E25 Object Tracking using Drone Swarms

Academic Supervisor: Richard Clare
Student Name: Nicholas Ranum – 53147503 - njr89@uclive.ac.nz

Executive Summary

This project aims to produce a system of drones capable of tracking a moving, flying target. The project has been sponsored by the Wireless Research Centre, who aims to develop a harmonic radar system cable of fitting to small insects. Traditionally, animal movement and behavioural patterns have been researched with radio transmitters, however a major limitation to their use in tracking insects is their size and weight [1]. An innovative solution was initially proposed by Scion Research to develop the drone swarm capable of following insects and providing valuable information in their movements and behaviour. This project is a continuation of work completed by a 2020 final year project (FYP).

With over 4000 threatened or at-risk invertebrate species [2], the conservation of New Zealand's insect population is an important aspect of Kaitiakitanga. Over 4900 additional species are classified as 'data deficient' and so by providing a new tool to provide data on these invertebrates, the project contributes to the protection of these species. Additionally, the project may help identify behaviour of invasive wood-burrowing species that result in the need for timber fumigation in the countries timber export business [3]. New Zealand has committed to reducing the emissions of Methyl Bromide [4] used in this fumigation process, and this project may provide methods of information collection that can aid in the reduction Methyl Bromide fumigation.

The project consists of developing a drone system capable of following a moving target. The UAV swarm will consist of a transmitter drone and multiple receiver drones, that work in combination by sending radar signals, and capturing the reflections of these signals off the target. The 2020 FYP developed a simulation tool, which they used to demonstrate a working system of 1 transmitter drone and 4 receiver drones flying in formation based on emulated radar readings. I will work on improving this simulation tool to assist in the progression of the project. They were also successful in producing By using a number of receiver drones, the differences in the times of arrival for the radar signals at the receiver drones will be used to estimate the position of the target using a multilateration algorithm. These readings, in combination with the GPS coordinates of the receiver drones will be sent to the transmitter drone through a flying ad hoc network based on a WiFi hotspot. I will be responsible for ensuring that the communication protocols are efficient and robust enough to support the needs of the project. At the transmitter drone, a Karman filter will be implemented to remove uncertainty and aid in the tracking and prediction of the target movement. Currently, improved multilateration and Karman filter techniques have been implemented and are waiting to be tested with the simulation, followed by a demonstration with a test flight. The position of the target will be the centre location of the drone swarm, which will be enforced as a square surrounding the target. In addition, it is necessary to provide a means of obstacle avoidance, especially during the take-off and landing procedures.

Project Overview

As part of the E25 final year project, I have been challenged with participating in a project sponsored by the UC Wireless Research Centre with the objective of using a swarm of drones to track a moving target. The project is being undertaken as part of a larger proposal, initially sponsored by Scion Research for the intention of tracking invasive insect species in order to understand their behaviour and movement as part of a conservation effort. The use of a drone swarm is required in this scenario, because of the difficulty in conventional tracking methods. Traditional GPS locators are too large to attach to such insects, and so cannot be used to track the insects, so instead a harmonic transponder is equipped to the insects, which allows for radio communications within close proximity. This is the interface used by the drones to locate the insect, and it is the purpose of this final year project to develop a system of drones capable of reliably and safely flying in a formation based on the location readings developed through this interface.

Although the project was initially proposed by Scion Research, the Wireless Research Centre has decided to continue the project with plans of extending the work developed by our final year project to produce a more comprehensive model. As our project is a continuation of a 2020 FYP, our job is to continue the work they produced, ideally producing a more capable model and allowing for future projects to easily use what we develop in their solutions.

The solution requires developing a system capable of the following:
1. Controlling the drones to safely follow a target in real time.
2. Controlling the drones to fly in a ‘swarm’ around the target.
3. Calculate the position (and estimate future positions) of the target in real time.
4. Reliably communicate the information necessary to fulfil the above requirements.

These are the high-level requirements of the system, and we have not been given the technical specifications corresponding to the requirements. Rather, the aim of the project is to improve on the progress made by the 2020 project and get as close as possible to fulfilling these requirements.

