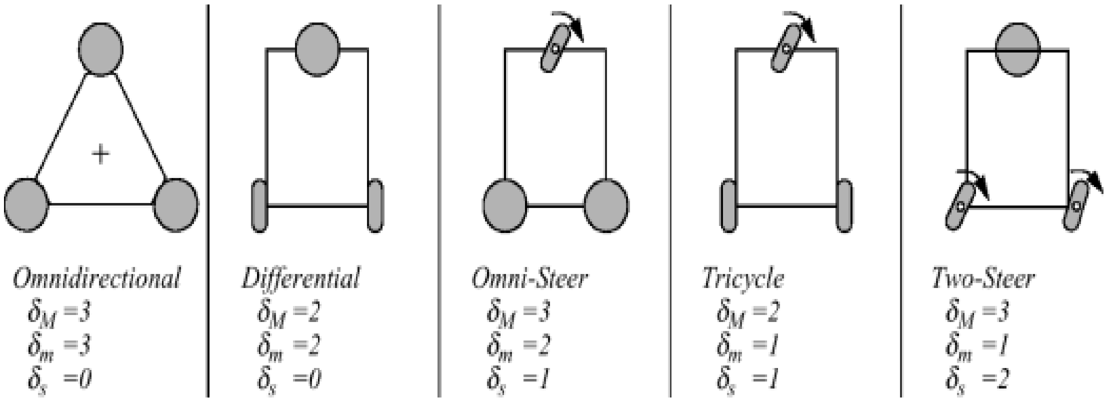

Figure 8 : Degree of Maneuverability [15]

2.2.3.2 Types of Locomotion

There are mainly five types of locomotion in WMR including differential drive, synchronous drive, tricycle, omnidirectional steering and Ackerman steering. Each locomotion system is unique and has some advantages and disadvantages.

a) Differential Drive

Differential drive is the simplest drive mechanism among all and easy to implement. Differential drive robot has two independent powered wheels with 2 degrees of freedom which attached to the back of the mobile robot as shown in *Figure 9*. Hence, it is very sensitive to the relative velocity of two wheels.

Figure 9 : Differential drive robot [14]

From *Figure 10* : Four cases for differentiate drive. If velocity for right wheel, V_R equal to the velocity of the left wheel, V_L means the robot is in the same direction [14]. The robot will move straight forward if the dc motor rotates anticlockwise and vice versa. If $V_R > V_L$, the robot will turn to the left side while $V_R < V_L$,the robot will turn to the right side [14]. Arbitrary motion and in-place rotation (zero radius) can be achieved [14]. However, one of the disadvantages is the mobile robot may not drive as expected especially using DC motor. This is because the difference in the number of rotations of each wheel in reality is not ideal. To solve this problem, a feedback loop can be added to adjust to the motor speed. For instance, if the robot is turning towards one side when need move straight forward, the correction factor can be added to reduce the speed of another wheel.

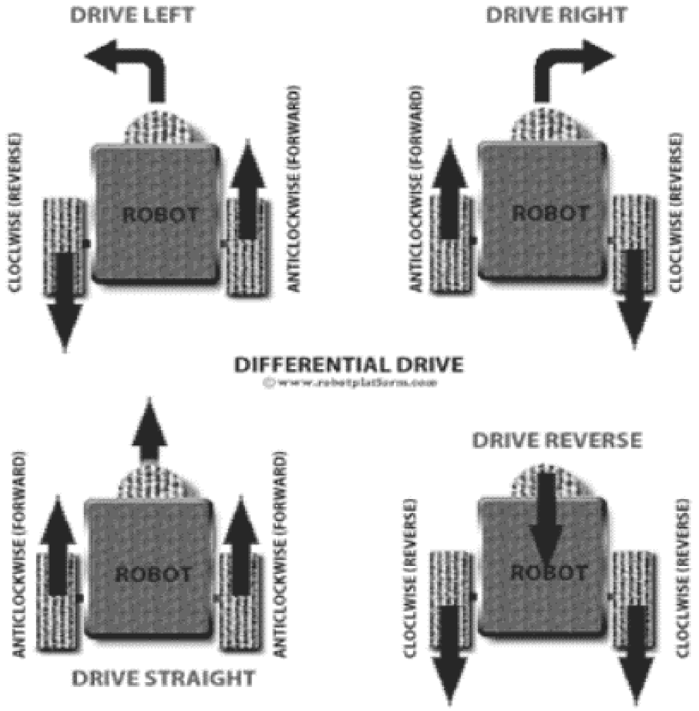

Figure 10 : Four cases for differentiate drive [14]

