Area Scanning Control System for Back-packable Robot Boats

Report for CS39440 Major Project

Author: Elizabeth Stone (eas12)
Supervisor: Dr. Mark Neal (mjn)

Version: 1.7 - Draft
Tuesday 2nd May, 2017

This report was submitted as partial fulfilment
of a BSc degree in Space Science and Robotics (FH56)

Department of Computer Science
Aberystwyth University
Aberystwyth
Ceredigion
SY23 3DB
Wales, UK

Declaration of originality

I confirm that:

- This submission is my own work, except where clearly indicated.
- I understand that there are severe penalties for Unacceptable Academic Practice, which can lead to loss of marks or even the withholding of a degree.
- I have read the regulations on Unacceptable Academic Practice from the University's Academic Quality and Records Office (AQRO) and the relevant sections of the current Student Handbook of the Department of Computer Science.
- In submitting this work I understand and agree to abide by the University's regulations governing these issues.

Name .....Elizabeth.Stone.....

Date .....30/04/2017.....

Consent to share this work

By including my name below, I hereby agree to this dissertation being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Name .....Elizabeth.Stone.....

Date .....30/04/2017.....

Acknowledgements

I thank my dissertation supervisor for helping me with this project...

Abstract

this project...

Contents

1 Background & Objectives

1.1 Background

previously was used manually using RC. Create a working controll system to autonoumously control the boat.

[1]

It is required to create a system that can autonomously scan a body of water. There are errors when controlling the boat over RC from a distance; namely it is hard to tell if the boat is keeping on a straight heading and it is often found that large sections of the area required to be scanned have infact been missed even when at the time it appeared not to be the case.

To autonomize the robotic boat - I learnt this... . [2]

The use of a general control sytem non-specific to sonar would be useful. A system that can be easily used across simiar platforms.

A project by AberSailbot [3] has similar aims to this project, so their system was looked into. There is the use of several different systems (e.g. arduino code, boatd [4], bahaviours) to make their boat function. This in ways is very useful as parts are easily swappable , but also inconvienient when there are too many layers of system to understand. The overall structure is good, and a particularly nice feature is the use of a Raspberry Pi to control high level logic and an Arduino to control all input and output; this distributed design means there is not too much processing being done on either board.

[5]

1.2 Analysis

1.2.1 Project Description

The AqASS (Aquatic Area Scanning System) project will produce a control system for a small, lightweight, motor-powered robotic boat to enable the boat to autonomously scan any given body of water, with selectable parameters.

Academics at Aberystwyth University Geography department studied Scottish lochs two and a half years ago using a lightweight remote control boat. The study required the boat to scan the lochs using sonar sensors to build up an image of the bottom of the lochs and to locate logs on the loch floor (in order to investigate climate change using dendrochronology)[5]. In that study, the boat was controlled by RC. This project aims to make the boat fully autonomous in order to increase efficiency.

The most basic aim for this project is to develop code to make the boat travel in a straight line towards a selected location on a body of water. This can then be built upon to make the boat travel to a series of way-points.

Building on this, the project will then develop an algorithm for automatically selecting the most efficient course for boat to take to scan a selected area (as defined by a series of coordinates).

It will then investigate telemetry and the design of a user interface that allows the user to communicate with the boat while it is on the water, and easily select the route the user wishes the robot to take.

It may also be useful to investigate semi-autonomous functions that can be used on the boat before and after starting the area scanning, such as heading holding, station keeping or return home functions, to aid in deployment of the system.

Suitable development methodologies will need to be investigated early on in this project.

1.2.2 Proposed Tasks

The following tasks are proposed:

- **Investigate Development Methodologies**
- **RC Lake Tests and environment research.** Investigate the environment encountered by the boats and the factors that affect their motion on the water (e.g. current, wind, waves), and what can be done to detect and account for them.
- **Investigate OS and programming languages.** Research which languages are most suitable for the hardware given, and which OS would be best to use on the Pi (if any).
- **Control System Development**
  - **Investigate types of navigation systems.** Research types of system and see which type is most suitable for this project (vector field systems, bearing systems etc).
  - **Investigate Control System Architectures** See which design would be best for this type of project. It may be that a modular approach will be necessary, which would allow easy swapping of hardware.
  - **Write code to get boat to travel in a straight line to a way-point/series of way-points.** This will involve accounting for factors discovered during rc testing.
  - **Investigate ways of representing and specifying body of water to be scanned and develop an algorithm to determine the most efficient route to scan the given area.** Specifying the body may be as simple as manually entering the data points, or as advanced as having a GUI where the user may draw the outline of the water on a map.The algorithm will likely depend on the shape of the body of water, current direction and other factors. It should also consider parameters such as desired resolution of scan (which would depend upon the sonar sample rate, speed of boat, and spacing of consecutive traversals of the area).
  - **Research and Develop Telemetry System** Develop easy to use interface to pass information to and from boat. Investigate if long distance communications would be useful and viable.
  - **Investigate plausibility of (and implement) collision avoidance system.** A system to prevent the boat from travelling into shallow waters, or crashing into objects in its path (e.g. other boats, buoys). This may involve processing the data from the sonar scanner(s), thus research will need to be done into how to process this data. It may also be necessary to develop a modular system so that sonar device may be swapped easily for another similar device.
- **Test control system** The methodology used will define the frequency of testing, but tests on one or more large bodies of water would be ideal nearer the end of the project. On land tests will be carried out throughout the rest of the project.
- **Project Meetings and Project Diary** Weekly project meetings will be held with the supervisor, and a project diary will be kept to keep track of all parts of the project. The diary will be written in markdown and backups will be kept in a git repository.
- **Demonstrations**

1.2.3 Deliverables

Deliverables expected from this project:

- Mid-project demonstration
- Control system software

- Usable user interface and telemetry software
- Collision avoidance software
- Final report
- Final demonstration

1.3 Process

This project used Feature Driven Development (FDD) methodology for orginization. Upfront a desgin for the hardware and a software flow diagram was created, as can be seen in Appendix C. A list of tasks to be completed was then kept, with an order of priority (the first tasks on the list needed to be completed before the next tasks).

