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# Navigation and Control of an Unmanned Surface Vessel

by

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*Progress Report*

Study leader: Prof Jaco Versfeld

July 2022

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# EXECUTIVE SUMMARY

Student: L.E.V Kingwill

Title of Project
Navigation and Control of an Unmanned Surface Vessel.
Objectives
The development of an independent navigation and control system that can be implemented on an unmanned surface vessel that uses electrical thrusters for propulsion and steering.
What is new in this project?
A new control system is going to be created to control the power to the thrusters and thereby steer the vessel. Building on this a navigation system will be created so that the vessel can navigate to a designated point autonomously.
If the project is successful, how will it make a difference?
With a successful navigation and control system, the system could be moved to vessels with better range and seafaring ability and these unmanned vessels can be used for research data collection, patrolling and search and rescue.
What contributions have/will other students made/make?
N.A.
Which aspects of the project will carry on after completion and why
For the vessel to be completely autonomous, a further project should add an obstacle avoidance system. This will be beneficial to avoid other sea vessels as well as fixed obstacles such as rocks and shore.
What arrangements have been/will be made to expedite continuation?
All the research and project documents will be archived with the university and the code-base will be thoroughly commented for ease of understanding.

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Student

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Date

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Lecturer

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# Chapter 1

## Introduction

### 1.1 Background

As technology has improved over the years, processes and systems have become more automated. Initially factories were replacing manual labour with automated machines but recently companies have been investigating self-driving cars and trucks. All over industries tasks are being automated or done remotely with fewer human involvement.

The ocean is the perfect area for unmanned surface vessels (USV) to be used as many of the issues faced with autonomous land vehicles such as self-driving cars are mitigated by open water. On the open water one gets a 360° of the surroundings of the vehicle and although there can still be high volumes of traffic in certain areas such as commercial shipping lanes, due to the expanse of the ocean these high traffic areas are avoidable. Finally, and probably the most desirable mitigating factor is that where a surface vehicle would need to look where the road surface is to follow it, an ocean vessel can move directly from point to point on any piece of water.

In South Africa there is a growing need to USVs with regards to ocean research and conservation. There has been a growing use of acoustic sensory systems to track dolphins and whales around the world. By combining this with the technology of USVs, a far larger area can be surveyed.

### 1.2 Objectives

This project will focus on the navigation and propulsion control of the USV. This is the building block of the USV upon which a future project can build by adding an



obstacle avoidance system or renewable power sources to keep the USV operational for longer. This project will have the following objectives:

1. Design and manufacture an electric surface vessel.
2. Designing and manufacturing the control system that will give a pilot manual control over the electric surface vessel.
3. Building on the manual control and implementing navigation control so that the electric surface vessel.

### 1.3 Motivation

Currently the marine community is using these acoustic systems as stationary systems. By using the USV in conjunction with the USV the area that is studied can be greatly increased with fewer acoustic platforms as have been used in passed projects. Furthermore, the technology can be adapted for use in other industries such sonar surveying, defence and search and rescue. The use of USVs is becoming more prominent as a USV can be cheaper to operate and therefore organisations can either save costs in the case of sonar and acoustic research or in the case or marine patrols and search and rescue, USVs can be used to fill up the ranks of vessels and close the possible.

The tasks previously mentioned are often time consuming and the crew of the assigned vessel need time to rest whereas a fully autonomous USV can operate constantly, stopping only to replenish its energy source and with further developments such as solar charging, USVs could begin to operate indefinitely, having to only come in for services or if there is a problem with the system.

# Chapter 2

## Literature Review

### 2.1 GPS

#### 2.1.1 History of GPS

Global Positioning System (GPS) is an everyday thing in our lives today and has become a luxury that most take for granted. There is GPS in our phones, laptops and even cars. We are using it to find directions on our commutes, hail taxis or ride shares and even for recreational sport, tracking how far we travelled.