b) Synchronous Drive

Synchronous drive robot as shown in *Figure 11* means all the wheels attached to the mobile robot are powered. All the wheels steer the same way simultaneous with fast moving. It also has 2 degrees of freedom. In other words, each wheel is capable of being driven and steered in the same direction and the same speed. All the wheels turn and drive in unison make it become a holonomic behavior. It has the ability to control the orientation of the pose directly [14, 16].

The synchronous drive has a synchronous operation and greater accuracy. Nonetheless, disadvantages of this design are that it requires a high-frequency power supply. Besides that, it has a complicated mechanical structure and the cost of building this robot also very high. If backlash or lose coupling is present in the chain transmission, velocity differences between wheels may occur [16].

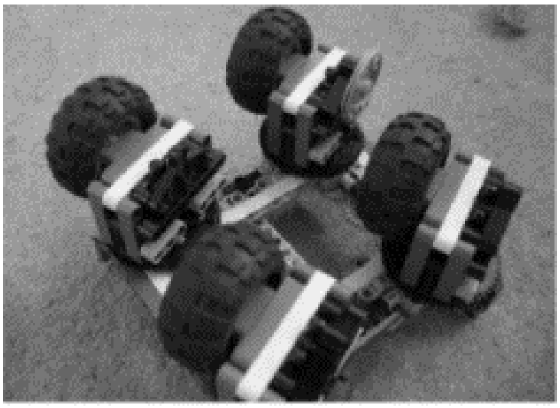

Figure 11 : Synchronous drive robot [14]

c) Steered Wheels (Tricycle or Car-like Drive)

Steered wheel robot as shown in *Figure 12* is one of the types of the drive which has on the steering wheel and two rear wheels. This robot is designed with a front steering wheel controlled by a motor. The rear wheels are attached to a common axle driven by a single motor with two degrees of freedom (either forwards or reverse Odometers is applied to the two rear wheels. The steering and power are provided through the front wheel [14].

Steered wheel robot has a limitation for the radius of curvature and cannot rotate 90 degrees. Both steers and drive controlled by the front wheel and the rear wheels act as supporting wheels to maintain equilibrium. This design is seldom used by others due to the design constraints and its drawbacks [14, 16].

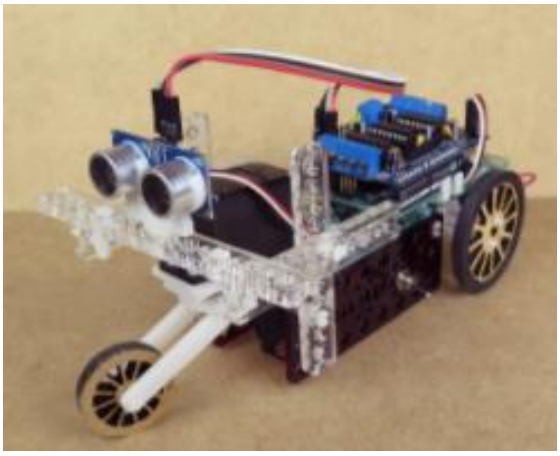

Figure 12 : Steered wheels robot [14]

d) Omnidirectional Steering

Figure 13 shows the omnidirectional steering robot. Omnidirectional steering has three or four powered wheels and the wheels are specially designed. Since Omni wheels have smaller wheels attached perpendicular to the circumference of another bigger wheel, it allows all wheels to move in any direction instantly. Hence, it has 3 degrees of freedom and can move without changing orientation.

However, Omni wheels are expensive compared to other and less efficient due to not all wheels are fully utilized for driving and controlling the robot. Besides that, there will have a greater resistance to rotate due to the contact between all wheels and ground will be greater.