2 Design

2.1 Overall Design

The hardware available for this project include rudder servos, servo motors, compass, gps and sonar scanner. The sonar scanner is not used in the final design. The final plan for the hardware is shown in Figure 1, with the GPS on the Pi and all other hardware on the arduino.

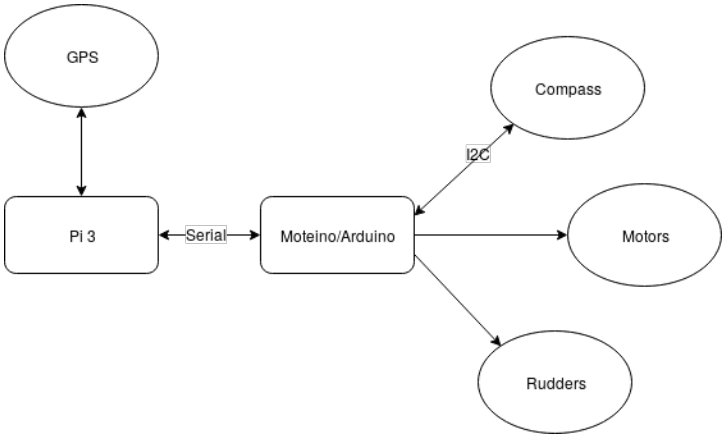


Figure 1: Final hardware design.

The control system has two seperate parts; one for high level computations for global navigation (deciding where to go overall) and one for low level control for local navigation (keeping the boat travelling along a given heading using pid). If the two systems were not seperate, the high level logic may delay the lower level logic and prevent the motors and rudders being updated in a short enough time for pid to work properly (this can result in oscillation of the boat about the heading it wants to go on, rather than going straight on the heading, which ultimately could lead to the boat going far off-course).

The lower level controller controls all input and output necessary to keep the boat steering on a desired heading (e.g. compass, motors, rudders).

The higher level controller communicates a heading to the lower level controller, and this heading is decided using the current GPS location, and given GPS co-ordinates to build a map of where to go.

The design is also be easily adaptable to different hardware, so that hardware can be easily updated or swapped easily. For this reason, for each piece of hardware there is a driver, separate from the main code, that the main code can use to talk to the hardware. For each new, or different, piece of hardware a new driver can be implemented.

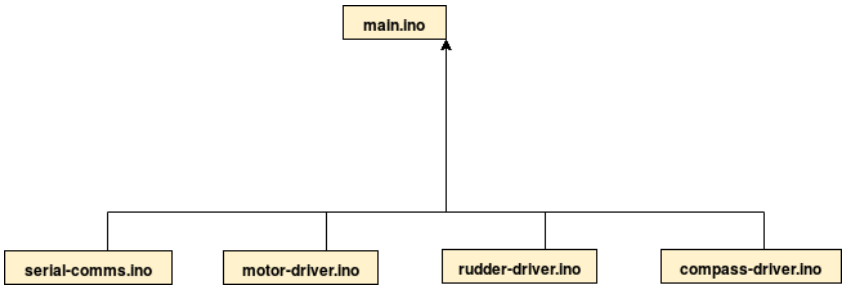


Figure 2: Design of the low level code.

The python code is similarly modular, with easily swappable sections:

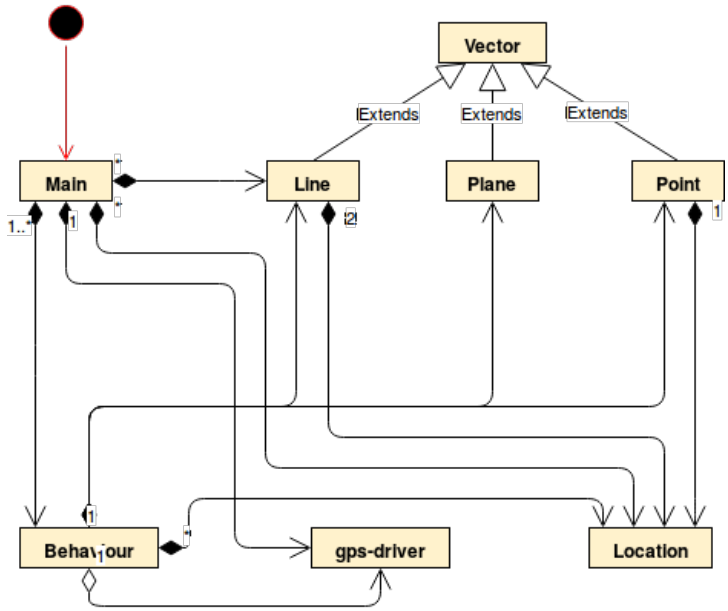


Figure 3: Design of the low level code.

As this project is open-source under the GPL3 license, having drivers for each separate piece of hardware is important as anyone who wishes to use this software will almost definitely have different hardware to what was used here.

The inital design can be found in Appendix C.

*** insert flow diagram below

See the final design.

*** insert flow diagram below

The input and output from and to the hardware is handled using drivers to allow easy swapping of hardware with this code. On the Moteino there are three peices of hardware attached; the rudder servos, motor servos and compass. There is also a serial connection to the Raspberry Pi, but the driver for this is more complex, as will be explained in subsection 2.4.

