Object Tracking using Drone Swarms

E25

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Executive Summary

There is a fundamental knowledge gap in the behaviour of invertebrate species within New Zealand. This has led to poor conservation management, resulting in 34.5% of the New Zealand invertebrate species either threatened or at risk [1]. An additional 1252 species have been identified as ‘data deficient’ [1]. Previous conservation successes have shown the benefits of radio tracking technology, providing vital data to aid in species recovery [2]. Current methods of insect tracking are labour intensive and do not provide precise information. The Wireless Research Centre (WRC) at the University of Canterbury is in the process of developing a new form of radar technology that is lighter than existing methods. The system allows tags to be placed on targets as small as insects to be tracked. However, due to the range limitations of the tags, the radio receivers need to be within 15 m of the target. The WRC have proposed using a moving drone swarm equipped with the necessary radar equipment to track the small moving targets.

This project exists as a proof of concept to demonstrate the potential ability for tracking objects using a moving drone swarm. The swarm consists of one transmitter drone and four receiver drones. The transmitter sends out a signal which is reflected by the target carrying the harmonic tag and then captured by each receiver drone. By utilising the radar readings captured by each receiver drone, the location of the target can be determined. Since the radar tag technology is out of the scope of the project, the radar readings will be simulated using a GPS transmitting target.

The project looks to improve the results achieved during a final year project last year, where a single flying drone followed a target with four other drones simulated. The goal is to produce a swarm consisting of five flying drones tracking a GPS transmitting target. The system requires development in five separate subsystems. A multilateration algorithm will be use to locate the target using the radar readings from each receiver. To increase the robustness of the multilateration, a tracking algorithm will account for radar drop out and provide a more accurate target location using a Kalman filter. Once the target location is identified, the drones positions must be updated to remain in formation using swarming logic. To ensure the drones do not collide, the current and expected drone positions must be checked through adequate failsafe’s. A robust inter-drone communication network is required to transmit radar readings and position updates. Each member has been assigned to develop a specific subsystem.

The team is currently on track to achieve the first two milestones in the upcoming holidays. The first milestone involves understanding the previous system to perform simulated and practical demonstrations achieved last year. The next step is to recreate the three practical flight tests conducted last year. The practical flights will range from a single drone following a target, to two drones flying in the air with 3 simulated. The target will be a person carrying a laptop with a GPS module attached, transmitting its location. In preparation for the first milestone, myself and another team member have achieved full operation of the simulation used last year. This has required a deep understanding of the code, learning how each module operates within the program.

The majority of my time has been spent improving the multilateration algorithm. The previous method was rudimentary and only operated in 2-dimensions. This introduced projection errors, was computationally expensive and did not expand easily to 3 dimensions. The localisation module was completely rebuilt, utilising the Time Sum of Arrival (TSOA) algorithm. To test this module, I generated a target path that emulated an insects movement. While getting the

simulation operational has taken longer than estimated, both the multilateration and tracking modules are now ready to be implemented into the previous code to meet milestone 1B.

Project Overview

Background

Despite New Zealand being recognised as a conservation leader, the invertebrate population is in danger with 34.5% either classed as threatened or at risk [1]. Globally, the population of terrestrial invertebrate is declining at 10% every decade [3]. Of the 4000+ invertebrate species that have been assessed by the Department of Conservation (DOC), 1252 species have been identified as ‘data deficient’ [1]. There demonstrates that there is a lack of knowledge required to provide the necessary conservation efforts. Previous conservation successes have shown the benefits of radio tracking technology, providing fundamental data to aid in species recovery. This information includes, nesting locations, movement patterns and foraging ranges.

Conventional RF telemetry methods involve placing radio transmitters on the object. The target is located by a taking multiple readings from a ground based radio receiver connected to an antenna. This method is currently used by DOC for tracking small ground based animals [4]. However, because even the lightest radio transmitters weigh at least 200g, this approach is unsuitable for tracking many of the threatened invertebrates. The Wireless Research Centre at the University of Canterbury is currently developing a new form of radar technology that is lighter and less bulky than existing methods. Harmonic radar tags can weigh as little as 7mg, making them suitable for placing on very small animals [5]. Using harmonic radar tags to track terrestrial invertebrates provides the opportunity to gain fundamental data required to aid in conservation management.

Due to the range limitations of the harmonic tags, the receivers need to be within 15 m of the target to get a signal. The WRC have proposed using a moving drone swarm equipped with the necessary radar equipment to track the small moving targets. This project exists as a proof of concept to demonstrate the potential ability for tracking objects using a moving drone swarm. As the harmonic radar tag is currently in development, simulated radar readings will be generated from a GPS module. The goal of the project is to create an environment where the harmonic radar tag could be substituted in, producing a working prototype. This would leave the WRC with a starting point to further develop and test the drone swarm tracking system.

Project Requirements

The final year project from last year successfully completed a practical test with one drone flying in the air and the other four simulated. The swarm was able to track a person walking with a GPS module, producing simulated radar readings. Unfortunately they ran into formation issues with more drones flying. This year, the goal is to implement five drones flying in the air tracking a GPS transmitting target. Certain aspects of the project will also be improved to produce a more robust system. This involves implementing the target localisation in 3 dimensions and incorporating a tracking algorithm. The requirements of the drone swarm are listed below.