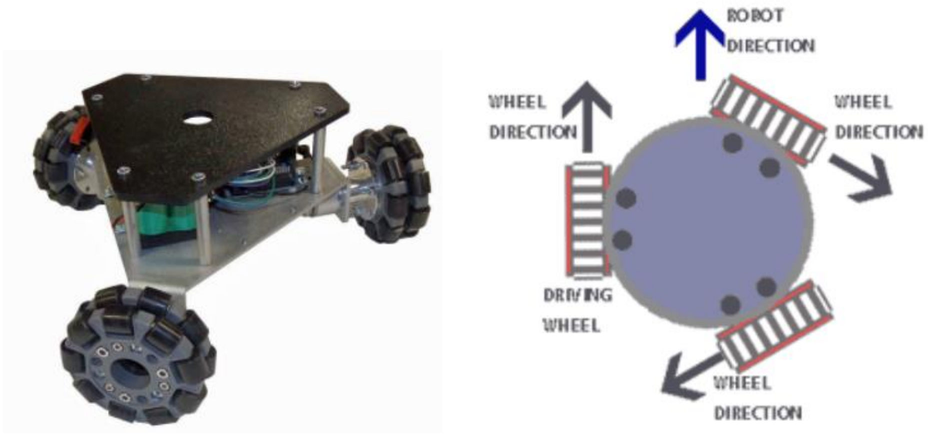

Figure 13 : Omnidirectional steering robot [14]

e) Ackermann Steering/ Car Drive

Figure 14 shows the famous drive that used in real world, but not in the robotics field. Ackermann steering is used in motor vehicles, the two front wheels are rotated slightly sharper than the outside wheel when changes direction. Ackermann steering provides a fairly accurate dead-reckoning solution while supporting traction and ground clearance.

The advantage of this design is increased control, less slippage, less power consumption, and better stability. However, when two wheels are attached to a tricycle design, then turning causes the robot to skid [14]. Furthermore, a slight inaccuracy results for wheel will cause a huge error and make the path planning become more difficult.

Figure 14 : Ackermann steering robot [14]

2.3 Sensor Fusion for Collision Avoidance

The robot needs miscellaneous of sensors to obtain information of the environment to avoid a collision. There are few measurement technologies that use for collision avoidance for a mobile robot such as an infrared sensor, ultrasonic sensor, camera and LIDAR (Light Detection and Ranging). All of these sensors can be used to detect different kinds of obstacles. Thus, the best sensor will be chosen from sensors above after considering all the requirements in this research. Sensor selection is a challenging task for the obstacle avoidance system, as it extremely affects the whole system performance.

2.3.1 Infrared Sensor

The infrared sensor is an electronic device which is used to sense certain characteristics of its surroundings by the object by emitting and detecting infrared light.

Infrared sensors are capable of measuring the heat being emitted by an object and detecting motion. It is very small, low cost and easy to use [17]. From the research in [11], the infrared sensor (IR) is placed on the three-wheel platform to detect the distance between obstacle and WMR. The WMR will receive distance data continuous from an IR sensor as an input for avoiding obstacles[17]. The IR sensor output analog voltages represent the distance to object in cm.

According to research in [11], the IR sensor can recognize distance from 10 cm to 80 cm. The power consumption for IR sensor is low compared to other sensors. IR sensor can be categorized as diffuse reflection sensors and retro-reflective sensor. Retro-reflective sensors are proper for harsh environmental conditions and have a much larger detection range compared with the diffuse reflective sensor.

Figure 15 shows the robot that using the infrared sensor as obstacle detection. As IR sensor detectors detect the infrared images based on the temperature variations of the object, it cannot detect the differences in an object which has approximation temperature. Besides that, the performance of IR sensor decreased when meets the bright color object. Since the IR sensor is easily affected by light, this leads to the inaccuracy when detecting an obstacle. At the same time, detection results also affected by the weather conditions and the sensing reliability of IR sensors decreases with moisture and humidity[10].

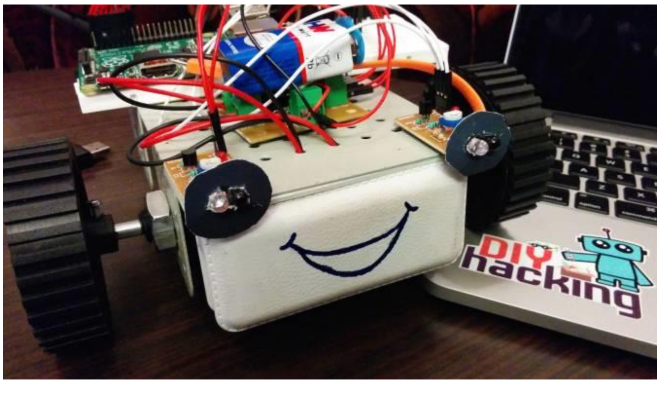

Figure 15 : Robot with an infrared sensor [11]