2.2 Arduino Code

Arduino C was used as the Aduino is a cheap and easily obtainable microcotroller ***, and Arduino C can be used on similar microcontrollers such as the moteino, so is usefull for anyone wanting to use this software on their own boats. In this implementation, a Moteino was used (though some code was also tested on an Arduino Uno and worked the same).

2.2.1 PID Controller

The local navigation system needs to have a pid control loop to control the rudders to adjust the boats' heading.

The motors could also be PID controlled, as this would mean that the boat will go at a steady speed despite

its environment (e.g. strong wave, wind) which, if used for sonar scanning of a lake (or sensor readings of any type), readings would be at approximately the same distance apart (as it is most likely that the readings will have to be taken at every given time interval***). This would be useful, but complex to implement. The feedback to say how fast the boat is going is only measureable by the GPS, and this only gives the *** average speed between co-ordinates, which is only updated once a second. There are two limits with this; firstly, when not travelling in a perfectly straight line the measured speed will be less than the actual speed, which posses problems when the boat turns a tight corner and thus appears to have moved no distance. Secondly, the readings for speed being given only once a second is not fast enough for PID to properly work; PID works best with as small as possible time steps*** and a second is too large. Thus it was decided to not controll the speed by PID.

With speed, there is an added complication that, when turning a tight corner, it is best to not travel at full speed as this increases the turning circle and means the boat must travel further to make it bake on course. It is better to travel slower while turning tight corners.

2.2.2 Rudder Driver

For this driver it would have been desirable to have an interface that the driver implements, to make it easier for alternative drivers to be easily implemented, but Arduino C does not support this feature.

As with the motors, both rudders are stuck together and cannot be turned in separate directions.

2.2.3 Motor Driver

As for the rudder driver, for this driver it would have been desirable to have an interface that the driver implements, to make it easier for alternative drivers to be easily implemented, but Arduino C does not support this feature.

Both motors are controlled off the same pin on the moteino and so differential steering was not possible. This means both motors will always run at the same speed. This limits the types of movement available from the boat as it is not possible to turn on the spot. A consideration must therefore be given elsewhere in the code for large turning circles.

2.2.4 Compass Driver

As for the previous drivers, for this driver it would have been desirable to have an interface that the driver implements, to make it easier for alternative drivers to be easily implemented, but Arduino C does not support this feature.

2.3 Pi Code

2.3.1 Navigation

For global navigation there are several different designs commonly used; waypoint navigation and vectorfield navigation***. Waypoint navigation is the simplest to implement as this involves creating waypoints and heading directly for them, one after another, using the robots current location and desired location. It may also be extended to use crosstrack error to bring the boat back on the line between the previous waypoint and the next waypoint (as this minimises the distance travelled).

Vector feilds use a much more complex strategy. Different objects, movements and behaviours can be described by equations that put a "force" on the boat *** (so obstacles would have a repelling force, and waypoint an attractive force). The forces will depend (in most cases) on distance from a the location of a waypoint or obstacle. These forces are therefore directional and can be represented as a vector. By adding

the vectors, an overall force is found which is the direction (and perhaps speed) the the boat should go at. This is much more complex to visualize than waypoint navigation, but for acheiving complex behaviour the code is much simpler with vectorfeilds and is much more efficient.

The waypoint navigation cannot easily handle avoidance of an obstacle; a series of points around the obstacle must be plotted, whereas with vectorfeilds a point with a repulsive force can be added at the obstacles location with a weight that relates to the size of the obstacle. The obstacle can be easily remembered throughout the rest of the robots navigating with no extra logic needed, whereas with waypoint navigation a new course must be plotted around the obstacle every time the robot approaches it.

2.3.2 Behaviours

The behaviour of the robot should be selectable and easily changable. There are simple behaviours the robot could use to fullfil the task of area scanning a lake, and there are much more complex behaviours.

The simplest behaviour possible is navigating toward a single point. More complex than this is navigating to a series of points. These two behaviours are very common ***.

With this project it is hard to find algorithms that instruct a robot to scan an area in the most efficient way; path finding algorithms would find the shortest route between two specified points, but would not yield the most efficient way to navigate to every point within an area. This problem is similar to the travelling sales man problem ***, but the points are generally in a predictable layout, so a computationally heavy algorithm like those needed to solve the travelling sales man problem are not needed.

2.3.3 GPS Driver

2.3.4 Vector Classes

2.3.5 Logs

2.4 Arduino-Pi Communication

Need a way of sending messages both ways between the pi and arduino. It would be complicated to have both the pi and arduino able to initiate messages between them, as this could cause clashes. A slave/master system is more appropriate, with the pi as the master, sending the initial messages.

The messages will consist of a single letter (e.g. 'e'), or single letter followed by a number in brackets (e.g. 'h(276)') if a number is required. This is for efficiency; the as messages on the arduino are stored as a char array and so must be compared char by char, rather than a simple comparison of strings (comparison of strings would make extracting the number that needs to be saved more challenging, and would probably result in the String being converted into a char array). It is sufficient enough to use a single letter for the meaning of the message; and there are only 4 - 5 *** meanings that need to be transmitted, so there is no danger of running out of letters to use.

The use of brackets means that the code can be sure exactly where the number is expected to start and end - if there was no character signifying the end of the message, if an extra number was transmitted accidentally by another part of code, or through noise on the connection, then the number read could be very wrong. It also makes defining the end of the message easier, as it may not be known how the message will be terminated (a new line, carriage return or null terminator are all valid options).

