A FEASIBLE ARCHITECTURE OF REAL-TIME COLLISION AVOIDANCE AND PATH PLANNING FOR SEMI-AUTONOMOUS UNMANNED GROUND VEHICLE (UGV)

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by

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ENDORSEMENT

I, Purawin Subramaniam hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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Date:

(Signature of Supervisor)

Name:
Date:

(Signature of Examiner)

Name:
Date:

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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(Signature of Student)

Date:

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A FEASIBLE ARCHITECTURE REAL-TIME COLLISION AVOIDANCE AND PATH OPTIMIZER FOR SEMI-AUTONOMOUS UNMANNED GROUND VEHICLE (UGV)

ABSTRACT

An Unmanned Ground Vehicle (UGV) is a vehicle that is on contact with ground and operates without human on-board. UGVs are widely used for mission-based applications that are often hazardous or inconvenient for humankind. Practically, UGVs are equipped with multiple devices like sensors and on-board camera to enable self-navigation and fulfil the mission requisite. In this project, the UGV combines two main elements, which are collision avoidance system (CAS) and path planning system (PPS). Costing is highly concerned for this project, therefore a low-cost ultrasonic sensor (HC-SR04) is used as a distance sensor for obstacle detection and avoidance purpose. Meanwhile, an Arduino Mega 2560 and ArduPilot Mega 2.6 (APM) are used as microcontrollers for obstacle avoidance and path optimization purpose respectively. Vehicle navigation is based on point-to-point basis and the waypoints are set in Mission Planner software that works alongside APM. In this project, the vehicle is programmed to maneuver at lower speed between 2 to 4 km/h. The maneuver is assisted with ultrasonic sensors (front and rear) sense and avoid the obstacles within 3 meters range. The ultrasonic sensors are programmed in such a way that it sweeps the sensors that the field of view of 180° angle both front and rear of the vehicle. Path planning is the key element for unmanned vehicle. Therefore, APM is used for navigation before and after approaching obstacles. Path planning algorithm in this project provides the best path to avoid the obstacle and create temporary new waypoints within split seconds. This

practice makes the UGV more authentic and proximately imitable with human sensors and its responses.

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ABSTRAK

Kenderaan Tanpa Pemandu (KTP) adalah sebuah kenderaan berasaskan misi dan beroperasi tanpa manusia. KTP digunakan secara meluas untuk aplikasi yang berbahaya atau menyusahkan manusia. Secara practical, KTP dipasang dengan pelbagai sensor dan kamera untuk memenuhi misi yang diperlukan. Projek ini terdiri daripada dua elemen utama, iaitu mengelakkan pelanggaran dan perancangan laluan. Kos adalah salah satu tumpuan utama bagi projek ini, di mana penggunaan sensor kos rendah dan perkakasan sumber terbuka yang digunakan secara meluas pada masa yang sama memberi tumpuan untuk menghasilkan keputusan yang menjanjikan. Dalam projek ini, sensor ultrasonik kos rendah (HC-SR04) digunakan sebagai penderia jarak jauh dan sensor pemetaan untuk tujuan pengesanan dan mengelakkan halangan. Sementara itu untuk perkakasan sumber terbuka, Arduino Mega 2560 dan ArduPilot 2.6 (APM) digunakan sebagai mikrokontroler untuk tujuan penghindaran halangan dan tujuan pengoptimalan perancangan perjalanan. Titik laluan ditetapkan dalam perisian Mission Planner yang diintegrasikan dengan APM. Dalam projek ini, KTP bergerak pada jarak halaju 2 hingga 4 km/j. Sensor ultrasonic (depan dan belakang) disepadukan dengan Arduino Mega 2560. Sensor ultrasonic dipasang sedemikian supaya mempunyai pandangan sudut 180° kedua-dua depan dan belakang KTP. Perancangan jalan adalah unsur utama navigasi untuk KTP. Oleh itu, APM digunakan untuk navigasi dan selepas menghampiri halangan. Algoritma perancangan laluan dalam proek ini memberikan

jalan terbaik untuk mengelakkan halangan dan menghasilkan titik arah sementara. Amalan ini menjadikan KTP lebih sahih dan tepat dengan sensor dan maklum balasnya.

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CHAPTER 1

INTRODUCTION

1.1 Background

UGV is a vehicle that operates without human on-board. It is widely used for application that is hazardous and inconvenient for humans. Generally, UGVs are equipped with sensors and camera for observation and acquiring data purposes. This project utilizes an ultrasonic sensor as a mean to sense and avoids obstacle. It is widely used for non-contact distance measurement from a point to any obstacles using the principle of sound waves propagation. Innovation of ultrasonic sensors inspired by bat echolocation. In fact, dolphins use echolocation to estimate the distance in the ocean (Szlachetko and Lower, 2014).

Obstacle avoidance is a vital feature for UGVs in order to navigate autonomously. As such, the accuracy of obstacle sensing is significantly important to estimate the geometry of the obstacle. This provides a clear picture and position of obstacle to the vehicle that is approaching. To achieve that, a special algorithm that works with ultrasonic sensor is needed to acquire the geometry of approaching obstacle and the response of the vehicle to avoid obstacle. Many types of ultrasonic sensors are available in the market today with a typical field of view of 30° and the maximum measuring distance is 280cm to 300cm (Szlachetko and Lower, 2014).