**Figure 2.1:** Early GPS receivers were large, heavy devices. (USAF) (1978)

The origins of GPS or rather any global satellite navigation system begins with the space race. It starts, in 1957, with the first satellite to successfully orbit the earth, the Russian satellite Sputnik. During its orbiting flight of the earth, Sputnik was emitting a radio signal which could be picked up on earth. During this orbit Scientists from John Hopkins University in America were monitoring the radio signals emitted by the Sputnik satellite when they saw the Doppler Effect in action with the radio signals, as the satellite drew closer, the radio signal frequency increased and vice versa. These scientists theorized that if they could determine the location of the satellite based on its signal frequency, the opposite would also be true, they could determine the location of a receiver on the ground given the satellites location. Aerospace (2021)

The first instance of a global satellite navigation system was the Transit. It was developed in 1958 by the Advanced Research Projects Agency and the first satellite was launch in 1960. The Transit satellites were mostly used by the military, specifically the Navy's missile submarines. The program was transferred to the Navy during the mid-1960s. During this time there were further Transit satellites launched and by 1968 the entire constellation of Transit satellites was operational, a total of 36 satellites. Aerospace (2021)

There was plenty of other research that was being conducted around the same time to improve on the current Transit. One such researcher was Phillip Diamond. Diamonds concept, from his study in 1963, lead to the Air Force forming a new satellite navigation program which he called 621-B. Further studies were undertaken by James Woodford and Hideyoshi Nakamura, which completed in 1966, proposed using four satellites. The use of four satellites would mean that the receivers no longer needed to be equipped with high-accuracy clocks. This was the first step in reducing the size and cost of the receivers. Aerospace (2021)

There was a range of technological advancements that help progress the satellite navigation systems such as new bandwidth utilization techniques, advancements in computer and the introduction of solid-state microprocessors. These technological advancements helped reduce the size and weight of the GPS receivers to what we now know today, figure 2.1 shows how large and cumbersome the early GPS receivers were. However, one significant technological advancement was the development of atomic clocks. This development led to another satellite navigation system known as Timation (Time Navigation). The third of three Timation satellites launched in 1974, became the first satellite equipped with an atomic clock, the previous two contained crystal oscillator clocks. The use of the atomic clock led to vast improvements in the accuracy of the navigation system and provided

three-dimensional location coverage. Aerospace (2021)

There were now three satellite navigation systems, and so when in the 1970s, the Department of Defence wanted a robust and stable system, the project team developed a new concept by cherry-picking the best aspects of all three, Transit, Timation and 621-B. This system was designated, Navigation System with Timing and Ranging (NAVSTAR), this was later changed to GPS I, the precursors to the GPS system we know today. The first NAVSTAR satellite was launched in 1978 and further satellites were launched in the following years, the system reaching its fully operational state with 24 satellites in 1993. Mai (2017)

Although the satellite navigation systems were operational and orbiting the earth, they were still used mostly by the military and the receivers were expensive. However, this began to change in 1983 when President Ronald Reagan authorized commercial airlines use of the NAVSTAR system. This was the start of civilian use of GPS. His (2011)