It would be ideal to have a confirmation message to so that the message had been received every time a message is sent, but implementing this seems too over engineered for this system; if a single message is missed, there will be a new message in around a second. The only place where there needs to be confirmation, is during the shutdown sequence. Here the arduino needs to turn the motors off before it is safe for a person to pick it out of the water, and so a missed message saying to shutdown cannot be ignored. Therefore,

during shutdown the pi will ask the arduino to sleep by sending the letter 'e', and will expect it to respond with 'e' if the message is received. If the pi does not get the response within a set time*** it will send the message again. If after five*** attempts the arduino still has not responded, it can be assumed something has gone wrong and that the python code should exit anyway.

3 Implementation

3.1 Support Tools

Originally this software was developed using PlatformIO *** as this gives a more C like file structure to the code, and allowed drivers to be easily imported into test files to allow the drivers to be tested. Unfortunately PlatformIO is not easily installed on a Rasperry Pi, where as the Arduino IDE can be easily installed, and so the code was adapted to be used with the Arduino IDE.

This project used GitHub for version control and for backing up code. As this project is open-source, it is held on GitHub under the GPL-3 license and is therefore available for others to use.

3.2 Arduino Code

3.2.1 PID Controller

The PID was implemented using the difference between two headings (the current heading and the desired heading) as P. Finding the difference between two headings was challenging due to the use of a circular scale, as it is not simply subtracting one value from the other as would be the case with a linear scale (the smallest angle between 5 and 355 degrees is 10, but by simply subtracting these values you get 350 or -350). With this circular scale, the values wrap at 360.

There are solutions that are extremely simple which use trigonometric functions to calculated the difference between the two headings easily, preserving the sign (which indicated a clockwise/anticlockwise turn). But these functions are computationally inefficient, so it is best to avoid using them where possible.

A more efficient way is using the equations below to calculate different angles between the headings:

$$(360 - A) + B \tag{1}$$

$$B - A \tag{2}$$

$$(B - 360) - A \tag{3}$$

The result of Equation 1 , Equation 2 and Equation 3 with the lowest absolute value is the smallest angle that can be moved through to get from A to B. A positive result indicates a clockwise turn, and negative indicates an anti-clockwise turn. Which equation gives the smallest result is dependant upon which quadrant the two heading lie (0-90,90-180,180-270 or 270-360). This solution works, but may not be the most efficient solution.

To tune the PID loop, different methods of tuning were researched. The two main methods investigated were the ZieglerNichols method, and manual tuning. According to a review of these methods by Wikipedia [6], the manual tuning requires experience whereas the Ziegler-Nichols method does not. Because this robot is a boat and tuning of the PID requires access to a large body of water for the boat to move on, it was impractical to tune the PID munually, so it was decided to use the Ziegler-Nichols method instead.

To make the boat turn tight corners it was decided to make the boat travel at half the maximum speed that the boat can travel at.

3.2.2 Rudder Driver

To calibrate the rudders, a test program was used that took the rudders left, right and center to test if the directions were correct, and to see if the limits were to high or low.

3.2.3 Motor Driver

Dude to the modular design of the system, and given that all parts relating to the motors should be easily swappable, it was decided that the main code should only preform logic in units of ms^{-1} rather than the raw motor values (which here is given in degrees). This is so that any motor working with different units or scales can still be used.

Therefore, the driver includes functions that translate from the scale the motors use to ms^{-1} and back. The maximum, minimum and stop raw values are held in the driver, and can be translated and returned to the main program by calling getMaxSpeed, getMinSpeed and getStopSpeed for the main program to work with (e.g. find a half max forward speed, by finding the average of getStopSpeed and getMaxSpeed). There is also a stopMotors function that will stop the motors (which is useful at the end of the program). There was the idea to detach the motors from the pin to prevent them being written to later in the program, but this would instead cause the values written to the motors to be left floating (changing randomly over time) which would be undesirable and dangerous (if removing the boat from the water at the end of a run, the motors could start turning at any speed at any time).

In initMotors, there is a five second delay after the motors are set to there armed value, which is required by this type of motor before any other values will work. This delay may be larger than necessary, but ensures that the minimum time is definitely reached. The need for a delay was noted in Aled Davies original code for these boats, which implemented semi autonomous features (such as heading holding).

The difficult part of this design is that it may not be know what speed the motors move the boat at, and this will vary under different conditions (e.g. high winds, strong currents).

The motors were calibrated by firstly using a simple test program that sends varying raw values to the motors and seeing how the motors respond. It was found that the theoretical maximum value of 180 was too high for the motors and so the motors would not turn on.

3.2.4 Compass Driver

By testing the compass, it was found that the compass readings were not correct initially, and that a simple zero error was not the problem as previously assumed. The compass measured different changes in degree at different bearings even though it was being moved through the same angle (results can be seen in appendix ***). Thus the initial design of simply adding an offset to the compass would not work.

To investigate this further, the compass was glued into the boat, the boat was placed on a wheeled platform and rotated through different angles. A calibrated compass was placed on the boat. The boat was turned in steps of 20 degrees *** from 0 to 340 according to the boats compass, and the actual heading according to the calibrated compass was recorded. By plotting this on a graph in LibreOffice Calc it was clearly visible that there was not a linear trend between the boats compass headings and the real headings.

To compensate for this, a trend line was plotted through the points and the resulting equation was used to transform the compass headings into actual headings.

An important point to note about this equation is that when the actual heading becomes 0, the points will shift on the graph so that a trend line cannot be found ***. For this reason, the value the compass reads as 0 (due north) was recorded, and any values greater than this must have 360 taken away from them before being passed to the transformation. The results of this can be seen in figure 4.