R1.1 – The drone swarm must consist of one transmitter and four receivers.
R1.2 – Each drone must be physically flying while tracking the target to demonstrate a successful system.

R1.3 – Each drone must stay within 15 m from the target, representing the range of the harmonic tag.
R1.4 – The system must be robust enough to track a walking target, with a stretch objective of tracking a small moving UAV.
R1.5 – Adequate failsafe's must be implemented to ensure the practical demonstration is safe and the chance of drones colliding is minimised.
R1.6 – The drones must be able to hold formation surrounding the target to ensure the multilateration calculations are accurate.

Project Solution

There a multiple components of the system that must work together to produce a successful outcome. These can be divided into communication systems, swarming logic, failsafe's, tracking and localisation. Figure 1, demonstrates how each submodule integrates, with each coloured box representing a module.

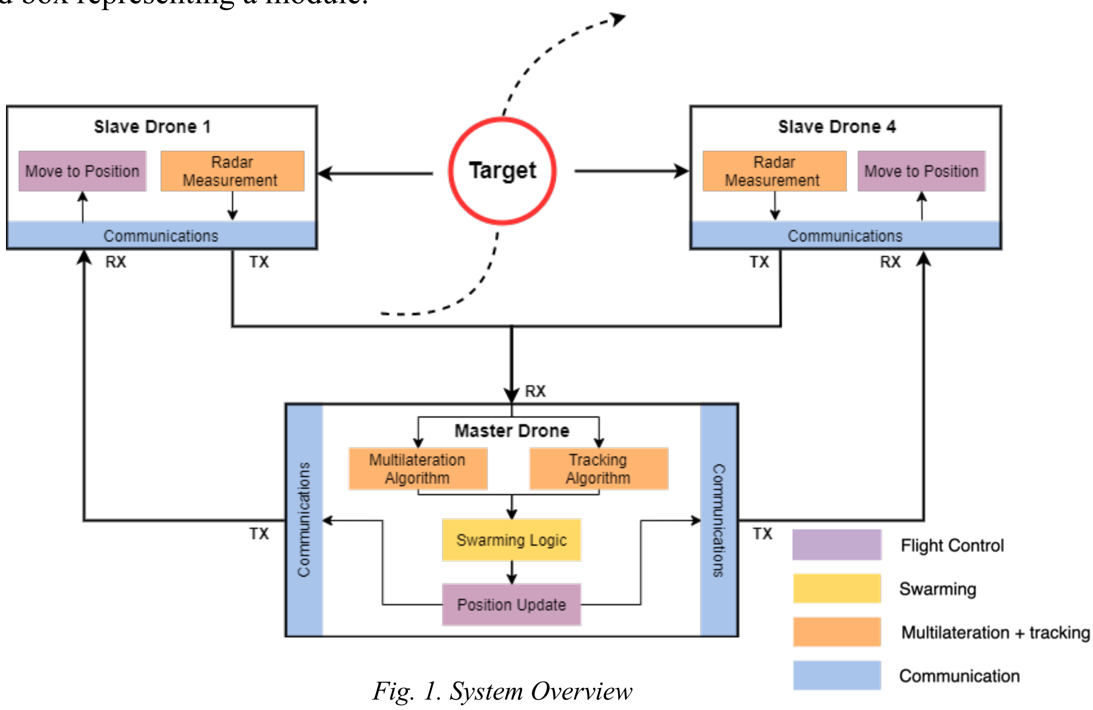

Fig. 1. System Overview

Multilateration – The first step is to simulate the radar ranges for each slave UAV based on the GPS locations of the drones and target. Using multilateration, the location of the target will be estimated in 3 dimensions. I will be focusing on this task.

Tracking – The tracking algorithm will take the multilateration location as an input and provide a more accurate estimate based off previous locations and physical limitations of the target path. This will also account for radar dropout and unsynchronised radar readings. Rowan Sinclair will focus on implementing this module.

Swarming Logic – The swarming logic determines the location for each drone to move to based off the determined target location. Connor O'Reilly will be responsible for improving this module, considering advanced dynamics of how the drones move.

Failsafe's – Formation checks must be implemented to ensure each drone is in a safe position, avoiding any collisions. Alex Scott looks to debug the formation issues experienced last year and further expand the functionality through implementing a computer vision based safe landing protocol.

Communication – For the entire system to operate there must be robust inter-drone communication. This allows the receivers to send current positions and ranges to the transmitter for localisation, responding with updated positions for each UAV to move to. Nicholas Ranum works to improve the communication network and implement suggestions left from the previous group.

Progress to Date

Introduction

To identify where the target is, each receiver drone samples a radar range reading. If the location of each drone is known, the location of the target can be calculated in 3-dimensions. The multilateration algorithm that was implemented in the 2020 project, was rudimentary and only operated in 2 dimensions. This introduced projection errors and did not take full advantage of all the radar readings from a five drone swarm. My primary role is to expand on this work, designing a system that is able to locate the target in 3 dimensions while still being computationally efficient.