Besides obstacle avoidance, path planning is significantly important for UGVs to determine the shortest path or optimal path from a starting point to desired destination. The algorithm of path planning minimizes the vehicle maneuvers in order to increase the efficiency. Every path planning method has certain advantages, drawbacks and constraints as well. Path planning algorithms need to work together with obstacle avoidance algorithms in order to sustain on the pre-planned route. In this project, the user fixes the waypoints via Mission Planner software. Path planning starts to function when the UGV approaches obstacle on its path by setting a temporary waypoint using Nearest Neighbor technique to avoid the obstacle and travels towards the initial fixed waypoints.

1.2 Problem Statement

Many research been involved in making autonomous platform yet most of the research involve small scale vehicles (mobile robots) and skid steer type steering (Mandow et al., 2007). This approach is not practical since it does not replicate the conventional on-road vehicles. Furthermore, previous projects and research on mobile robots are not suitable on off-road terrain due to absence of suspension system.

Nowadays, collision avoidance system (CAS) is widely implemented across research discipline. A typical setup is using static and multiple ultrasonic sensors on the platform. Certainly, utilizing multiple sensors provide results that are more accurate for CAS but it does not satisfy the optimization objective.

Path planning is crucial for autonomous platform to satisfy navigation objective. Most research work does not make PPS work along with CAS. Either CAS or PPS work independently. CAS without PPS is like moving cautiously without direction and destination. On the other hand, PPS without CAS is like moving incautiously with direction and destination. Autonomous vehicles will join human drives on our roads sooner than most people think. However, as quickly as this self-driving car technology is advancing, these vehicles struggle operating in off-road conditions. Recent research and advancements have focused on introducing technologies into such driverless cars to make them safer, more viable in the widest range of real life, (both on and off-road) driving environment and weather conditions so that future highly automated and fully autonomous technologies are not limited to tarmac. The researchers in the automotive giants, Jaguar and Land Rover, are currently developing and demonstrating the next-generation sensing technologies to introduce an all-terrain capability into the future autonomous vehicles. Innovations in driverless cars technology-ensuring safety of driverless cars in extreme off-road conditions is a current pressing requirement in the industry. The theme for this work centered on the following objectives.

1.3 Objectives

1. To construct a robust autonomous platform that is able to navigate on the road and off-road terrain.
2. To develop an algorithm for optimized collision avoidance system (CAS).
3. To develop a system which bridges CAS and path planning system (PPS).

1.4 Thesis Outline

The thesis consists of five chapters. Chapter 1 consists of sub-topics e.g. background, problem statement, objectives, etc. Chapter 2 describes the previous and current researches within this area. In addition, this chapter includes the outcome of other research work as well. Chapter 3 explains the method used to carry out the project work and relates them with a simple set of experiments. Chapter 4 contains all the results of the experiments based on the test run done on the UGV. Finally, chapter 5 summarizes the entire research work and suggested plans for future improvement.

CHAPTER 2

LITERATURE REVIEW

With the advent of automobile technology in the early 80s, humankind could easily travel from one place to another. As a result, the accident rate has increased significantly due to road accidents (Mane et al., 2018). Although there are numerous reasons to blame according to (Rolison et al., 2018), the major contributor of road accidents is due to human error. Therefore, many car manufactures work hard towards introducing collision avoidance system (CAS) which could reduce the number of road accidents (Shaout et al., 2011). A CAS consists of three parts: 1) *object detection* 2) *decision-making* 3) *actuation* (Llorca et al., 2011). Autonomous collision avoidance was first introduced for unmanned aerial vehicles (UAVs) (Morrel, 1958). It has been installed onboard domestic transport aircraft since the early 1990s (Kuchar and Yang, 2000). The installed system is called Traffic Alert and Collision Avoidance System (TCAS) (Kuchar and Drumm, 2007). The collision avoidance system for automobile commenced with Forward Collision Warning (FCW) system which alerts the driver through visual and/or audio when driver gets too close to the vehicle ahead (Kusano and Gabler, 2012, Braitman et al., 2010). Yet, this system only alerts and does not take any corrective actions even if there is no driver input. Then many more collision avoidance systems e.g. Pre-crash Brake Assist (PBA) and Pre-Crash Braking (PA) were introduced.

Even though these technologies are contributing to collision avoidance, they are still not sufficient to completely eliminate collisions (Hayashi et al., 2012). According to (Adarns and Place, 1994), maneuvering the steering alone would be more effective in collision avoidance. This statement also supported by (Hayashi et al., 2012) saying that, evasive steering can be an alternative solution for collision avoidance. The advanced version of this solution is that, integrating steering with BAS (Eckert et al., 2011). In this project, there is no braking mechanism installed on the UGV. Therefore, the project is highly inspired with steering method for collision avoidance.

There are many ways available for object detection especially using a non-contact sensing. It could be done by visual, light and sound etc. depending on the type of applications and each method has different method has different advantages and disadvantages. As for the visual object detection, the use of camera through monocular and stereo techniques could improve field of view and distance estimation respectively. Monocular vision uses a single camera while stereo vision uses two cameras. In monocular vision, the relative size cue used to detect frontal collisions (Mori and Scherer, 2013). In the similar article, it is said that detecting and avoiding frontal collision in monocular vision is challenging since there is no motion parallax and optical flow. Therefore, stereo vision was introduced. Stereo vision is highly inspired by the human vision (Ashoori and Mahlouji, 2017). Stereo algorithms can provide distance information (Oleynikova et al., 2015, Park and Kim, 2012). Even though stereo camera provides more accurate data on distance, they are expensive (Bhagat et al., 2016). Besides that, stereo vision systems do not perform under certain environmental conditions e.g. plain wall and poor lighting conditions(Mohammad, 2009). Apart from visual technique, radar method is also being widely used for collision avoidance (Coelingh et al., 2010, Braitman et al., 2010). Radar is reliable during bad weather, rain and fog. However, does not provide enough data points to detect obstacle boundaries. Furthermore, radar is also not reliable to detect small obstacles like pedestrians (Bertozzi et al., 2008). In addition, radar sensors are expensive and difficult to package due to the size (Shaout et al., 2011). From this context, radar is not suitable for the project.