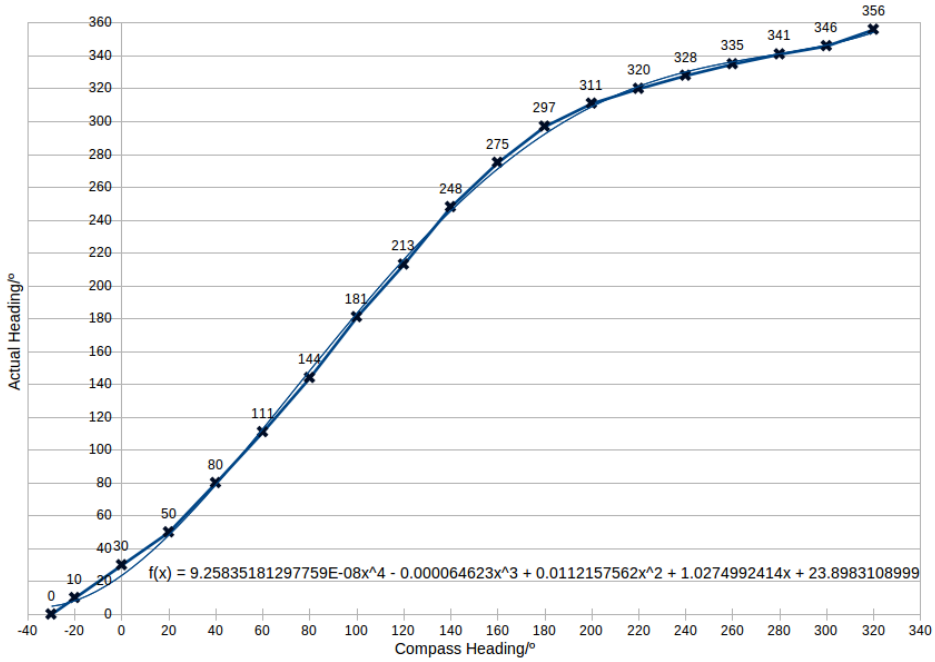


Figure 4: Graph of compass heading vs actual heading. The equation is that of the trend line.

This tranformation was added to the compass driver, so that any values returned to the main program will be calibrated. It was checked that values of 360^2 could be held by a float in Arduino C as this comes to a very large number (1.68^{10}). Fortunetely floats can be between 3.4028235×10^{38} and as low as $-3.4028235 \times 10^{38}$ [7] so there is no way that any values can wrap in this equation.

3.3 Pi Code

3.3.1 Navigation

Vectorfeilds were chosen as the navigation system.

Three different vectors were

The input files were formated as .csv as this is a common format and python has modules that can be included to read .csv files easily. Example files from all the tests can be seen in Appendix D.

3.3.2 Behaviours

After exploring several options, a simple algorithm was devised for scanning bodies of water of almost any shape; given the outline of the lake as points defining the perimeter, the two furthest points apart are found. Between these two points, lines perpendicular to the line joining the two points are found at regular intervals (the frequency at which a user would like traces of the water to be taken). The ends of these lines are limited to 5m within the boundary of the water, and attractive Point objects are initialised at these points. The lines between the points are also initialised as Lines. By storing successive waypoints and lines in a list, and iterating over this list, the waypoints can be nagivated in a logical order to scan the entire area (the lines would be used to keep the boat on a straight line between the points). See *** for a visualisation of this.

Another strategy explored was the spiral, where points are placed 5 meters in from the points defining the boundaries of the water until the centre is reached, drawing lines between points equidistant from the perimiter, and following those lines. This would be much more complex to implement, and a comparison

of these strategies as seen in Figure 5, led to the conclusion that the spiral covers more distance than the square-wave strategy, or at best covers the same distance.

Figure 5: A comparison of possible area scanning strategies. The top lake yeilds a result of ***km for the spiral, and ***km for the square wave, the middle a result of ***km and ***km, and the bottom *** km and ***km for the spiral and square-wave strategies respectively.

The square-wave strategy appears to work in most shaped lakes but there are cases where it will not work; most notably it will not work on an ox-bow lake, nor a meandering river (though it should be noted that this boat should only be used at most very slow moving rivers in order to avoid been dragged downstream - a lake is the prefered environment).

3.3.3 GPS Driver

3.3.4 Vector Classes

3.3.5 Logs

3.4 Arduino-Pi Communication

this was interesting as the python and arduino C default print in two different formats. The python needs to be cast to b' ' *** before it can be printed. It was decided to leave the arduino in its default read/write format as libraries or logic to convert the values would waste memory and time in conversion.

The python also by default included the \n and \r characters in the read in string (so if the arduino send 'e', the python code would read and save this as 'e\n\r'). This is not ideal for easy comparison of strings, so the .strip() function was used to remove all syntax*** from

4 Testing

4.1 Arduino Tests

These were nearly possible when using PlatformIO but in reality it was impossible to make them work. When testing in ArduinoIDE there is no support for unit tests, so alternative approaches had to be taken.

4.1.1 PID Controller

Testing the PID tuning proved difficult, as this must be done on the water, and in order to check the PID tuning, there must be a way of seeing if the boat is oscillating about a heading or not. This is difficult as this cannot be done from shore; one of the main motivations for this project is the impossibility in telling if the boat is travelling in a straight line or not from shore. It would be possible to record the location of the boat according to GPS as it travelled, but GPS is only accurate to 5***meters which is not accurate enough for fine tuning. The added fact that waves and currents will effect the motion of the boat unpredictably means that fine tuning the PID was impossible.

Some tuning of the PID was done during the land tests described in subsubsection 4.4.1, but the tuning was found to be wrong during the water tests (described in subsubsection 4.4.2. This is due to an underestimation of the speed of the boat and therefore how fast the boat must move its rudders in order to stay on course.

In the end, the Ziegler-Nichols methods implemented were removed during the lake tests and the manual method was implemented instead (as this is the simplest method) by increasing the value of P until the rudders moved sensibly and proportionately to a change in heading (turning the boat on the spot). The PID was not tuned any further as this was sufficient for the boat to move on the correct heading.