To minimise the cost and complexity of each drone, there is only one drone equipped with a radar transmitter. This is the master drone and is located in the centre of the swarm. Radar signals are transmitted from this drone, striking the target and then received by the four surrounding slave drones. The multistatic radar arrangement is described in Figure 2. This type of formation is less popular and increases the complexity of the calculations.

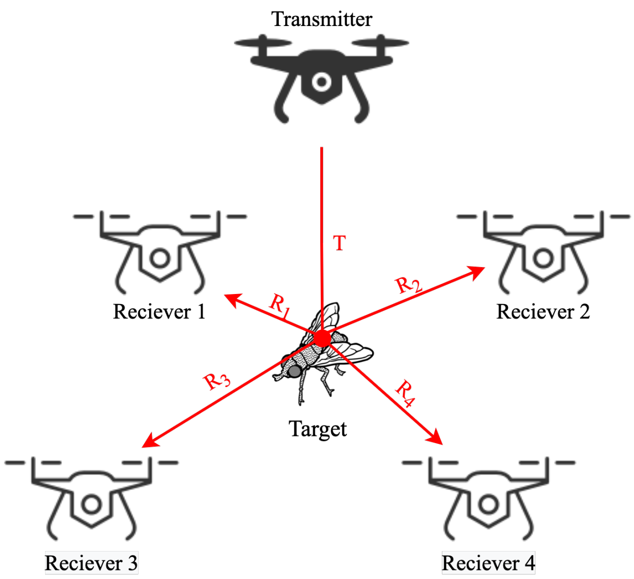

Fig. 2. Multistatic radar arrangement

The radar ranges that the four drones receive can be described by the following equation:

$$Range_i = T + R_i = \sqrt{(x_T - x)^2 + (y_T - y)^2 + (z_T - z)^2} + \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} \qquad (1)$$

Where (x_T, y_T, z_T) and (x_i, y_i, z_i) represent the location of the transmitter drone and receiver drone respectfully. The value of i ranges from 1 to 4, representing each receiver drone. The solution to these equations (x, y, z) represents the location of the target.

Previous Work

The previous method operated by first placing the drone locations on a 2 dimensional grid. By iterating through all of the grid locations, the corresponding radar ranges from each receiver are calculated. The real ranges received are then compared to the ranges associated with each grid location. The location on the grid that produces the smallest error between the ranges is deemed to be the location of the target. While this method proves to be robust, it is unoptimized, leads to projection errors and does not expand easily to 3 dimensions. Thus, I decided to take a different approach to locating the target, utilising the system of non-linear equations formed in equation 1.

Background research

Due to the unique arrangement of the transmitter and receivers, common conventional multilateration methods cannot be used. These methods assume the radar range is a simple time of arrival (TOA) measurement transmitted directly from the target. Because the radar signal received is not transmitted directly from the target, the range received consists of the transmitter-target path summed with the target-receiver path (Figure 2). This is a characteristic of the harmonic radar technology and outlined in requirement R1.1. Many common methods such as Bancroft's algorithm and Fang's method can only be applied to the trivial case of direct radar ranges ([6], [7]). The most popular methods used for multistatic arrangements (multiple transmitters or receivers) include Time Difference of Arrival (TDOA) and Time Sum of Arrival (TSOA). These methods both involve a system of non-linear equations forming intersecting hyperbolas for TDOA or ellipses for TSOA.

TDOA

To locate an object in 3 dimensions, the TDOA algorithm requires at least four receivers to operate [8]. This algorithm takes the difference between the radar ranges for each receiver, with each pair forming a hyperbolic surface. This eliminates the transmitter-target component that was a common path between each radar range. Where these surfaces intersect is the location of the target. For example, with four receivers, these three equations could be formed:

$$\begin{aligned} R_1 - R_2 = &\sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \\ &-\sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} \end{aligned} \tag{2}$$

$$\begin{aligned} R_1 - R_3 = &\sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \\ &-\sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} \end{aligned} \tag{3}$$

$$\begin{aligned} R_1 - R_4 = &\sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \\ &-\sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} \end{aligned} \tag{4}$$

TSOA

The TSOA method forms four elliptic non-linear equations to locate the target in 3 dimensions [8]. It is very similar to the TDOA method, however, this method does not subtract the common distance from the transmitter to the target. An elliptic surface is formed around each receiver, and the intersection of the four ellipses results in the true location of the target. As there are four equations and three unknowns, a least squares estimate can be used to determine the location of the target with the minimum error.

$$T + R_1 = \sqrt{(x_T - x)^2 + (y_T - y)^2 + (z_T - z)^2} + \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \tag{5}$$

$$T + R_2 = \sqrt{(x_T - x)^2 + (y_T - y)^2 + (z_T - z)^2} + \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} \tag{6}$$

$$T + R_3 = \sqrt{(x_T - x)^2 + (y_T - y)^2 + (z_T - z)^2} + \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} \tag{7}$$

$$T + R_4 = \sqrt{(x_T - x)^2 + (y_T - y)^2 + (z_T - z)^2} + \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} \tag{8}$$

Implementation and Testing

Both the TDOA and TSOA algorithms were implemented in 2 dimensions for visualisation and testing. Both techniques were able to locate the target with zero error if the range readings were 100% accurate. Noise was introduced into the system to test the robustness of each technique. This involves adding a random inaccuracy to each simulated radar reading with a gaussian distribution and standard deviation of 1. The estimated target location (black marker) and real target location (red marker) can be seen for each technique in Figure 3.