In addition, Light Imaging Detection and Ranging (LIDAR) (Hayashi et al., 2012) is also used for collision avoidance. According to (Manduchi et al., 2005) LIDAR helps building a symbolic representation of the scene in terms of an obstacle map. LIDAR are attractive because they offer a low-cost option and easy to package due to small size comparative to radar. The drawback of LIDAR is its inaccuracy in bad weather conditions and laser beams blocked by dirt build up on sensor lenses (Shaout et al., 2011). This statement is also supported by (Distner et al., 2009) where LIDAR in Volvo cars is mounted on top of windscreen to ensure a clear view since the area in front of the sensor is cleaned by the windshield wipers. Due to these factors, LIDAR is not considered for the project.

Besides that, (Panda et al., 2016) explains that four medium parameters has high effect on speed of sound. The most concern among the parameters is air temperature. However, the author also mentioned that maximum percentage error of speed of sound is 0.33. After all these consideration, ultrasonic sensor is chosen as the sensor for this project.

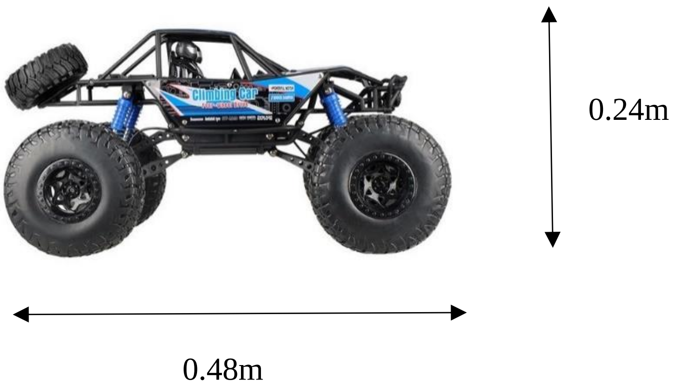
Choosing the steering system for this project is also crucial. Currently, there are many types of steering system availably used in our life e.g. front-wheel steering system (FWS), rear-wheel steering system (RWS), four-wheel steering system (4WS) and all-wheel steering system (AWS) (Zhang et al., 2017). The most common steering system is FWS which is currently used for automobile vehicles (Klier et al., 2004). RWS is mainly used for forklift (Lee, 2011). In the RWS, only the rear wheel would steer left and right for maneuvers. Meanwhile, AWS is being used in rovers for especially for Mars exploration (Patel et al., 2010). AWS provides a unique approach in steering system since the turning radius is zero (Shahrom and Peeie, 2017). AWS can be used in situation where the mobile robot needs to make lateral movement at minimum space. RWS is not practical to be used on roads since the transport system is aligned to FWS. Using RWS in this project would make not adapt the current road transport system. On the other hand, 4WS can be used for huge vehicles that require to make sharp turns (Singh et al., 2014). Of all these consideration, FWS is used for this project.

CHAPTER 3

METHODOLOGY

3.1 Prototype of UGV

The UGV used in this project is based on the commercially available 1:10 RC Car as shown in Figure 3.1. The RC car is purchased from the website link: https://goo.gl/GLmjYr.



(a) Side View

(b) Bottom View

Figure 3.1: RC car (https://goo.gl/GLmjYr)

The dimension of the vehicle is 0.48m × 0.24m × 0.24m. The car runs on two separate DC motors, which makes the front and rear wheel driven independently. The chassis of the car is made from Acrylonitrile Butadiene Styrene (ABS) material-lightweight and strong. An experiment was carried out on determining the radius of the turning and the distance of one complete rotation of the wheel. The turning radius is approximately 0.98m. Meanwhile, the distance of the full rotation of the wheel, which is also the circumference of the tire, is 0.44m. Complete specification of the car is stated in Table 3.1.

Table 3.1: Specification of RC car

Parameter	**Value**
Class of Vehicle	Four wheel drive (4WD)
Steering	Front Wheel Steering (FWS)
Scale	1:10
Operating Voltage	8V
Operating Current	4A (2A × 2 DC Motors)
Maximum Speed	10 km/h
Weight	2.14 kg
Wheel Size	140 × 45 mm
Wheelbase	500 mm

To accommodate the features of the proposed UGV, some modifications were done. A microcontroller needs to be installed as a control device. Although numerous microcontrollers available in the market today, a basic microcontroller Arduino Mega 2560 is chosen for this project because it provides a sufficient digital I/O pins to accommodate the sensors and other components required in the project. Moreover, this microcontroller is easy to code and troubleshoot. A snapshot of Arduino Mega 2560 is shown in Figure 3.2

Figure 3.2 *:* Arduino Mega 2560 (image courtesy of google Inc.)

The detailed specification of Arduino Mega 2560 is stated in Table 3.2.