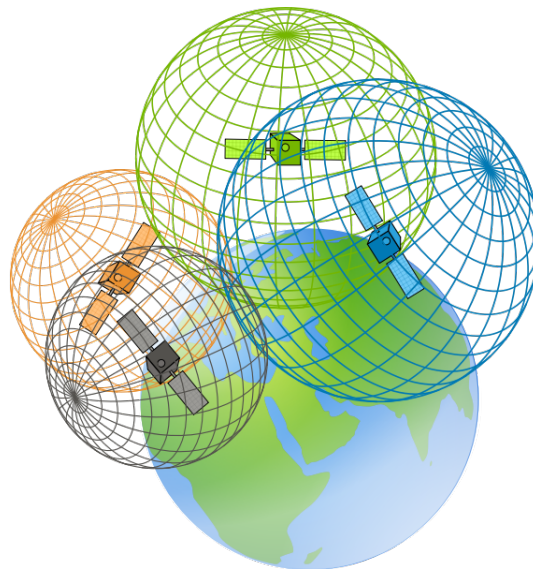
### 2.1.2 Modern GPS

The cost of GPS receivers began to decrease in the late-1990s, early-2000s, the first cell phone containing GPS technology was released in 1999. The cost reduction can be attributed to the American government approving more non-military signals as well as the technological advances in processors that was leading to cheaper processing chips. And naturally from the cheaper access, GPS use began to grow and putting more tax on the system which although upgraded to GPS II was not equipped to handle the modern requirments. In 2000 a plan was formed to add new signals to satellites that had not yet been launched in order to handle the increased use. Furhtermore, a new system was to be developed, GPS III, that could fully meet the modern requirements. The first of the GPS III satellites was launched in 2018 with a couple more in the following years and the remaining 6 to be launched by 2023. Aerospace (2021)

### 2.1.3 How GPS works

There are a total of 31 GPS satellites currently sitting in a medium earth orbit. These are the satellites that are sending the radio signals that a GPS receiver can use to determine its location.

The signal that the satellites broadcast has a range of information that is used

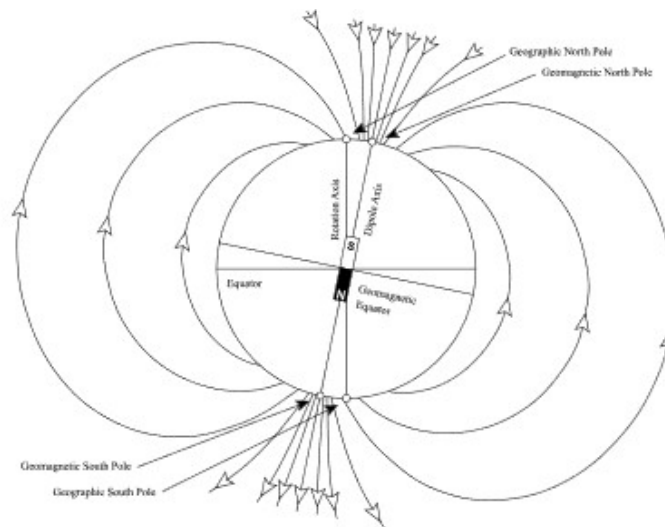


**Figure 2.2:** Distance spheres around each satellite intersect at one point

by receivers, this information contains data needed to determine the location of the satellite as well as the time that the signal broadcast, using the satellites atomic clock. Based on the time taken for the signal to reach the receiver and corrected for propagation delays or delays from the signal passing through the ionosphere and troposphere, the receiver can calculate the distance between itself and the satellite. This creates a sphere around the satellite upon which the receiver must lie. By adding in a second and third satellite and their distance spheres, there will be only two points of intersection between the three spheres. The one will be the receiver's location, while the other will be impossible location in space. However, to accurately calculate the distance, the receiver would have to have a synchronized atomic clock to determine exactly how long the signal takes to reach it. As it was mentioned earlier, highly accurate clocks were taken out of the receivers by adding a measurement from a fourth satellite to ensure that the distance calculation is accurate. Figure 2.2 illustrates the concept of the distance spheres and their intersection being the location of the GPS receiver. (Federal Aviation Administration)

## 2.2 Digital Compass

Compasses have been used extensively over the past centuries for navigating, surveying, and map-making. The compass is thought to have been in use from around