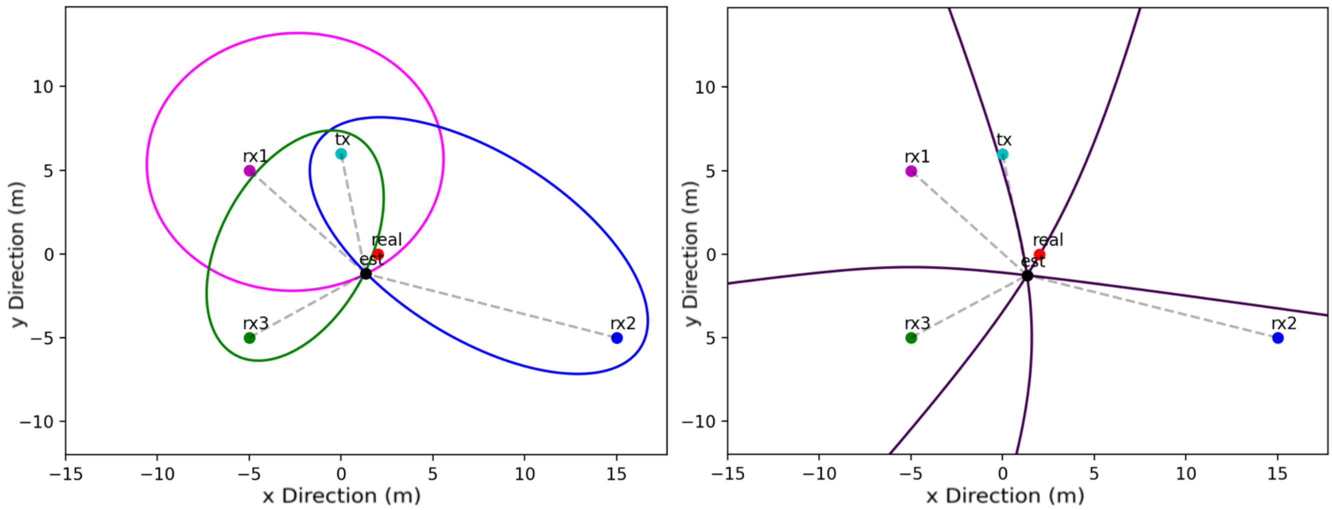

Fig. 3. Comparison of 2-Dimensional localisation techniques. (TSOA on left, TDOA on right)

Both techniques performed well, locating the target position within 1.5 m of the true location. The TDOA method was a magnitude faster than TSOA at an average computation time of 0.5ms and 5ms respectively. These algorithms were proven to be computationally suitable as the brute force method previously implemented took 2.5 ms. They also delt with noise which the previous method was not designed for.

Expanding the scope of the multilateration from the previous year, both methods were implemented in 3 dimensions. Again, both the algorithms were able to consistently locate the target with no noise. However, after adding noise to the radar readings the TDOA algorithm went unstable and the solution failed to converge. As the ellipses and hyperbolas went from 2D lines to 3D surfaces, it became harder to visualize the intersections and the impact of noise. Thus, because the TSOA method produced robust results it was selected for use. As previous studies have shown the TDOA algorithm to produce the best results, an attempt to linearise the equation was also made. These equations also produced inaccurate results and development was discontinued. It was initially thought that the algorithms would need to be optimised due to the size of the non-linear system of equations. However, after testing it appeared the TSOA was computationally suitable for real-time use and was therefore left in its original state.

To fully test the multilateration capabilities, a random target path had to be generated. The full location system first utilises multilateration to get an initial estimate, followed by a tracking algorithm to generate a more accurate location. Rowan Sinclair is developing the tracking portion of the project and is also accounting for radar dropout and unsynchronised radar readings. The tracking module involves a Kalman filter which requires certain path specifications to be defined. To ensure they path was realistic these were imposed in the path generation function and are shown in Table 1. The estimated position of the target over 2 minutes can be seen in Figure 4 and Figure 5.