Table 3.2: Specification of Arduino Mega 2560

No.	Parameter	Value
1	Operating Voltage	5V
2	Input Voltage	7V-12V
3	Digital I/O Pins	54
4	Analog Input Pin	16
5	DC Current per I/O Pin	40 mA
6	DC Current for 3.3V Pin	50 mA
7	Flash Memory	256 KB
8	SRAM	8 KB
9	EEPROM	4 KB
10	Clock Speed	16 MHz
11	Weight	37g

Basically, the motors were driven by a pair of relays connected directly to the controller board. This connection only allows the motor to run on single speed. However, this project demands the UGV to vary in speed during the autonomous navigation. Therefore, the speed control board needs to be replaced with a motor driver based on L298N chip.

L298N motor driver in Figure 3.3 has operating voltage from 5V to 35V, which is within the range of DC motor operating voltage. It takes PWM signal input from microcontroller and drive the motor at the respective speed accordingly; the motor driver can operate two DC motors simultaneously in a single board. Furthermore, it is cheap, light and small to accommodate on UGV.

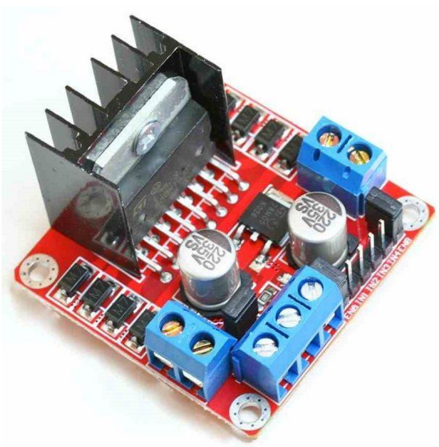


Figure 3.3: L298N motor driver (image courtesy of google Inc.)

The specification of L298N motor driver is included in Table 3.3.

Table 3.3: Specification of L298N motor driver.

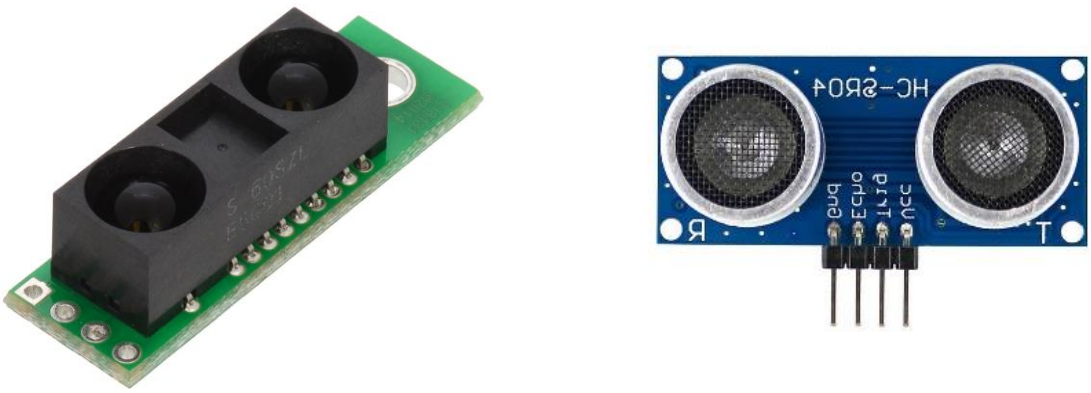
No.	Parameter	Value
1	Logical Voltage	5V
2	Drive Voltage	5V-35V
3	Logical Current	0-36mA
4	Drive Current	2A
5	Max Power	25W
6	Dimensions	43 × 43 × 26 mm
7	Weight	26g

The UGV has to be equipped with range sensors to fulfill collision avoidance purpose. Today, several sensors are available at the market e.g. Infra-Red (IR) sensor, RADAR, LIDAR etc. A few experiments were to evaluate the performance of IR sensor in Figure 3.4a and ultrasonic sensor in Figure 3.4b. Both sensors are used for object detection. IR sensors use light at the speed 3×10^8 m/s as the medium to determine the distance of an object (Mohammed et al., 2017). The author also has mentioned that the transmitter and receiver of an IR sensor work within a wavelength of 810 nm. According to (Hubballi et al., 2015) IR sensor is capable to detect obstacles within short range like 10 to 40 cm. This range is significantly short for the project. Similar author mentioned that, IR sensor could sense the radiation from the sun, which causes error at output. Since the UGV for this project functions on the road under the sun. IR sensor seems to be not the best choice for this mission.

Next, ultrasonic sensor uses ultrasound to detect and obtain information about distance of an object. Typically, ultrasonic sensors emit ultrasound at frequency 40kHz

(Garethiya et al., 2015, Ruan and Li, 2014) which is beyond the hearing frequency of humans range that is from 20Hz to 20kHz (Kar and Sur, 2016). In particular, ultrasonic sensor HC-SR04 has measuring range of 2cm to 4m which is a within the operating range for UGV. Furthermore, ultrasonic sensor is not interrupted by noise of surroundings like IR sensors interrupted by UV rays.

Despite the advantage, this sensor is inexpensive, light and consumes less power (Andersone, 2017). The good thing about ultrasonic sensors is that, it operates well under poor lighting environment as oppose to visual technique. However, this sensor may not be able to determine distance of round-shaped objects due to reflectance properties (Mohammad, 2009) which is not very critical for this project. This sensor is chosen used for this project.