My personal involvement is focused with requirement 4. In the initial project meetings, we proposed to split the work of the assignment similarly to how the previous FYP group had done so. With the help of our supervisor, we decided that my role in the assignment is ensuring that the communication within the system is suitable to allow for the reliable transmission of information between the drones. This role may widen from communication, to improving the simulation tools, and helping integrate the tools created by the other team members into the overall system. As a group, we intend on picking up where the 2020 FYP team left off, as they had many ideas on how to improve their project, but where unable to do so due to time constraints. The improvements to the tracking of the target have already been made by Oli and Rowan with an improved Multilateration algorithm as well as a Karman filter which produces quicker and more accurate estimations of the position and direction of the target. Alex has been working on investigating fail-safe methods to ensure the physical protection of the drones as we expand the number of drones in the air at one time. Connor has also been working on data logging methods, to enable the collection of data during our test flights.

Because this project has been inherited from a previous FYP, the project has had a significant amount of progress, leading to a successful flight demonstration where 4 drones (1 transmitter and 3 receiver drones) where simulated to fly in formation with a real drone, communicating over a WiFi hotspot. The drones followed a set of GPS coordinates produced by a GPS module on the laptop used to simulate the drones. This flight demonstrated the ability of the system to successfully multiliterate the position of the target based on emulated radar readings, follow the position successfully in formation, and communicate effectively between two machines. A successful implementation of the requirements listed above would be realised in a live demonstration of four drones flying in formation, tracking a target (likely a laptop) which emits a signal replicating that transmitted by a real harmonic transponder. A stretched goal, would be able to attach a radio transmitter to a 5th, smaller drone and use the same system to follow this drone as it flies in three dimensions.

Progress to Date

To this date, my entire progress has comprised of background research, investigating the previous years implementation of the project, and recreating the work done by the previous year. This has resulted in very little evidence of the work completed but I will attempt to give a detailed account of the research and work I did do. I have attempted to reach 9 hours of work each week from the beginning of this project, dedicating Fridays to complete this work.

If I was expected to perform 9 hours of work each week during the first time, in reality I performed closer to 30 out of 54 expected hours. Looking at my timesheet, I can see that around 10 of these hours was related to researching the project, 5 hours was performed on the project proposal, 5 hours was spent in team meetings, and the remaining 10 hours was performed attempting to set up a simulation created by the previous FYP team.

Background Research

I began by researching keywords and technology related to the project brief, and the 'Further Work' sections of the 2020 FYP final report. Research that grew from the project brief included gaining a better understanding of the purpose of the project through a paper co-authored by our project supervisor which describes the technology used to 'tag' insects [5], allowing for radar technology to locate the tag in three dimensions. This transponder technology generates a time-of-flight reading indicating the distance from a transmitter. Figure 1 demonstrates how this technology works with a transmitter releasing a radar signal and a receiver listening for the reply from the transponder.

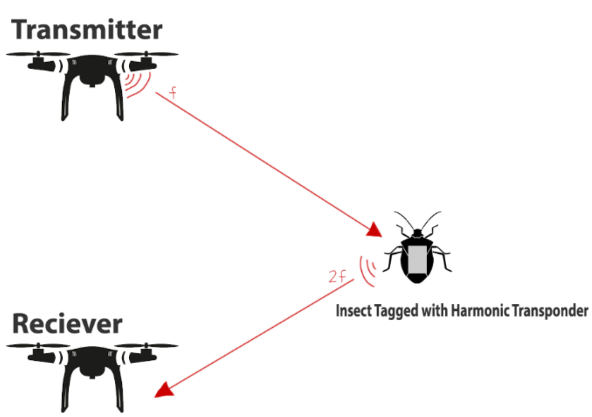

Figure 1. Transmitter and Receiver Interaction with Harmonic Transponder

This research into the transmitter receiver relationship is applicable mostly to the work related to multilateration and target tracking, however it was important for me to be familiar with the flow of information throughout the system to understand and work on the communications between the drones. Figure 2 shows how the system of drones is run with multiple receiver drones and Figure 3 gives a more detailed view into the architecture inside the drones. In this figure the transceiver drone is labelled as the ‘Master’ drone and the receiver drones are labelled as ‘Slave’ drones.