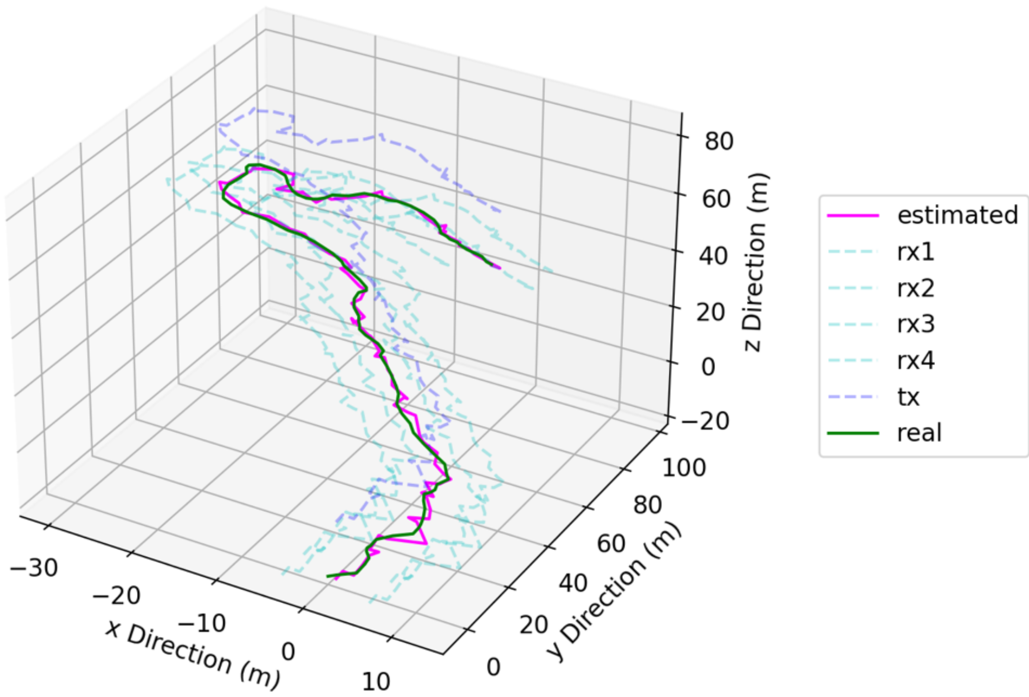

Fig. 4. Drone, target and estimated locations over 2 minutes

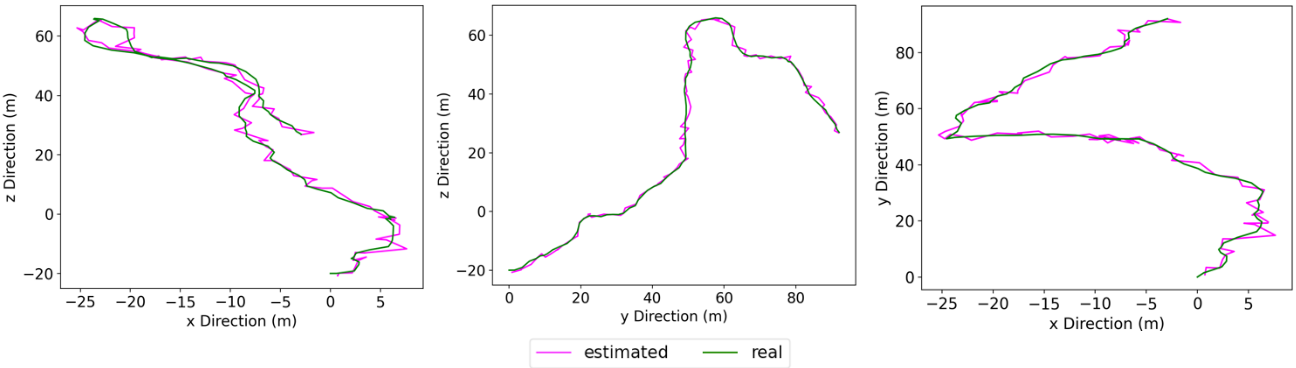

Fig. 5. Estimated target path in each plane of view

Table 1. Generated target path movement constraints

Specification	**Limits**
Velocity	3 m/s
Acceleration	1 m/s^2
Rate of acceleration	1 m/s^3
Horizontal rate of change	30 deg/s
Vertical rate of change	30 deg/s

Higher values simulate a more erratic and fast moving insect, while lower limits create a slower, gentle path. The sample rate of the multilateration was operating once per second. This was used last year, providing a good starting point for testing. The sample rate can be adjusted along with the path generation specifications, to further test the robustness of the multilateration and tracking.

The multilateration algorithm is able to calculate the location of the target with an average accuracy of 0.7m and takes 4.5 ms to compute. This was tested over 10,000 iterations. In Figure 4, the path of the drones followed the estimated target position by applying the swarming logic used in the previous project. This simply involves adding an constant position offset from the targets location to each receiver, forming a 10 x 10 m swarm flying around the targets location. Currently, it is assumed that the receiver drones are instantly able to move to the desired location after the new target location has been calculated. This is not an accurate representation of the dynamics of the system, thus will need to be further tested in the gazebo simulation and in the practical environment.

Simulation setup

While the multilateration was being developed, I also assisted with setting up and running the previous year's simulation. As the project was an extension on previous work completed, it was vital we spent time understanding the code and learnt how the modules of the system integrated. Nicholas and I both installed the Linux environment onto our personal computers and followed the readme instructions to download the required packages. Due to the poor quality of the readme file and the lack of information left behind, it was difficult to understand how the previous code worked. This was a very time consuming process, however, we have now achieved full operation of single and multicomputer simulations. The most complex simulation involves a laptop simulating four drones with a GPS module connected. The laptop is connected to the Wi-Fi hot stop of a Intel NUC, which is simulating one receiver drone. Through wireless communication between the laptop and NUC, the drones move in formation – tracking the position of the GPS in real time. This puts us in a position to achieve a practical test flight, recreating the final test the team did last year. With the simulation operating, the multilateration and tracking modules can also be incorporated for testing.