(a) (b)

Figure 3.4: (a) IR sensor (b) Ultrasonic sensor HC-SR04
(image courtesy of google Inc.)

Specification of ultrasonic sensor is as stated in Table 3.4.

Table 3.4: Specification of Ultrasonic sensor

No.	Parameter	Value
1	Voltage	5V
2	Current	15mA
3	Frequency	20-40 kHz
4	Maximum Range	3m
5	Minimum Range	0.02m
6	Effectual Angle	15^o
7	Weight	10g
8	Dimension	45 × 20 × 15 mm

Placing the sensor at the right position on the UGV is vital. Sensor positioning would also provide the information on the numbers of sensors needed for the project. The front and rear of UGV must be equipped with the sensor to assist in collision avoidance. Initially, the idea of installing six sensors (three sensors at the front and rear) as shown in Figure 3.5(a) was suggested. The idea of installing more than one sensor on the same axis is not recommended because the sensors have high tendency on receiving other sensors' sound, which may produce false data on distance measurement. Therefore, it is decided that only two sensors will be used, one at the front and rear of the UGV as illustrated in Figure 3.5(b).

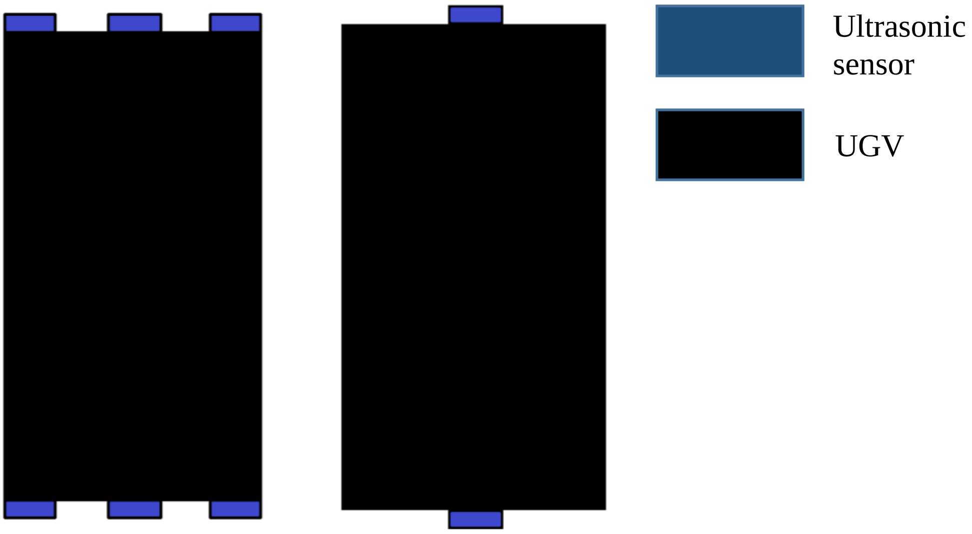


Figure 3.5: (a) UGV with six ultrasonic sensors (b) UGV with 2 sensors

Next, a test conducted to study the beam pattern of the sensor. A cube box sized 5cm x 5cm x 5cm was placed in front of the ultrasonic sensor and the distance is monitored. The cube box is continuously moved until the sensor does not capture the distance. This experiment determines that the cube box is out of the beam pattern. Then the beam pattern is drawn as the test is carried and shown in Figure 3.6. From the figure, it is observed that, on the left part of the beam pattern degrades after 140cm. This scenario happens since the echo source is not receiving any reflected sound waved from the region. Meanwhile, on the right side of the beam pattern seems to have a straight line. From this test, it provides a clear sensing pattern so that further development can be done on this pattern.

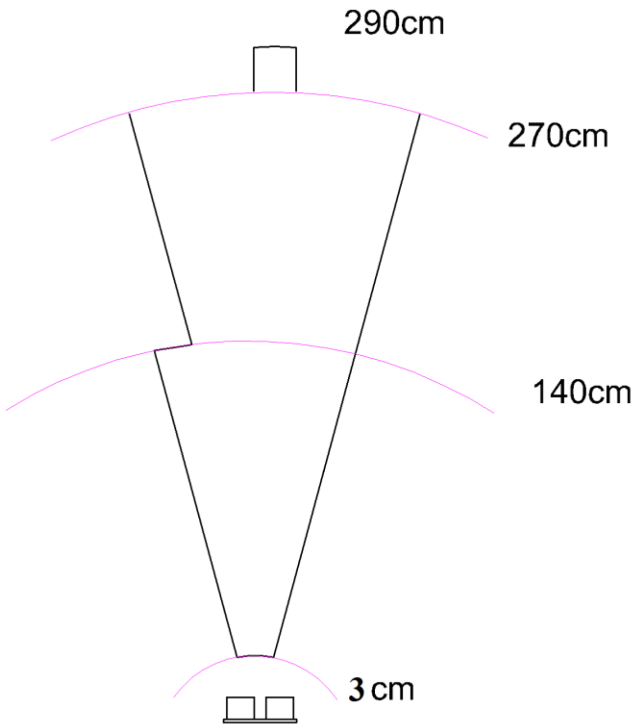


Figure 3.6: Beam pattern

The beam of ultrasonic sensor would extend up to 30^o. The UGV needs to have 180^o view. In this case, the static ultrasonic sensor would not provide satisfactory results. Therefore, servomotor is attached with the sensor to rotate from 0^o to 180^o as shown in Figure 3.7. By default, the servomotor rotates from 0^o to 180^o with increment of 1^o angle. The default method is not the best for the project because the ultrasonic sensor over scans a specific region.