A way to improve the tuning in future would be to enable the PID to be adjusted on the fly (through use of wifi to the Pi and passing messages to the moteino via serial, or through another moteino talking to the boats moteino over radio). By having the PID easily adjustable, and then following the robot in a boat so it can be seen close up how the robot is moving, it should be possible to finely tune the PID. This was not possible in this project as there was not time, and fine tuning was not critical to making the control system functional.

4.1.2 Rudder Driver

4.1.3 Motor Driver

The motors were tested under RC in the harbour area of Aberystwyth. Using the old monitoring system (designed to be used under RC) data was recorded about the location of the boat over time.

4.1.4 Compass Driver

The main tests for the compass driver involve testing the calibration, as described in the implementation in subsubsection 3.2.4.

Looking at Figure 4 in subsubsection 3.2.4, it can be seen that the final equation still does not perfectly calibrate the compass, as there are places where the trend line deviates from the data points; specifically between a compass heading of -20^o and 20^o(which corresponds to an actual heading of 10^o to 50^o). The deviation is at most 10^o, so this should not have too great an impact on the navigation of the boat; the heading may be out by 10^o at some times but the PID*** should compensate for this. The most impact this will have is in making the boat curve towards its target instead of taking a direct course. Further investigation of this problem is discussed in subsubsection 3.2.4.

4.2 Python Unit Tests

4.2.1 GPS Driver

4.2.2 Vector Classes

4.2.3 Navigation

Testing of the single waypoint behaviour*** was test using a raspberry pi with only a gps attached. Every new desired heading was saved along side a the current GPS location, and in later tests the time stamp. GPS co-ordinates outlining a feild and waypoints within the feild were found using GPS Visualizer and were passed to the code as further discussed in subsubsection 3.3.1. To test the algorithm, the Pi was moved around the feild in a zig-zig shape to cover the whole field, including right up to the field boundaries and beyond.

It was found by looking at the desired heading on when at each location within the feild, the algorithm was working correctly.

More specific tests are outlined in the appendices

insert vector diagram here

4.2.4 Behaviours

4.2.5 Logs

4.3 Arduino-Pi Communication

Communication was tested using the main code on the Arduino and python test code on the Pi. The python test code included only bits of code necessary to send messages in order to solely test the functioning of the communications, for these bits of code to be later integrated into the main python code.

4.4 Overall Behaviour

To test the functionality of the overall control system two different types of test were used; land tests and water tests.

4.4.1 Land Tests

Firstly, the boat needed to be tested on the land, as testing a control system on the water when it has not been tested all together before could result in losing the boat. Therefore so called "Carpark tests" were carried out on the boat; this involves loading the full program as though it is about to go out on the water, but instead carrying it or placing it on a trolley (see Figure 6) to be wheeled around a field or large open space (such as a car park). By watching the rudders and adjusting the boats heading according to the rudders, it is possible to simulate how it would move on the water.

With this technique it is possible to tell if the final behaviour of the boat is correct, and it is possible to tell if it is safe enough to place on the water (e.g. it doesn't try to move in the completely wrong direction at any point).

Figure 6: Testing boat in a field on a trolley. The righthand picture shows the route the GPS recorded. The purple zig-zig shows the most efficient route between the waypoints chosen (with waypoints at each turn in the purple line). The boat started at the top of the red line, and ended at the dark purple line on the right. The different colours indicate a change in which waypoint is trying to be reached.

With the first land test, the boat seemed to move in large loops rather than directly between the waypoints, though this could be as a result of the GPS inaccuracies (this will make the boat want to go on a different heading as it appears to be in a different location to where it is in reality).

The GPS location results for this test are shown in Figure 6 . It can be seen that there is a lot of variation with the GPS readings, as expected with this type*** of GPS, and in a somewhat built up location. The bright green line and dark blue line are particularly inaccurate, but this was the case only for a short amount of time.

As the GPS was jumping so much, it was hard to tell how well the control system was working so it was decided to test it on land again using points further spread out (***

4.4.2 Water Tests

Figure 7: Both traces from lake tests. The first test is the trace that starts turquoise and goes to purple as the trace moves clockwise. The second test is the trace that starts red and fades through orange, yellow, green.