**Figure 2.3:** The differentiation between magnetic and true north

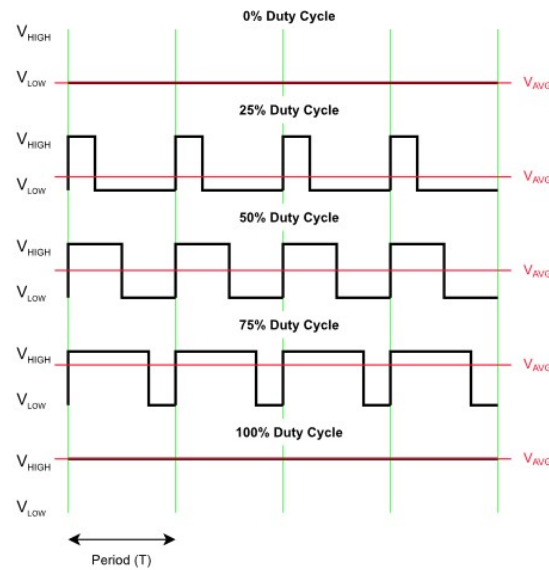
the 12th century in Europe and possibly earlier in east Asia Jones (2019). Although as many things have over the years been digitalized, so has the compass. The digital compass uses a technology called magneto-induction. This allows the digital compass to electronically detect the earth's magnetic field. Being as sensitive as it is an embedded microcontroller is needed to filter out any magnetic fields from ferro-magnetic materials or other electrical systems that are creating a magnetic field. (Advanced Safety Devices) (2013)

### 2.2.1 What is magnetic north

True north is always fixed and is the direction that is directly in line with the north pole. However, compasses do not point to true north, they point to magnetic north. This is because a compass aligns itself with the magnetic field caused by the earth's magnetic core. The distinction between true north and the magnetic field at magnetic north is shown in figure 2.1. To further complicate the matter however, the earth's magnetic core experiences changes and these cause small shifts in the magnetic field around the earth. Jones (2019)

## 2.3 PWM

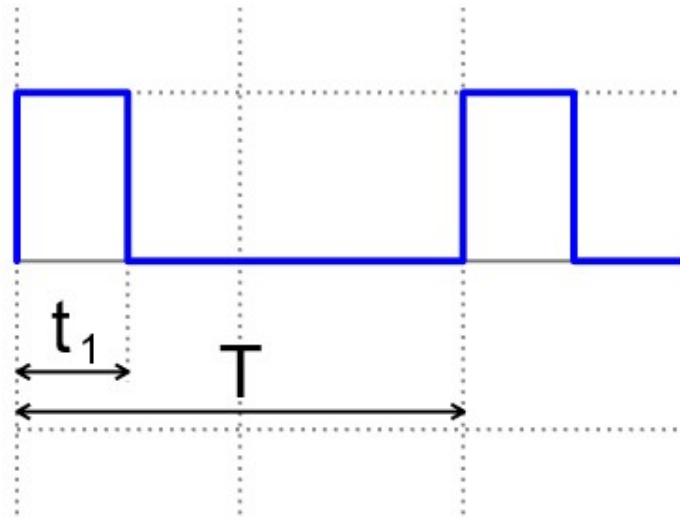
Pulse Width Modulation (PWM) is a technique of using a digital signal to represent an analogue signal which is used to control analogue systems. The cost of switching a digital circuit between on (high) and off (low) is a cheaper alternative



**Figure 2.4:** Duty Cycle of PWM Signal

to creating an analogue circuit that will incur not drift over time. These PWM signals are mostly used in speed control of DC motors or controlling the brightness of lightbulbs. Christ and Wernli (2014)

PWM is a digital signal that is switched between high and low, leading to the generation of a square wave signal. The time that the signal goes high can be modulated to vary the power delivered to the system. Typically, microcontrollers are used to generate and control the PWM to power an external system. There are a few signal parameters that will be highlighted in this explanation of a PWM signal. The signal amplitude, this is the maximum voltage that can be supplied to the external system. If the microcontrollers output voltage is insufficient for the external system, the signal can be passed through an amplifying circuit to provide the required voltage. Secondly is the signal period, and therefore the frequency as they are inversely proportional, and is the total time for one signal wave to propagate. The frequency is set depending on the requirements of the system, but this frequency will be needed later to help with the calculation of the duty cycle. The duty cycle is the final parameter. The duty cycle is the ratio between the time the signal is high and the time the signal is low. It is always a value between 0 and 1, however, the duty cycle is often expressed as a percentage.