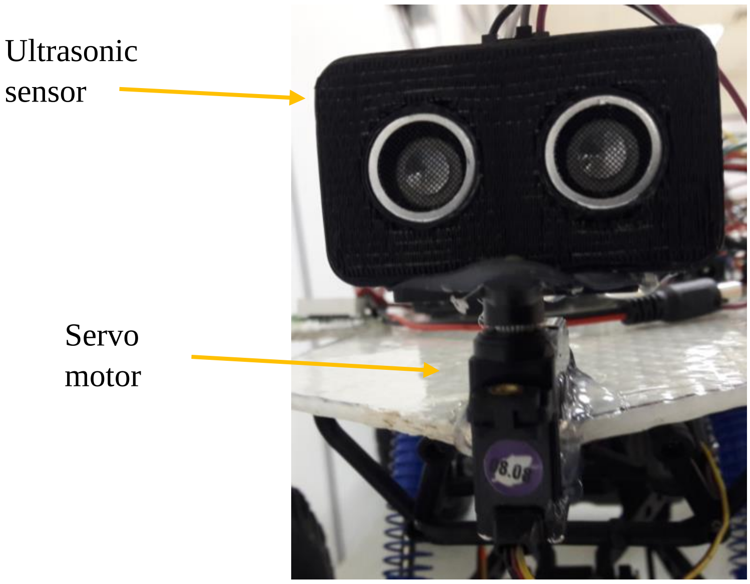


Figure 3.7: Servo motor (MG996R) attached with ultrasonic sensor

Therefore, an idea of stepping the angle by 30º is introduced. The sensing angle begins with 15º with the increment of 30º and sweep until 165º left to right as shown in Figure 3.8.

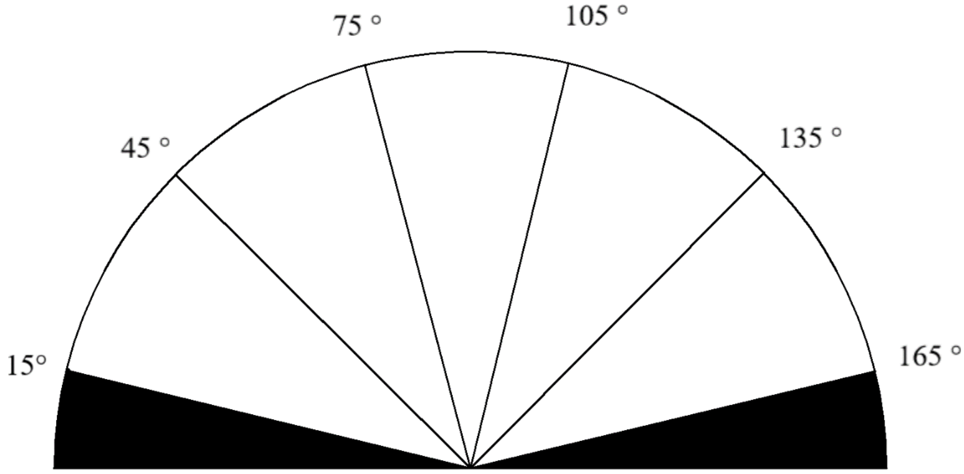


Figure 3.8: Ultrasonic sensor sensing angle.

The angle 0º to 15º and 165º to 180º are the blind spot regions since the servo motor angle has limitation, which do not affect the functionality of project. This method allows the ultrasonic sensor to scan the distance at six different angles (15º ,45º, 75º, 105º, 135º, 165º) at one sweep. The system makes one complete that consists of two sweeps. This method seems to provide better data accuracy. The readings are taken from the first and second sweeps. Figure 3.9 shows the overlapping region of beam pattern when the ultrasonic sensor sweeps at specific sensing angle. The overlapping region is found to be 7° to 8°.