2.3.2 Ultrasonic Sensor

Figure 16 shows the robot with three ultrasonic sensors. An ultrasonic sensor typically utilizes a transducer that produces an electrical output in response to received ultrasonic energy. The normal frequency range for human hearing is roughly 20 to 20,000 Hertz. Any frequency above 20,000 hertz may be considered ultrasonic. The sensor operates by emitting high-frequency sound waves and evaluates the echo which is received back by the sensor. By using the speed of sound and the time interval between sending the signal and receiving the echo, the distance between the sensor and the object can be calculated.

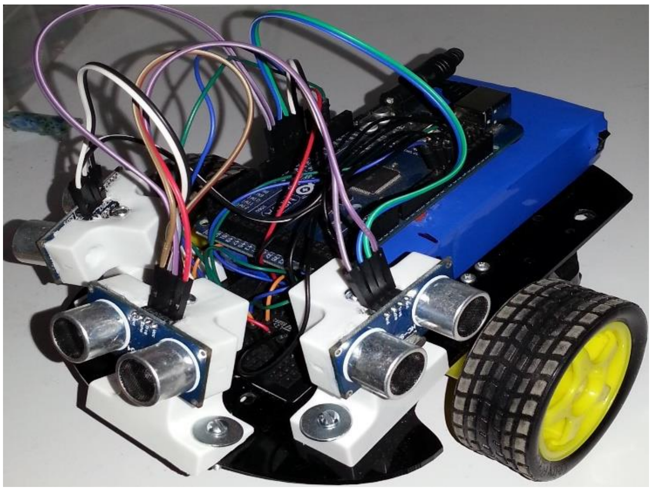

Figure 16 : Robot with three ultrasonic sensors [12]

From [12], application of ultrasonic sensor for obstacle detection has been proved that can work efficiently at close distance. Normally, the ultrasonic sensor can detect obstacle up to 4 meter and their accuracy of object localization decrease in proportional to the distance. Since in this project the obstacle detection is done in a short distance range, so the accuracy of the sensor does not affect. Also, [12] had briefly described eight ultrasonic sensors is used in [12] so that it does not have any blind spot for the robot.

As proposed in [18], ultrasonic distance measurement is a non-contact detection method. It has a certain ability to adapt to the dark, the dust, the smoke and the electromagnetic interference. Also, it is not affected by the light and the color of the object surface. Hence, it is used as an "eye" for quad-rotor UAV to detect an obstacle in real time in [18]. Nonetheless, interference between the projected waves and the reflected waves takes place if two ultrasonic sensors placed too close.

2.3.3 Camera

A robot that using a camera as a sensor to detect obstacle is as shown in *Figure 17*. Vision detection technique can also to be used to detect the obstacle to avoid a collision. A single overhead camera based on the principle of artificial potential fields cab detects obstacle using image space and integrates the CAD-based recognition method [19]. A predefined map of the robot must be used to generate an optimal obstacle-free path in the global path method. This overhead camera is used to map the 3D environment into 2D image model. From [10], due to the limitation of IR sensor and passive infrared sensor (PIR), a camera feature is recommended to implement in order to improve the accuracy of collision avoidance.

Figure 17 : Robot with camera [20]

A moving obstacle can also be detected by the single overhead camera. The obstacle will be detected when the robot moves near to it by using block-based motion estimation. As mentioned in [20], the robot uses histograms of images obtained from a monocular and monochrome camera to detect and avoid obstacles in a dynamic environment. Nonetheless, not every camera is suitable to use for object detection. For example, stereo camera vision does not perform very well under any environmental conditions such as glass surfaces, plain wall or poor lighting conditions [20].