**Figure 2.5:** The relation between the time the signal is high and the signal period.

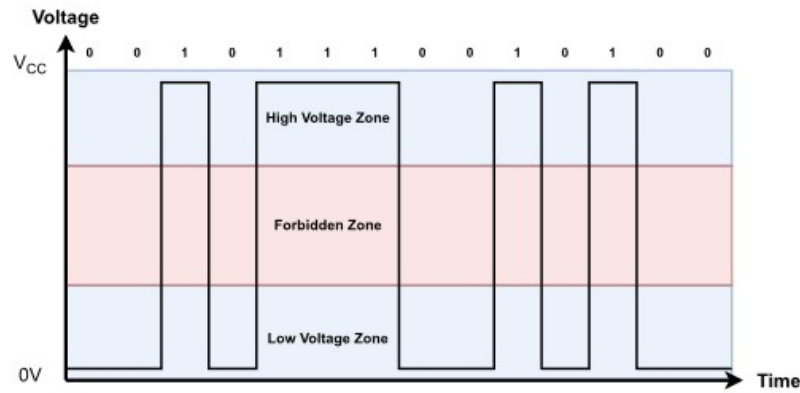
A PWM varies the voltage supplied to the system by varying the duty cycle. A small duty cycle means that the signal is high for a short portion of the signal period while a large duty cycle means that the signal is low for a large portion of the signal period. The system that is being supplied then uses the average voltage of this period. Therefore, a low duty cycle, a short high signal followed by a long low signal, would lead to a low average voltage. The variation in duty cycle and the associated average voltage is shown in figure 2.4. Ibrahim (2014)

To determine how long the signal must go high, the duty cycle is multiplied by the signal period. The duty cycle is often expressed as a percentage and so the duty cycle is the percentage of time that the signal is high. Therefore, by multiplying the duty cycle with the period gives the time for which the signal is pushed high ( $t_1$ ). Figure 2.5 shows the relationship between  $t_1$ , the time the signal is high, and  $T$ , the signal period.

## 2.4 Analogue vs Digital Signals

Signals are used to convey data and information from point to point. For this project only electrical signals will be used although there are plenty of other mediums through which signals can be sent. There are two predominant signals that





**Figure 2.6:** A digital signal and its three zones.

are used when regarding electrical signals, analogue and digital.

A digital signal, most simply represents discrete values, more precisely 2 discrete values. This makes digital signals perfect for conveying data in a binary data format but slightly more troublesome when more than two values are required. It will transmit a signal as either a low voltage, a zero, or a high voltage, a one. The low voltage is generally 0V while the high voltage is the voltage supply of the driving device. However, because voltages can have small fluctuations and will therefore not always be exactly 0V or equal to the nominal voltage, a range is pre-set whereby the receiving device can denote the value as low or high. A buffer zone is also incorporated, a voltage range around half the value of the nominal voltage, to prevent a small fluctuation in the voltage possibly altering the value of the signal. This buffer zone along with the area in which the signal can be read as high or low is shown in figure 2.6. This buffer is called the forbidden zone any signal received within the forbidden zone is considered floating and will be randomly assigned as either high or low.

An analogue signal on the other hand is continuous and where the digital signal ranged from 0 to an upper voltage, an analogue signal ranges from a low voltage to a high voltage. Typically,  $\pm V_{CC}$ , the voltage of the microcontroller, is used for these upper and lower limits. An example of a continuous analogue signal between  $\pm V_{CC}$  is shown in figure 2.7. An analogue signal can therefore transmit an infinite number of values between these limits. By assigning an upper and lower limit to the sensor that will transmit the data, a max min transformation can be computed, and the transformed value transmitted along the analogue signal. Because the analogue



# Chapter 3

## Methodology

This chapter will describe the methodology used in the project. The project is mostly software based and so that will be the focus. However, there is a physical element in that of the vessel and the electrical hardware. The mechanical design and fabrication of the thruster mounts is outside the scope of this project and so it will be described only in terms of how it interfaces with the electrical hardware.

### 3.1 Software Environment

The microcontroller that was chosen for this project is a Arduino DUE. An Arduino microcontroller was chosen as there is a wide range of Arduino libraries available online, as well as several forums and code examples. Furthermore, the Arduino environment uses the C language.