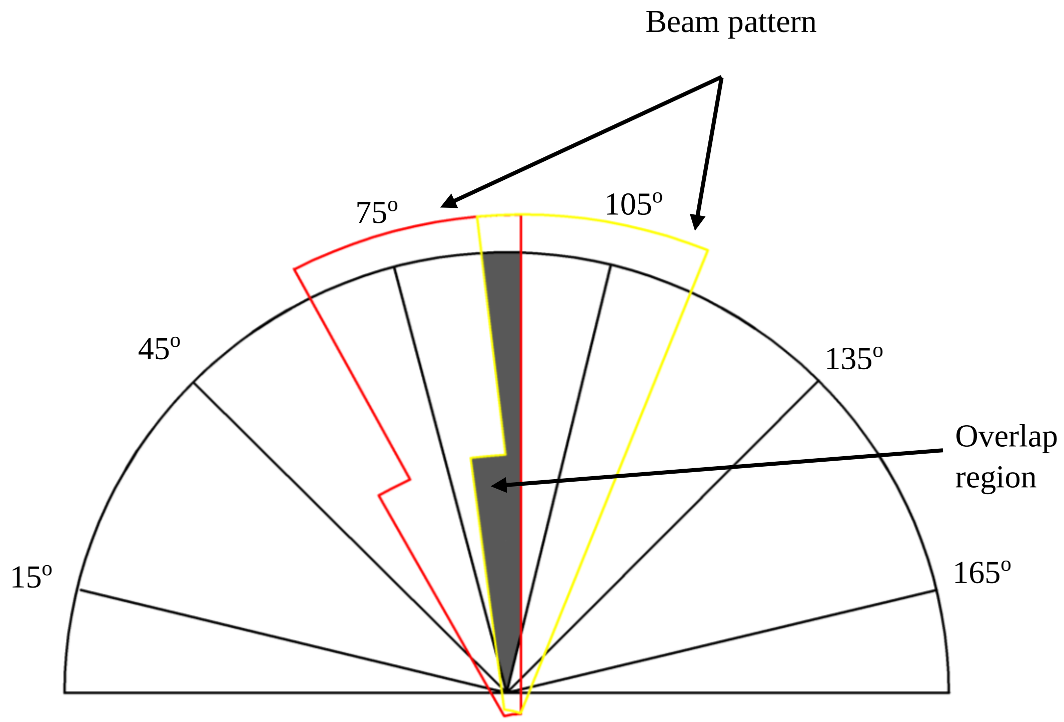


Figure 3.9: Overlapping region of beam pattern.

In this project, navigation is essential to make autonomous trajectories. Generally, navigation operates on a microcontroller. ArduPilot Mega (APM) in Figure 3.10 is used in this project for navigation. APM is a microcontroller that utilizes Arduino Mega 2560 chip. APM has specially designed I/O pins for telemetry connection, GPS and many more components. APM can be programmed via an open-sourced software called Mission Planner. Mission Planner can be downloaded from the website link: http://ardupilot.org/planner/. APM communicates with Mission Planner via 915MHz 3DR telemetry antenna connector. A GPS is also installed with APM board for navigation purpose.

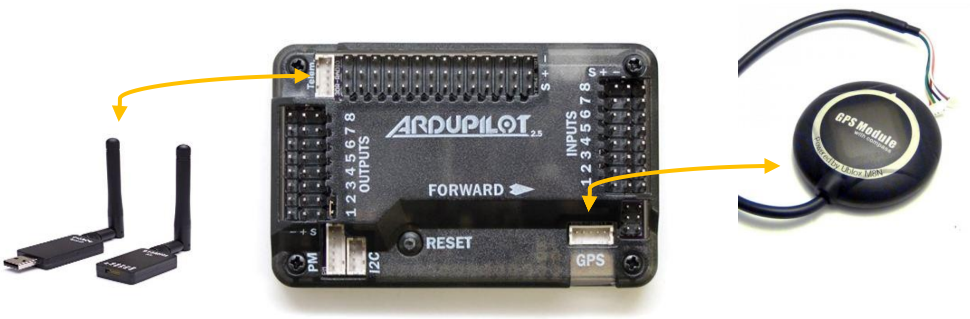


Figure 3.10: APM board (image courtesy of google Inc.)

The specification is stated in Table 3.5.

Table 3.5: Specification of APM

No.	Parameter	Value
1	Voltage	5V
2	Current	15 mA
3	Weight	39g
4		3-axis gyro meter
5		6 DoF accelerometer
6	Embedded Systems	Magnetometer
7		Barometer
8		Compass
9	Dimension	45 × 20 × 15 mm

3.1.1 Power Management

UGV runs on battery to power all components on board. A sufficient battery capacity is essential to provide a consistent power throughout the mission. The battery has to be small, lightweight and importantly its capacity must be able to supply power to all the components for long duration at single charge. Several types of batteries are available in the market e.g. Lithium Polymer (Li-Po), Nickel Cadmium (Ni-Cd), Lithium ion (Li-ion) etc.

Due to different supply voltages, this project encounters a few challenges when comes to choosing the suitable battery since Arduino Mega 2560 operates at maximum 12V but DC motors operate at 8V. From this finding, two different batteries (battery (a) and battery (b)) needed for the project. Components run on battery (a) will be categorized as Group A and components run on battery (b) will be categorized as Group B. Before choosing a battery a simple power analysis has to be done. Li-Po batteries are made up of cells. One cell is 3.7V. Therefore, under the limitation of components maximum operating voltage as mentioned earlier, the most suitable battery voltage for Group A and Group B is 11.1V (3 cells) and 7.4V (2 cells).

The operating current (I_o) of components can be obtained from manufacturer datasheet. Next, the power required (W) can be calculated using Eq. (1). Table 3.6 shows the I and W by each components in Group A.

$$\text{Operating voltage } (V) \text{ x } I_o = W \tag{1}$$

Table 3.6: I_o and W by components Group A.

No	**Component**	***I_o*** **(amp)**	***W*** **(Watt)**
1	Arduino Mega 2560	0.8	4
2	Ultrasonic Sensor ×2	0.03	0.15
3	Servo Motor ×3	2.7	16.2
4	APM	0.015	0.075
5	915MHz Telemetry	0.1	0.5
6	GPS Module	0.1	0.5
	Total	**3.745**	**21.42**

Table 3.7 shows the I_o and W by each components in Group B.