Summary

Overall, I have researched and tested an improved multilateration method that accurately locates the target in 3 dimensions. During the testing process, I implemented both the TDOA and TSOA algorithms in 2 dimensions and 3 dimensions, with additive noise on each radar measurement. As the TSOA produced the most robust solutions and was computationally efficient, it was selected for further development. I designed a target path generator that takes dynamic limits inputs, producing a random path for testing. The TSOA algorithm proved to be robust on a stream of locations generated. With the simulation now operational, the next task is to implementing the multilateration module into the previous code for further testing.

Group Timeline

The project has been split into four major milestones; Milestone 0 involves catching up on previous work done, milestone 1A achieves five drones flying in a swarm following a series of GPS locations, milestone 1B implements the new 3-dimensional localisation into the simulation, and milestone 2 brings these two separate subsystems together to form a fully functional system. An outline of completion dates is shown in Figure 6.

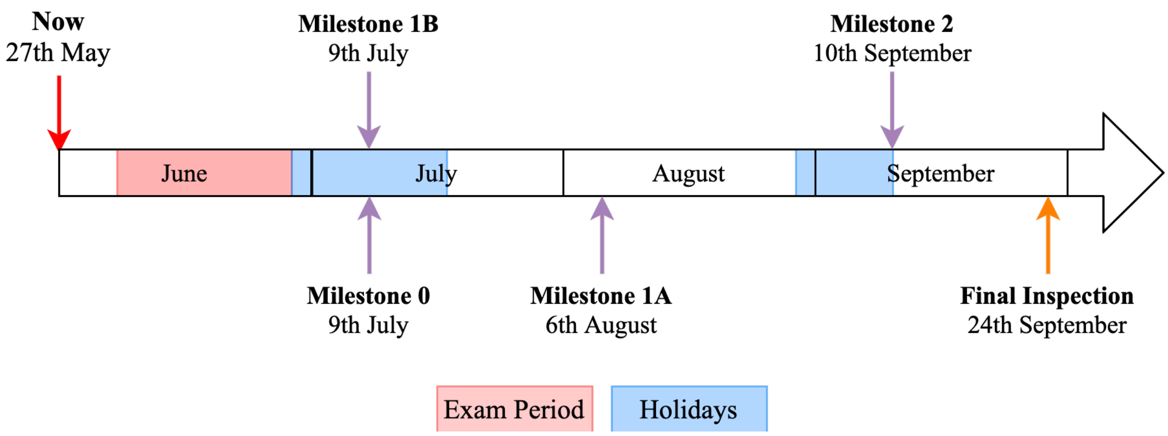

Fig. 6. Expected project milestone completion

Milestone 0: Getting up to speed

This milestone involves recreating the tests the group last year completed. Nicholas and I have successfully setup the gazebo and communication simulations. The next step is to recreate the physical test flights that were conducted. As there was a lack of data logging implemented, this will also be incorporated to ground truth the results. The following flight tests are as follows.

- **Test 1:** A single drone in the air following a GPS broadcasting target.
- **Test 2:** A single flying drone with 4 other drones simulated in gazebo, tracking a GPS broadcasting target.

- **Test 3:** Two flying drones and 3 simulated, tracking a GPS target. Last year, this practical test triggered a failsafe error which was unidentified.

Milestone 1A: Five drone swarm following a GPS

This milestone demonstrates the ability for five drones to safely fly in formation, following a GPS target. Each drone will receive the GPS location and move to the next required position, governed by the swarming logic. The communication will need to be improved as well as debugging the formation error encountered last year with two flying drones. Failsafe's will be implemented at this stage to ensure there are no collisions. This milestone will test the communication, flight control and swarming modules.

Milestone 1B: Tracking Implementation

This milestone involves emulating a target path and simulating the radar ranges based for each receiver drone. An estimate of the targets location is determined using multilateration, which is then passed into a tracking algorithm to provide a more accurate approximation. The mathematical models for these two modules has been tested, the next step is to implement these into the previous year's code for testing in the gazebo simulation. This system is being developed independently of milestone 1A.

Milestone 2: Full system implementation

This milestone involves combining the localisation and tracking modules developed in milestone 1B with the improved swarming and communication developed in milestone 1A. The end goal is a swarm of five flying drones successfully tracking a target with simulated radar readings generated using a GPS module. This could involve a person walking with a GPS module, as done for last year's demonstration. A stretch objective would involve the swarm tracking a small UAV flying with the GPS module attached.

Budget

Currently there have been no costs associated with the project. The equipment that will be used for the project is currently owned by the WRC. This includes the drones, ground control unit and Intel NUC's. The GPS module was purchased as part of the project last year and will continue to be used. There are no forecasted costs as the future tasks for the project only consist of software development.

Individual Tasks

In order to meet our milestones outline in Figure 6, we have delegated tasks to each member for the remaining period. To ensure we are on track to finish the project, it will be vital to complete both Milestone 0 and Milestone 1B in the upcoming July holidays. This will set us up well to begin implementing and testing improvements.

Table 2. Task breakdown for individual members to meet the milestone deadlines.