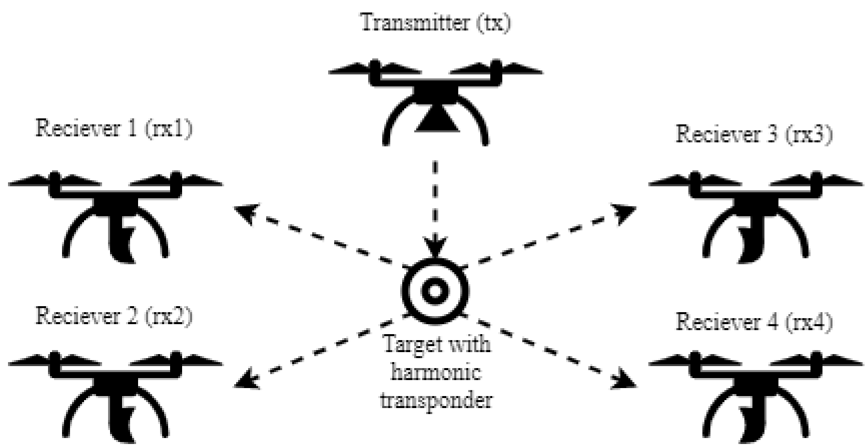

Figure 2. Transmitter and Receiver Drone Architecture

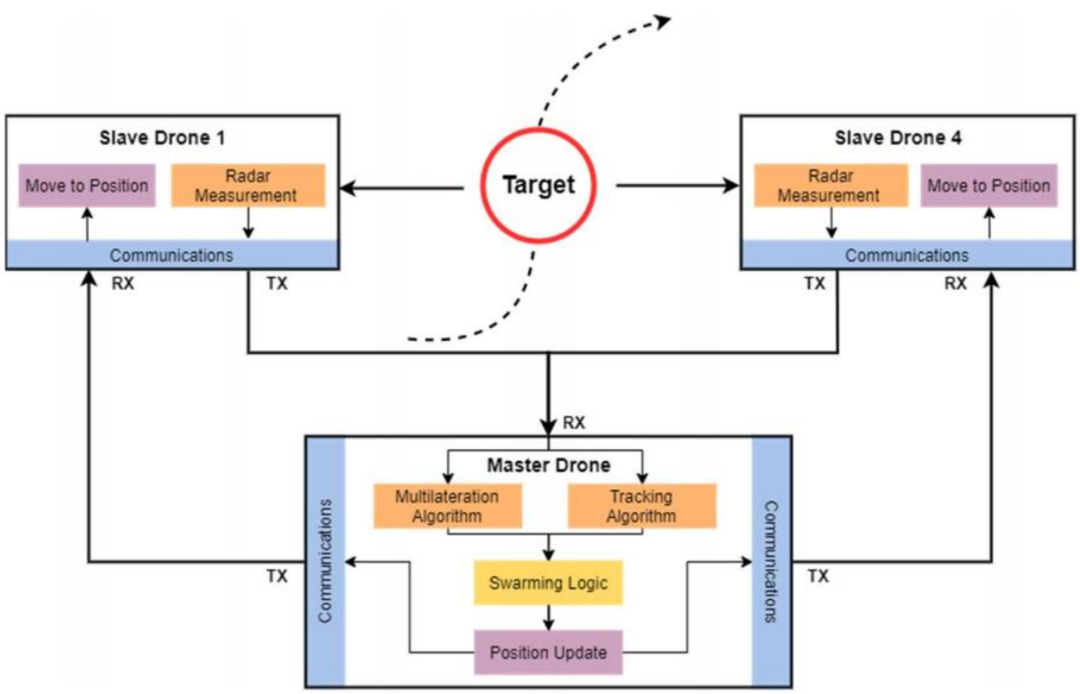

Figure 3. Internal drone Processing Architecture

In the second term, I was more determined to participate in the project and help the team move forward and reach our milestones. During a meeting in the first time, I had elected myself as the team member responsible for setting up and running the simulation created by the previous year as part of their project.

The simulation uses Gazebo as a physics environment and QGroundControl to provide flight control to simulate up to four drones following either a list of GPS coordinates or a live stream of GPS telemetry from a USB connected GPS module. On the 21st of May I was able to demonstrate the working simulation to my supervisors. Despite working on the simulation every week, numerous setbacks, bugs, and delays prevented me from finishing the work sooner. I will attempt to describe the process and approach that caused me to spend so much working towards running this simulation successfully.

Much of the time was following the research was spent attempting to set up the environment for the simulation. This involved installing Linux on my personal computer and following the installation guides written by the previous FYP group. On the last Friday of term 1, I was successful in obtaining the correct environment. This allowed me to run the Gazebo application, view the simulated drones, and gave me limited control flight including launching them in the air. I attempted to follow the README provided as it gave instructions on the steps necessary for launching the simulation, however I was still unsuccessful. I struggled to understand how to control the software and decided that it may be beneficial to attempt a multi computer simulation since I more instructions where available for this type of simulation.