### 3.2 System Description

This section will give a broad overview of the system as a whole and describe the different sub-systems and their interactions. Several of these subsystems are outside the scope of the project but have been included to provide a foundation upon which the applicable detailed descriptions will build.

#### 3.2.1 Vessel

The vessel is outside the scope of this project as it was acquired before the start of the project and the project was designed around the use of the vessel for testing. The vessel referred to in this project is a Spider 3, a small single hulled fibreglass boat. The vessel measures  $1.3\text{m} \times 3.2\text{m}$  and is rated to carry 4 people and a 15hp traditional outboard motor.

### 3.2.2 Thrusters and Energy Cells

The propulsion system consists of two electric thrusters mounted at the back of the vessel. These thrusters are each capable of producing up to 18kg of thrust. They are mounted onto the back of the vessel with a metal mount that is removable and height adjustable. Each thruster has a submersible ESC attached which is controlled by a 5V PWM signal. The ESC can drive the thruster in both forward and reverse direction.

The thrusters are powered by a battery bank of 4 Lithium Iron Phosphate cells. Each cell has a voltage of 3.3 V and a capacity of 100 A h. The 4 cells are connected in series to provide 12 V. The battery is connected to the thrusters through a smart battery management system (BMS) which has an allowable discharge current of 100 A and an allowable charge current of 50 A.

### 3.2.3 Control System

The control system is the intended scope of the project and consists of a manual and automated control. For manual control, there is a two lever throttle system that is used to control the thrusters. In automated control, the control system uses a GPS and digital compass to navigate to prescribed points. At the centre of this control system is the PCB motherboard containing the MCU, GPS and connections to both the throttle and the thrusters.

## 3.3 Control System

The control logic of the control system is all implemented through the software on the Arduino MCU. This section will go into detail on logic and how that logic is carried out in software.

### 3.3.1 PWM Signal

The thrusters are each controlled by a 5 V PWM signal. There is limited information on the datasheet for the ESC and the signal boundaries, full forward, full reverse and neutral positions are described in the unconventional terms of the time that the signal is high. The values are shown in table 3.1. Initially it was thought that the ESC operated at 50 Hz, however there was no response from the thruster at any duty cycle.

In order to be sure that the correct PWM signal was being sent through and to be able to quickly vary both the frequency and the duty cycle, a PWM signal

**Table 3.1:** ESC boundaries and PWM duty cycle at various frequencies.

Position	Time ( $\mu$ s)	Duty Cycle @		
		50 Hz	60 Hz	500 Hz
Full Forward	2000	10 %	12 %	100 %
Neutral	1500	7.5 %	9 %	75 %
Full Reverse	1000	5 %	6 %	50 %

generator IC was connected to ESC and trial and error was conducted to determine that the ESC began responding to a signal above 60 Hz. It was then decided to push the frequency up to the maximum of 500 Hz as this would offers the finest control because it has the maximum allowable duty cycle difference between the signal boundaries.

The Arduino libraries contain a function that can output a PWM wave, given the duty cycle and the pin to output on as a parameter however, the default frequency of the Arduino DUE PWM pins is 1000 Hz. Therefore, the frequency had to be manually changed by changing the timer settings driving the PWM signal.

The information needed to change the timer settings is available in the Arduino Datasheet. The process to configure the PWM outputs is as follows. First, the peripheral clocks for timer channels 6 and 7 were enabled. Secondly, the pins input output controller on peripheral A needed to be disabled and the pins switch to peripheral type B. Then came the configuration of the timer itself. The channel mode was set to waveform mode using clock 1 with the counter being incremented on the rising edge. Furthermore, the waveform was set to UP mode (signal being set high) being triggered when the counter reached the register C (RC) value and the signal being cleared when the counter reached the register A (RA) value. Once the timer is configured, the RA and RC values can be filled and the interrupt set to trigger when the counter reaches RC. Finally, the channel control register is set to perform a software trigger, reset the counter and start the clock. There is also a interrupt handler that needs to be added where in the status register is read. This is done because the flags in the status register are automatically reset when the status register is read, at the end of every period.