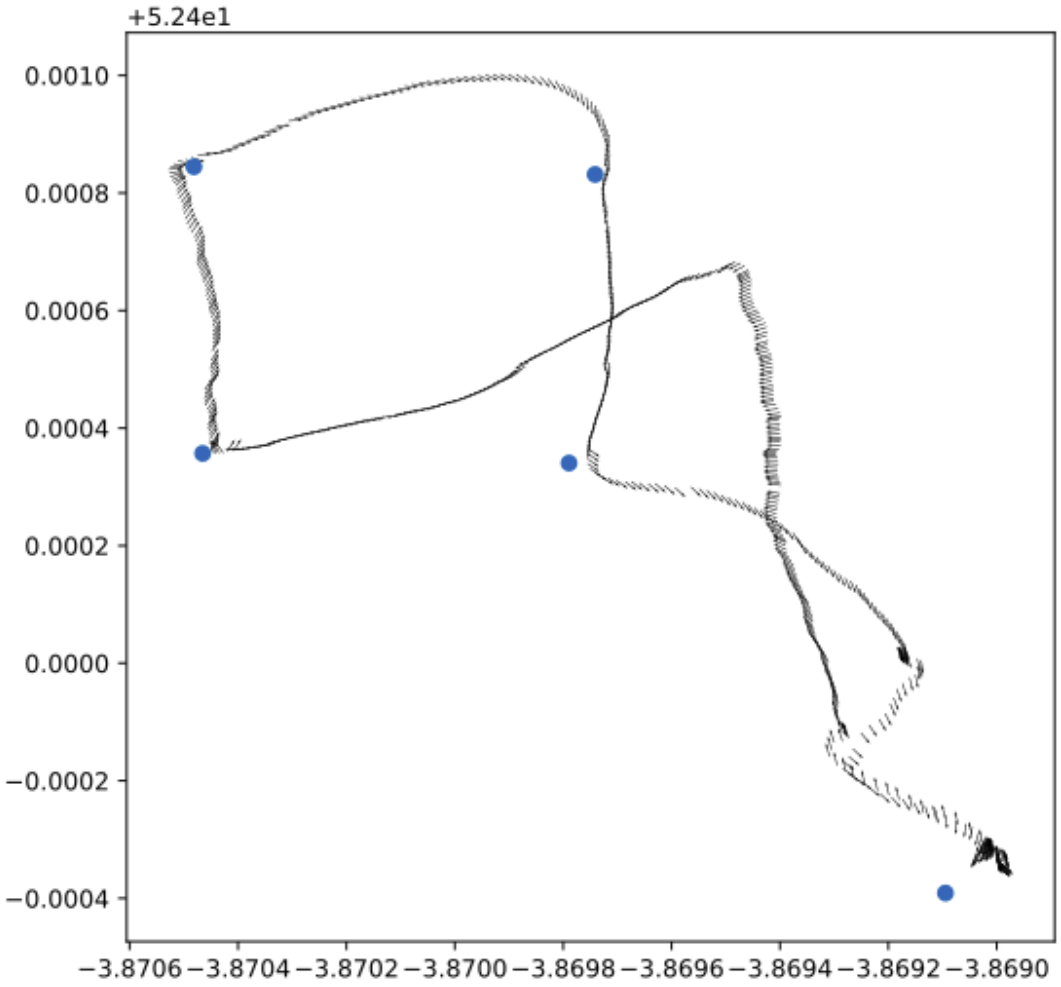


Figure 8: The lake.

5 Evaluation

A Appendix A: Ethics Questionnaire

AU Status
Undergraduate or PG Taught

Your aber.ac.uk email address
eas12@aber.ac.uk

Full Name
Elizabeth Stone

Please enter the name of the person responsible for reviewing your assessment.
Reyer Zwiggelaar

Please enter the aber.ac.uk email address of the person responsible for reviewing your assessment
rrz@aber.ac.uk

Supervisor or Institute Director of Research Department
cs

Module code (Only enter if you have been asked to do so)
CS39440

Proposed Study Title
MMP Backpackable Robot Boats for Sonar Surveys

Proposed Start Date
30/01/2017

Proposed Completion Date
08/05/2017

Are you conducting a quantitative or qualitative research project?
Mixed Methods

Does your research require external ethical approval under the Health Research Authority?
No

Does your research involve animals?
No

Are you completing this form for your own research?
Yes

Does your research involve human participants?
No

Institute
IMPACS

Please provide a brief summary of your project (150 word max)
Develop a control system for a small light-weight motor boat in order to scan a body of water autonomously.

Where appropriate, do you have consent for the publication, reproduction or use of any unpublished material?
Not applicable

Will appropriate measures be put in place for the secure and confidential storage of data?
Yes

Does the research pose more than minimal and predictable risk to the researcher?
No

Will you be travelling, as a foreign national, in to any areas that the UK Foreign and Commonwealth Office advise against travel to?
No

Please include any further relevant information for this section here:

If you are to be working alone with vulnerable people or children, you may need a DBS (CRB) check. Tick to confirm that you will ensure you comply with this requirement should you identify that you require one.
Yes

Declaration: Please tick to confirm that you have completed this form to the best of your knowledge and that you will inform your department should the proposal significantly change.
Yes

Please include any further relevant information for this section here:

B Appendix B: Additional Libraries

The following libraries, or code, were used or built upon in this project.