2.3.4 LIDAR (Light Detection and Ranging) / Laser Rangefinder

LIDAR are devices that are using a laser beam to measure the distance of an object from the user. These rangefinders have two methods to measure the distance of an object, which is the time of flight and triangulation. Interaction processes of the emitted radiation with the atmospheric elements can be used in the LIDAR for allowing the determination of the basic environment variables of state such as humidity, temperature, wind, and pressure. A robot with LIDAR is as shown in *Figure 18.*

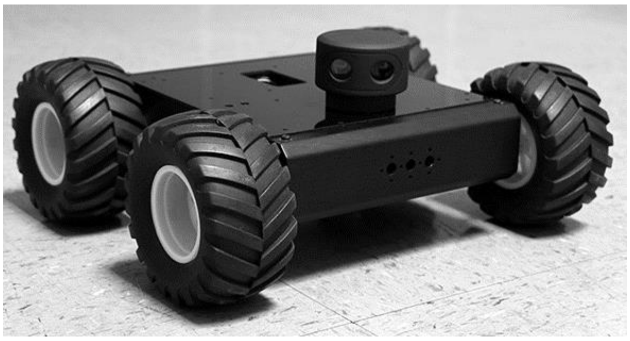

Figure 18 : Robot with LIDAR [10]

From researches in [10], LIDAR is suggested to use in collision avoidance strategy compare to IR sensor to improve the performance of the robot. The laser-based (LIDAR) sensor system is robust, especially in off-road outdoor environments. LIDAR can give accurate scheme for generating information about the shape and surface characteristics of an object using image processing. Besides that, LIDAR able to create a precise, three-dimensional image of the object, whether a person, vehicle, aircraft, cloud, or mountain. From [12], the application of LIDAR for obstacle detection has been proved that can work efficiently at close distance. Hence, it is used in self-driving technologies.

As mentioned in [21], LIDAR cannot detect a low object and overhanging obstacle because of its predefined, constant, scanning height and angle. LIDAR offers good accuracy in longitudinal distance measurement, but poor accuracy in lateral distance measurement. Vision has the opposite properties. Hence, according to the research in [21], it used the camera and LIDAR to improve the accuracy of the obstacle detection. Although LIDAR was better than infrared sensors, it will exceed the project’s budget if a laser finder is purchased because the laser sensor has a higher cost than the infrared sensor and the ultrasonic sensor.

2.4 Path Planning

Path planning is divided into two categories which are local path planning and global path planning [19]. Path planning algorithms can be roughly classified into four categories which are artificial potential field method, grid method, template model law and artificial intelligence method. While the common method for local path planning algorithms includes the artificial potential field method (APF), DWA, Bug algorithm and Virtual Force Field (VFF) as proposed in [21]. Since in this research local path planning with sensor fusion is determined, the algorithm will be focused on local path planning.

2.4.1 Artificial Potential Field (APF) Method

APF basically developed as an on-line collision avoidance for local path planners. The global path planning technique based on the APF was defined in to provide stationary obstacle avoidance and path planning for the mobile robots and re-evaluate manipulator. The major problem in the real-time path planning using APF method is the local minimum issue, which can make a trap for a robot before reaching its goal location. However, by considering the entire path in the global path planning using APF method, the local minimum problem is greatly reduced, allowing the method to be used for global path planning.

As proposed in [22, 23], obstacle avoidance algorithm based on APF using ultrasonic sensor. In the APF, the mobile robot is assumed as a moving point in an abstract artificial force field, and the potential function can be defined over free space [23]. Potential field force can be divided into two categories according to their functions. Firstly, it is the attractive force generated by the goal point. Secondly, it is the repulsive force developed by the obstacle. Hence, with the ultrasonic sensor, the robot can move towards the destination and avoid obstacles. The situation can be observed visually from *Figure 19* below.

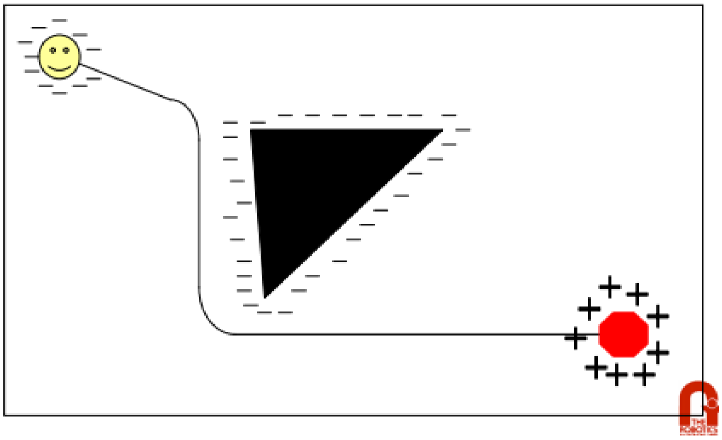

Figure 19 : APF from starting point to the goal [23]