The signal is being cleared when the counter reaches RA and set high when the counter reaches RC and so RC can be equated to the period of the signal and RA to the time when the signal is high. Using this and that the clock is set to clock 1 which is the MCU clock (MCK) divided by 2, the RA and RC can be expressed in terms of MCK, frequency and duty cycle as shown in equations 3.1 and 3.2. RC

is kept constant throughout while RA is changed to change the duty cycle of the PWM signal sent to the ESC and therefore control the ESC and thruster.

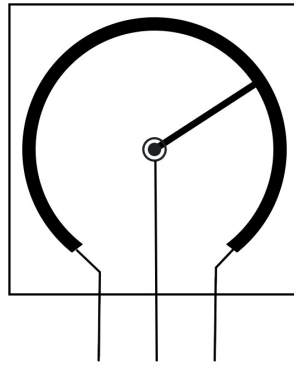
$$RC = \frac{\frac{MCK}{2}}{Frequency} \quad (3.1)$$

$$RA = RC \times DutyCycle \quad (3.2)$$

### 3.3.2 Throttle Input

The initial concept was to use two throttles that can move independently from each other and two electronic throttles were purchased to be used. However, when these components arrived, they were much smaller than they had appeared and they had very small range of movement. The next solution was to use two linear potentiometers (POT) and to build a throttle system that linked to the POTs. The workshop designed and built the throttle system.

The POT has three pins as shown in figure 3.1, high voltage, ground and the output. The high voltage and ground are connected to the connections on either side and the output is connected to the middle. The output is therefore a voltage in the range of  $V_{CC}$  to GND. The Arduino DUE pins are 3V tolerant and so the  $V_{CC}$  is driven by 3V signal.



**Figure 3.1:** Fundamental illustration of a linear potentiometer

The output of the POT is connected to analogue pins on the MCU and so the function, *analogRead()* can be used to convert the analogue voltage into digital value using the built in ADC. The ADC has a 10 bit resolution and so the digital

value is an integer in the range 0 to 1024 and the smallest discernible voltage change is 3mV. However, the design of the throttle does not use the full 300° range and so the physical limits needed to be measured to calibrate the throttles. The measured limits and centre points for the two throttles are shown in table 3.2. The neutral position is described by two values so that there is a neutral range that could easily be achieved by the users input.

**Table 3.2:** Measured physical limits and neutral range of the throttle POTs

Throttle Position	Left POT	Right POT
Full Forward	677	700
Neutral	530	540
	490	500
Full Reverse	321	340

Using table 3.1 and 3.2 a relationship can be created to determine the RA value for a given throttle position. Because the forward operation is in the duty cycle range 75 % to 100 %, the analogue input from the POT needs to be linearly mapped to represent an equivalent duty cycle in this range. Equation 3.3 shows how this is done for the forwards operation. The same logic can be used to determine the duty cycle for reverse as equation 3.4 shows. However, neutral is a set value that is written to RA whenever the throttle is within the neutral range.

$$DutyCycle_{Forward} = 100 - (100 - 75) \left( \frac{POT_{MAX} - POT_{Input}}{POT_{MAX} - POT_{Neutral}} \right) \quad (3.3)$$

$$DutyCycle_{Reverse} = 75 - (75 - 50) \left( \frac{POT_{Neutral} - POT_{Input}}{POT_{Neutral} - POT_{MIN}} \right) \quad (3.4)$$

### 3.4 GPS Module

The GPS module used is a PmodGPS and it has two connectors J1, which has 6 pins and J2 which has 2 pins. J1 is used to power the GPS module as well as connect to the MCU using UART communication with a baud rate of 9600, 8 data bits, no parity and 1 stop bit. The GPS module transmits a series of 5 sentences containing various information. Each sentence begins with a '\$GP' and then the specific message ID. The data is then sent through comma separated and finally ends with a checksum and the end of line characters <CR><LF>. For this project the 'RMC' sentence is the only sentence of interest as it contains all the necessary information, longitude, latitude, speed over ground in knots and course over ground in degrees. An example of the 'RMC' sentence is shown below.

```
$GPRMC,064951.000,A,2307.1256,N,12016.4438,E,0.03,165.48,260406,3.05,W,A*55<CR><LF>
```

The entire sentence is read by the MCU before it starts to pick out the specific data out of the string using the commas and full stops as the guide to what array position is what data. Each piece of data is then added to an instance of a GPS structure that can then be easily parsed to the navigation algorithm and easily analysed. The variables within the GPS structure are shown in table 3.3.