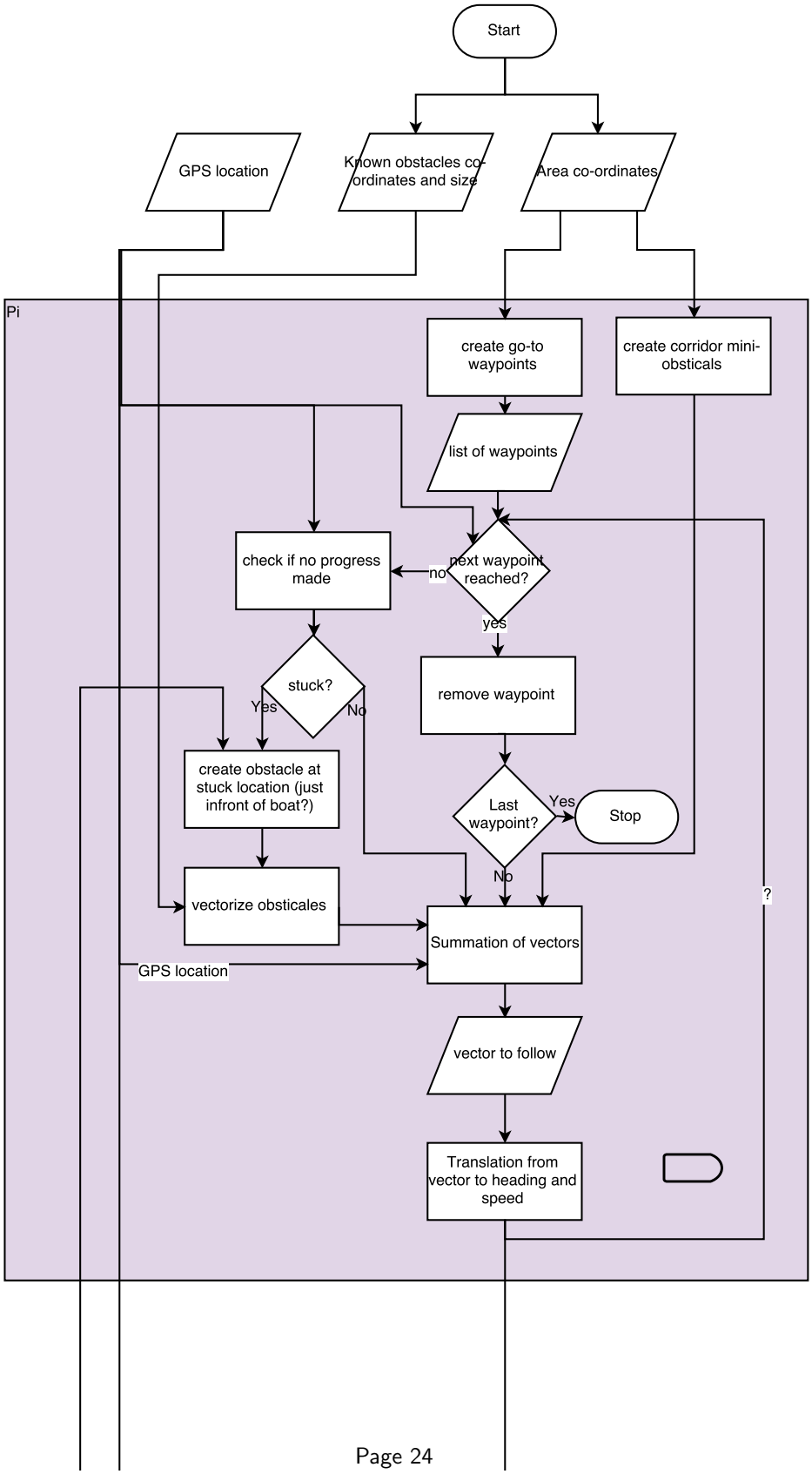
Arduino, avr/sleep, Wire, Servo Come as standard with the ArduinoIDE. These libraries were used without modification.

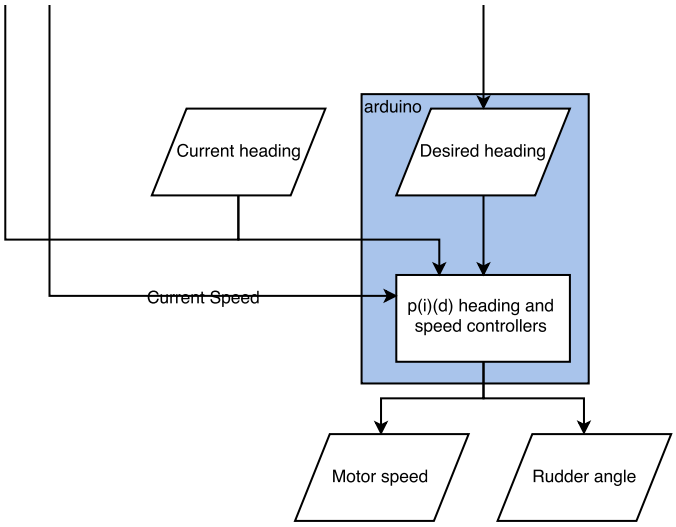
Adafruit_HMC5883_U and **Adafruit_Sensor** are libraries developed by Adafruit for use with the HMC5883 compass. They are released under the BSD license and Apache License, Version 2.0 respectively.

numpy, unittest, csv, time, threading,serial are modules included by default with python.

gps

C Appendix C: Initial Design Flow Diagram




arduino
Current heading
Desired heading
Current Speed
p(i)(d) heading and speed controllers
Motor speed
Rudder angle

D Appendix D: Simple Algorithm Tests

D.1 Castle grounds Test

Water csv file:

Object csv file:

D.2 Second Castle grounds Test

Water locations:

```
52.4139445,-4.0910125
52.4138627,-4.0911117
52.4133948,-4.0905726
52.4137874,-4.0901327
```

Waypoint Locations:

References

[1] R. Siegwart, I. Nourbakhsh, and D. Scaramuzza, *Introduction to Autonomous Mobile Robots*. Intelligent robotics and autonomous agents, MIT Press, 2011.

This book talks about the different control systems that can be used .

[2] J. C. Alves, "Robotic sailing 2016," in *Proceedings of the 9th International Robotic Sailing Conference*, 2016.

Discussion of robotic sailing boats, particularly how they behave and navigate .

[3] AberSailbot, "abersailbot." `https://github.com/abersailbot`, 2017. Accessed 2017-04-30

The github pages for AberSailbot and their code for controlling their robotic sailing boats.

[4] L. Taylor, "boatd." `https://github.com/boatd`, 2017. Accessed 2017-04-30

The robotic sailing daemon used to control robotic sailing boats.

[5] R. Bates, "Travels with applied geophysics - dendrochronology glen affric, 2014." `http://geophysicistatlarge.blogspot.co.uk/search/label/dendrochronology`, 2014. Accessed 2017-02-08.

This blog talks about a previous use of the boats, under remote control, that are to be used in this project .

[6] Colaboration, "Pid controller." `https://en.wikipedia.org/wiki/PID_controller`, 2017. Accessed 2017-04-30

Talks about PID controllers and the different ways of tuning them .

[7] Arduino, "float." `https://www.arduino.cc/en/reference/float`, Year unknown. Accessed 2017-04-28

Reference pages for the Arduino language. This talks about the range of values a float can take.