Week	**Milestone**	**Team Members**				
		Oliver Dale	**Rowan Sinclair**	**Nicholas Ranum**	**Alex Scott**	**Connor O'Reilly**
Mid-year Break	M0 and M1B	Implement multilateration module and test using sim.	Incorporate Kalman Filter and test using sim.	Improve simulation software, launch files, and plotting tools.	Test sim with two drones being held. Fight test with two drones.	Mothership-slave UAV dependencies, data logging.
1+2		Test robustness of localisation for integration.	Add Loss detection to Kalman Filter and calibrate for practical test.	Investigate the effects of adding artificial network delays / constraints.	Achieve two drones flying, prepare for M1A.	Account for inertia / drift, axial rotation around mothership.
3+4	M1A	Perform practical test.				
5+6		Integrate localisation module into improved communication and swarming code.	Improve tracking capability by measuring noise and reducing dropout.	Investigate methods of reading GPS timestamps to group radar readings.	Optimize landing function. Prepare for M2.	Improve swarming states, optimise code efficiency
Mid-sem Break	M2	Prepare for practical test.				
7	Prepare for Final Inspection					
8	**Final Inspection – September 24th**					
9	Analyse the flight test and inspection.					
10	**Oral Presentation – October 8th**					
11	Comment code, add README and associated files.					
12	**Final Report – October 22nd**					

Implement multilateration module

My next stage is to implement the multilateration module with the code from the 2020 project. This allows the module to be tested with the other subsystems in the gazebo simulation. So far, the multilateration module has been re-written to take the same inputs and outputs as the 2-dimensional method. The GPS coordinates of the previous target location and drones are taken as inputs and then converted to cartesian coordinates using the location of the transmitter drone as a reference point. For the module to be successfully implemented, minor changes will need to be made to the receiver and transmitter communication modules to include altitude values. The transmitter drone will also need to record the last estimated position of the target for an initial guess to be used in the next location calculation. Once both the multilateration and tracking modules have been tested to work in the simulation, a practical test will be organised ensure full operation.

Robustness testing

The multilateration algorithm needs to be rigorously tested to determine the breaking points of the system. This process is key, ensuring the test flight occurs under suitable conditions with the necessary failsafe's implemented. The testing can be separated into two sections.

Radar ranges – To avoid exact solutions when solving the non-linear system of equations, the radar readings had gaussian noise added. While this ensured the solution was a least squares approximate to the true location, the noise was not an accurate representation of inaccuracies with simulated GPS readings. Further research with the GPS module should be completed to provide a more accurate model of noise for testing.

Swarming formation – The accuracy of the multilateration is dependent on the formation of the UAV swarm. It appears, the multilateration calculations are the most robust when the transmitter is located above the receiver drones. Further testing should be done to check which formation provides the best results to further tune the swarming logic. If the target moves too far away from the swarm, the calculations also go unstable. Understanding this breaking point will be vital to determine how fast the target can move before the signal is lost.

Sustainability Analysis

Economic

The ability to gain more knowledge about small invertebrates provides economic benefits in environmental conservation and in industries, specifically agricultural and logging. An estimated $880 million dollars of native biodiversity is lost due annually to invertebrate pests [9]. In the agricultural industry, invertebrate pests are estimated to cause an annual loss up to $2.3 billion dollars [10]. The logging industry is also susceptible to economic damage from pests. Currently, 22% of the exported timber is required to be treated using a harmful and expensive pesticide, methyl bromide [11]. As the current methods of pest eradication are ineffective, there is a need for new pest reduction methods to be developed. This can only be obtained with a deeper understanding of invertebrates, which WRC aims to provide. [12].

As this technology is far from commercialised used, there are still significant forecasted development and research costs. Currently, there are initial, operational and maintenance expenses. The current swarm consists of 5 UAV's which have a total cost close to $100,000 NZD. Using the same drones, an effective deployment would require multiple swarms, increasing this cost. As the UAV's are battery powered, there will be operational costs to charge the drones. However, this is likely to be relatively minor compared to the initial cost. Finally, as the drones will experience wear in the harsh outdoor environment, there will be associated costs with replacement parts and units. Because pest eradication impacts billion dollar industries in New Zealand, it is expected that these environmental losses will be offset – producing an economically sustainable solution.

Environmental

The 1993 Convention on Biological Diversity and 2000 New Zealand Biodiversity Strategy outline the importance of environmental conservation and protection to New Zealand [12]. However, the current state of invertebrate conservation management has fundamental gaps, leading to 34.5% classed as either threatened or at risk, with another 1252 classified as 'data deficient' [1]. This demonstrates the lack of knowledge required to provide necessary conservation efforts. The current methods for gathering knowledge about invertebrate species are ineffective. They are often labour intensive and provide unreliable data. An example of this is the previously used marker technique. Insects are marked. with dye or coloured tags and then trapped in various locations, allowing a path to be mapped. Due to the difficulty of trapping insects and the bias introduced into the system (as traps are only placed in certain areas for surveying), this method does not provide sufficient information. This has led to a fundamental knowledge gap required for effective conservation management of these species.