**Table 3.3:** Variables and their types within the GPS structure.

Name	Type	Description
UTC	int	Coordinated Universal Time in the format (hhmmss).
lat	int	The whole number portion of the latitude.
latDecimal	int	The decimal portion of the latitude.
n_s	char	A character indicating North or South.
longi	int	The whole number portion of the longitude.
longiDecimal	int	The decimal portion of the longitude.
e_w	char	A character indication East or West.
knots	float	The speed over ground in knots.
course	float	The course over ground in degrees.
date	int	The date in the format (ddmmyy).



# Chapter 4

## Planning

The system has progressed well and although there have been delays, the system is very close to an operational state. Most of the physical hardware is complete and ready and there are only a few small elements left to complete before testing and refinement can commence.

### 4.1 PCB

The PCB for the motherboard still needs to be printed. An earlier version of the PCB was made, however, there were design flaws and it was designed to be an interim Motherboard as it did not have space for the GPS module. The design has been redrawn as the final design and is ready to print. The delay in PCB printing is due to a lack of doubled sided PCB board in stock and as soon as it is restocked, the board can be printed. Finally, the soldering of the components is a short process and then the motherboard will be ready to implement.

### 4.2 Energy Potential

Based on the datasheets and the minimal running that the thruster has done, it does not look like a 12V system will have enough potential to provide sufficient thrust to move and control the vessel. However, there is plenty of capacity with the current cells.

The simplest way to increase the potential of the battery would be to increase the number of cells. However, as the BMS is designed for 21V and 4 cells. An increase in the number of cells would require a new BMS. This would be a very costly solution, not only because of the new BMS required but mostly due to the

fact that the cells are very costly. These cells are particularly expensive as they have a large capacity. Therefore, an alternative solution is to step up the voltage.

By stepping up the voltage on the thruster side, it would naturally step up the current on the battery side. Given that it is a 100 A BMS, running at the maximum current draw continuously and only draining the battery to 50 %, would offer a 2 hour run time. This would be plenty of time to test the system between charges.

Ideally, a DC to DC step up voltage converter would work best. However, the high current loads of this system prevent any sort of device being applicable. Instead a similar device will have to be designed. A preliminary design is to use a standard inverter to step the voltage up to 230 V alternating current where it can be stepped back down using either a transformer or for variability in the design, a variac. Finally the alternating current can be transformed back to direct current using a high power rectifier bridge.

### 4.3 Unmanned Control

Once the system is operational and the manual controls have been confirmed to function as designed, the unmanned control can be implemented. The unmanned control will be given a prescribed path to follow. This path will consist of coordinate points and the order in which these points should be reached. If there is room in the scope of the project, an optimization algorithm can be incorporated to determine what is the ideal order in which to access the points.

### 4.4 Safety

The system is not yet completely developed and so there is planned refinement in the system and the encapsulation of the electronic hardware. Primarily for the purposes of safety. The battery will need to be placed within a sealable box. Furthermore any high voltage equipment should be contained in a water resistant container. Even low voltage equipment should be contained to ensure that no equipment is possibly damaged and lost. Finally, a kill switch will be implemented to cut the power from the battery to the rest of the system so ensure that if there is any accident or error the power can immediately be cut.

## 4.5 Testing

The testing of the vessel will be done in a controlled environment on an enclosed body of water. During all testing and operation there must be a person either on the vessel or alongside in another vessel so that manual control can be assumed if needed. There will be a fire extinguisher suitable for electrical fires on hand at all testing.

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