As proposed in [23], the mobile robot, obstacle, and the destination point is defined as a point in a two-dimensional coordinate system. Given a two-dimensional coordinate space be Xmax × Ymax, then a point is expressed as q=[x,y], where 0≤x≤Xmax, 0≤y≤Ymax. In the abstract potential field, the repulsive potential field function generated by the obstacle to the robot is defined as Urep(q). The generated potential field size is related to the distance between the obstacle and the robot. The further the distance is, the smaller the potential energy is[14]. The gravitational potential field function generated by the target point to the robot is defined as Uatt(q), the further the distance between the robot and the goal point is, the greater the potential energy is.

$$\text{Gravitational potential function, } U_{att}(q) = \frac{1}{2}\,\eta\,\rho^2\,(q,qg) \qquad (2.2)$$

where η is the proportional gain coefficient $p(q, q_g)$ represents a vector, the magnitude of the vector is the Euclidean distance $|q-qg|$ between the vector size q and the target point position q_g, and the direction of the vector is the direction from the robot to the point of the target [23].

The attractive force generated by the gravitational field is:

$$\vec{F}_{att}(q) = -\nabla U_{att}(q) \qquad (2.3)$$

$$\vec{F}_{att}(q) = \eta\rho(q,q_g) \qquad (2.4)$$

The repulsive potential function is expressed as:

$$U_{rep}(q) = \begin{cases} \frac{1}{2}k\left(\frac{1}{\rho(q,q_0)} - \frac{1}{\rho_0}\right)^2, & 0 \leq \rho(q,q_0) \leq \rho_0 \\ 0 & \rho(q,q_0) > \rho_0 \end{cases} \qquad (2.5)$$

where k is the proportional gain coefficient; p_o is a normal number, which represents the maximum distance that the mobile robot has an effect on the mobile robot; $\rho(q, q_o)$ represents a vector. And the magnitude of the vector is the Euclidean distance between the closest obstacles to the robot and the robot in the obstacle area around the mobile robot, and the direction of the vector is from the obstacle position to the robot position [23].

The repulsive force generated by the repulsive field is :

$$\vec{F}_{rep}(q) = \begin{cases} k\left(\frac{1}{\rho(q,q_0)} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q,q_0)}\nabla\rho(q,q_0) & 0 \le \rho(q,q_0) \le \rho_0 \\ 0 & \rho(q,q_0) > \rho_0 \end{cases} \qquad (2.6)$$

The resultant force of the robot is

$$\vec{F}(q) = -\nabla U(q) = \vec{F}_{att}(q) + \vec{F}_{rep}(q) \qquad (2.7)$$

The total potential field function is formula as shown in (2.6) and *Figure 20.*

$$\mathbf{U}(q) = \mathbf{U}_{att}(q) + \mathbf{U}_{rep}(q) \qquad (2.8)$$

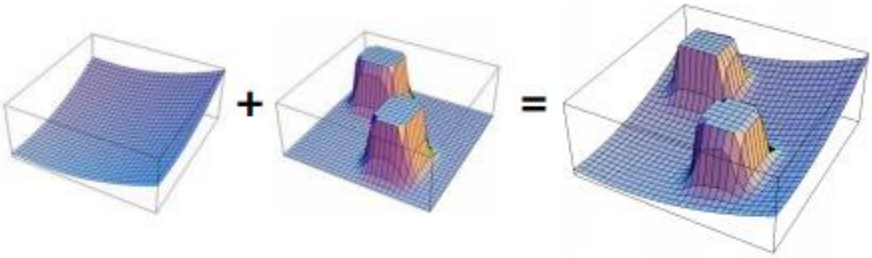

Figure 20 : Total potential field function [23]

However, the local minima problem has been a serious issue for potential field methods. From [24], some attempts were made to solve this problem.

2.4.2 Dynamic Window Approach (DWA)

The DWA is a velocity space search method which takes robot dynamics into consideration. This method including three stage process. Firstly, DWA eliminates unreachable velocities coming from the acceleration limits of the robot. At the second stage, all velocity pairs which are not able to stop before colliding with an obstacle are eliminated. At the last stage, DWA evaluates an admissible velocity set by maximizing its objective function [25]. In other words, it will calculate the states at each speed during