Invertebrates are the most diverse group of terrestrial species, providing vital components for local ecosystems across the country. They play crucial roles in pollination, organic decomposition, energy transfer and reducing the spread of weed seeds [13]. Invertebrates are one of the few species that are able to break down the fundamental components for plant life, converting plant litter into layers of nutrients [13]. This project aims to provide tools to protect invertebrates, the native bush and natural ecosystem. The vision of this project closely aligns with the principles of kaitiakitanga. Kaitiakitanga is an important practice that outlines a sustainable way of managing the environment with underlying values in guardianship and protection.

Resulting from a lack of invertebrate knowledge, New Zealand's biosecurity is under threat from invasive species. Pesticides are becoming less effective, with some species developing biological resistance [9]. With stricter regulations, older pesticides are being phased out, leaving groups of invertebrate pests untreated. One example of this is methyl bromide, a pesticide used to treat timber before export. Methyl bromide is an ozone depleting gas and banned for use in 2020 [14]. The industry is looking for chemical free alternatives to protect exported and imported timber [14]. This project looks to provide a method for gaining this fundamental information to assist in developing a new pest reduction strategy.

Life Cycle Analysis

A Life Cycle Analysis (LCA) provides a method for determining the environmental impact of a project from start to end. The drones used in the project are designed by the local New Zealand business, Aeronavics. They consist of a carbon fibre frame with electronic components (Pixhawk flight controller, NUC processor, webcam, etc.) and a lithium ion battery. The electrical components require raw material extraction, leading to the depletion of finite resources and environmental pollution. While the drones are deployed in the environment, there is also a possibility of e-waste due to drone malfunctions, collisions and tag pollution. Efforts should be made to ensure correct failsafes are designed, and battery levels are sufficient to return home. Research could also be conducted to determine biodegradable tag alternatives. The electricity used by the drones will be sourced from 82% renewable energy generated in New Zealand [15]. At the end of the life cycle, it is vital that the correct recycling methods are enforced to reduce the impact of electronic waste.

While this analysis provides an insight into some of the environmental impacts, it is difficult to obtain information about the specific materials and manufacturing methods used to assemble the drones. A full scale life cycle analysis should be completed once the project is developed and ready for commercial use, allowing accurate conclusions to be drawn.

Social

Providing the ability to learn more about invertebrate species allows the development for new pest eradication methods. The previously mentioned pesticide, methyl bromide, exposes humans to severe lung damage and long term neurological damage [16]. There is constant pressure for non-toxic alternatives, reducing the harm to humans and their environment. The flying drone swarm has the potential to create noise pollution and disturbances in the outdoor environment. This is likely to disrupt the public, taking away from the serenity of many outdoor recreational activities. The drones also pose health risks to the public, with units or broken components falling from the sky. Due to the vast size of the New Zealand native bush, a viable solution involves placing the drones in areas inaccessible to humans. With further technological developments, it is also likely drones will become smaller and quieter.

Conclusions

The team is currently on track to achieve both milestone 0 and milestone 1B in the upcoming holidays. Working towards milestone 0 has been a time consuming process, taking longer than expected. It has required a deep understanding of the code to learn how each module operates and interacts within the program. The next stage for milestone 0 is to recreate the three practical flight tests conducted last year. In preparation for this, data logging will be implemented to allow ground-truthing of the flight. With a good understanding of the code, improvements can now be implemented in the communication and swarming modules, working towards milestone 1A. This milestone involves getting four drones flying in the air, overcoming a formation error that was triggered at the flight test last year. In parallel with this progress, the localisation module was completely rebuilt, allowing the target to be located in 3 dimensions. It is now ready to be implemented and tested within the simulation to meet milestone 1B.

The new localisation system consists of a multilateration (myself) and tracking module (Rowan Sinclair). The multilateration module uses a TSOA approach to locate the target in 3-dimensions. This method takes 4.5 ms to process which is comparable to the previous 2-dimensional approach which took 2.5 ms. During the research stage, both the TDOA and TSOA approaches were tested. In 2-dimensions, both approaches produced reliable and accurate results that were resilient to radar readings with gaussian noise. After expanding them to 3-dimensions, the TSOA remained stable, however, the TDOA failed to converge to a suitable answer. Hence, the TSOA algorithm was selected for further testing and development. The first step was to generate a target path that moved with dynamic restrictions. This was required to create a realistic path and also for the implemented Kalman filter designed by Rowan. The TSOA algorithm was tested using the generated target path, where the initial guess of the next location calculation was the previous location estimate. The multilateration remained stable and was able to track the target successfully. Further expanding on the localisation, the tracking algorithm developed by Rowan took the multilateration estimates and applied an unscented Kalman filter. This smoothed out the estimates to more accurately follow the true generated path. The new localisation system consists of multilateration and tracking modules, developed by myself and Rowan.

Future steps involve implementing the multilateration and tracking modules into the gazebo simulation. This will involve minor changes to the previous system to operate with altitude values. The robustness of the TSOA algorithm also needs to be tested. The breaking points are yet to be researched which will be vital for accurate failsafe's to be designed. Once the new multilateration and tracking modules are robust and compatible with the previous year's system, a practical test flight can be conducted. This will allow the localisation system to be merged with the new communication and swarming modules (milestone 1A) developed in parallel to meet milestone 2.

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