Table 3.7: I_o and W by components Group B

No	Components	I_o (amp)	W (Watt)
1	Motor driver	0.036	0.18
2	DC motors ×2	4	29
	Total	**4.036**	**29.78**

Next, the battery run time is also crucial for this project. The battery run time is depending on the capacity of the battery (Ah) and operating current (I_o) draining the battery. Using Eq. 2, the battery run time can be calculated.

$$(Ah \div I_o) \text{ x } 60 \text{ mins} = \text{Run time (mins)} \quad (2)$$

Another aspect to be considered is the run time for battery (a) and battery (b) must be similar if not, one of the Group A or B components would stop functioning earlier than the other one. According to the project need, the UGV satisfactory mission run time is 60 minutes before replacing a full charged battery. Therefore, minimum battery capacity needed is 3745mAh and 4036mAh for battery(a) and battery(b) respectively. On the other hand, the batteries should last at least 20 minutes longer than mission time (60 minutes) for tracking purpose, in total this makes the battery run time at single charge is 80 minutes. This makes suitable capacity for battery(a) and battery(b) is 5000mAh and 5500mAh respectively as shown as the calculation below: -

Battery (a):

$$[5.0 \text{ (Ah)} \div 3.745] \times 60 \text{ (minutes)} = 80.10 \text{ minutes}$$

Battery (b):

$$[5.5\ (Ah) \div 4.036] \times 60\ (minutes) = 81.76\ minutes$$

The calculations proved that both battery(a) and battery (b) has the almost similar run time.

Discharge rate (*C*) is differs for different Lithium-Polymer batteries. C and battery capacity (*Ah*) determines the maximum current output. Using Eq. (3), the maximum current output of the battery can be calculated.

$$C \times Ah = \text{maximum current output} \quad (3)$$

Group A and B components does not require high current usage. Therefore, the discharge rate is not very crucial for this project. Therefore, 10C is suitable for battery(a) and battery(b). Note that, in the market it is difficult to find the battery with the above calculated specification. Therefore, batteries with nearest to calculated specification are used for this project and it is tabulated in Table 3.8.

Table 3.8: Specification of battery (a) and (b)

No.	**Parameter**	**Battery (a)**	**Battery (b)**
1	Battery Type	Lithium Polymer	Lithium Polymer
2	Number of Cells	3	2
3	Rated Voltage	11.1 V	7.4 V
4	Capacity	5200 mAh	5500 mAh
5	Discharge	10C	20C
6	Current Supplied	52 amp	110 amp
7	Weight	436g	260g
8	Dimension	142 × 49 × 22 mm	143 × 44 × 24 mm

3.2 Collision avoidance system (CAS)

Ultrasonic sensor uses ultrasound which is generally known as a sound frequency greater than 20 kHz (Koval et al., 2016). Ultrasonic sensors consist of components namely transmitter (T) and receiver (E), which enables to transmit and receive ultrasonic sound as shown in Figure 3.11. Therefore, ultrasonic sensor uses the principle of time of flight (*ToF)* to measure distance. Eq. 4 will provide a better understanding on how distance is measured from *ToF*.

$$d_t = (a \; x \; t) \div 2 \tag{4}$$

d_t = Distance travelled
a = Speed of sound
t = Time taken

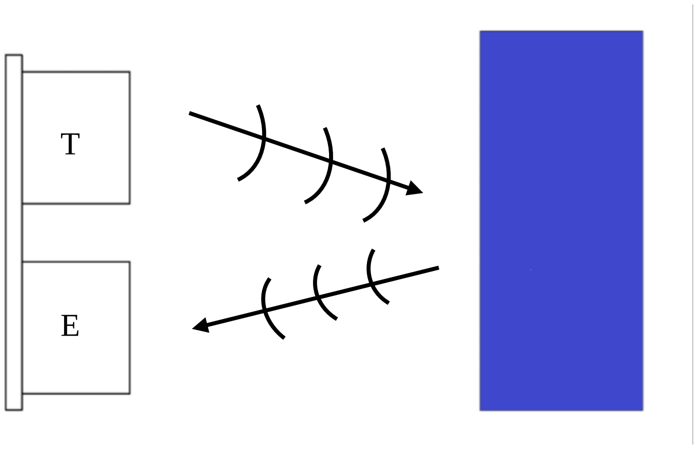


Figure 3.11: Working principle of ultrasonic sensor HC-SR04

3.2.1 Temperature Effect on Ultrasonic Sensor Reading

Effect of temperature on speed of sound is the major concern of this project since UGV exposes to sunlight all the time. The potential operating temperature of ultrasonic sensor in this project is from 16°C to 30°C. Using Eq. (5), the speed of sound at different air temperature is calculated.

$$a = \sqrt{\gamma RT} \quad (5)$$

a: Speed of sound
γ: Heat ratio
R: Air constant
T: Air temperature

The data above portrays the significant effects of temperature on speed of sound. Therefore, ultrasonic sensor fitted on the rover has to consider the instantaneous surrounding air temperature before measuring the distance of obstacle. While, the efficiency ultrasonic sensor contributes in relative error in measuring the distance. Therefore, a simple experiment was done to validate the theoretical approach. Table 3.9 shows the calculated and experimented speed of sound corresponding to air temperature.

Table 3.9: Speed of sound corresponding to air temperature

Temperature, °C	**Theoretical Speed of Sound, m/s**	**Experimental Speed of Sound, m/s**	**Relative error/%**
16	340.25	338.55	0.50
17	340.84	339.44	0.41
18	341.43	338.83	0.76
19	342.01	341.41	0.17
20	342.60	338.55	1.19
21	343.18	340.38	0.83
22	343.77	340.17	1.05
23	344.35	339.85	1.32
24	344.93	342.43	0.73
25	345.51	343.21	0.67
26	346.09	343.19	0.84
27	346.67	343.57	0.90