The multi computer simulation runs a separate instance of *Rx.py* / *Tx.py* for each drone, however one of the receiver drones (running *Rx.py*) is running on a separate machine, and communicates to the other drones through a WiFi hotspot connection. This simulation experiment was tested by running three receiver drones on an Intel NUC, and the fourth receiver drone on a personal laptop. Both the NUC and the laptop will create separate instances of ‘run_drones.py’, which where initialised to launch with their respective number of drones and appropriate IDs for communication. The laptop also runs the program ‘server_data.py’ which pulls communicates the GPS coordinates of the target to transmitter drone on the NUC. A system diagram for this simulation implementation is included as Figure ##. The lines entering and exiting each of the programs represents the flow of communication through publish / subscribe style ZMQ sockets. The transmitter drone, *Tx.py* binds to a socket and with a process in *gps_data.py* and receives periodic updates on the location of the simulated target. Each instance of *Rx.py* similarly binds to a socket with *Tx.py*, and information is exchanged both ways. The receiver drones inform the transmitter of their current GPS location, which the transmitter drone uses in combination with the target location to calculate (using the multilateration and swarming logic) and transmit a new GPS location to the receiver drones. Each receiver drone receives a broadcasted packet over the socket connection, which is parsed and used in with the QGroundControl software to move the drones to their new location.

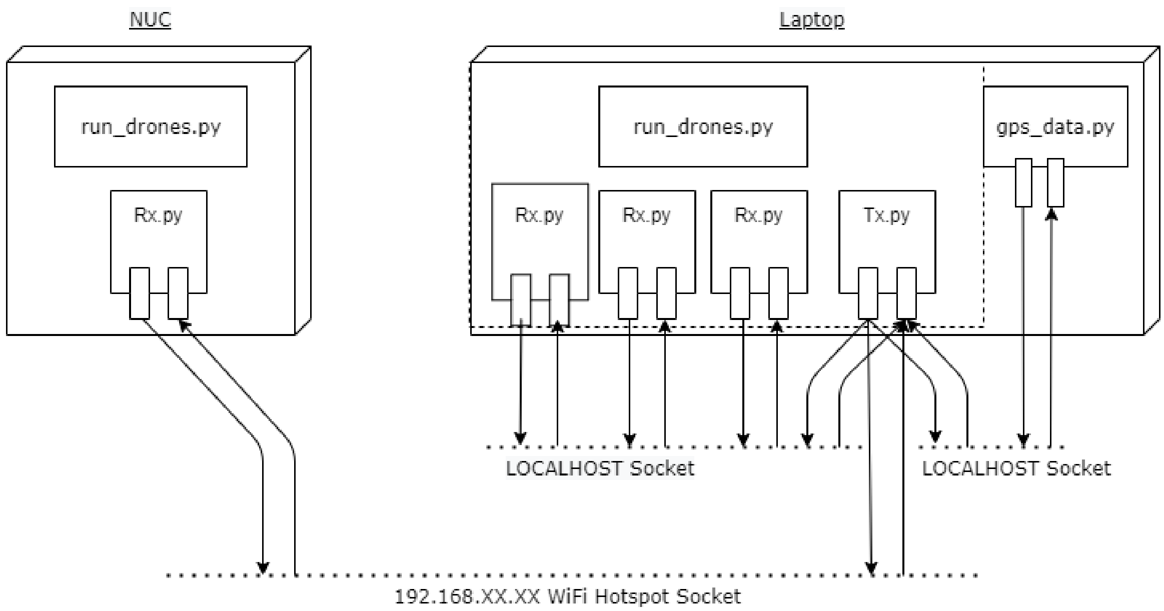

Figure 4. Multi-Computer Simulation Architecture

The first step in achieving this multi-computer simulation was installing the correct environment onto the Intel NUC. In the 2020 git repository, a second installation guide for Ubuntu 16.04 was included, and because the NUC was given to our group running this OS version, I followed the installation guide to set up the environment. Because I was only committing to working on my FYP on Fridays for around 9 hours, this step alone took more than a week to complete. The problem was compatibility between the necessary Linux installs and this now out of date operating system 'Ubuntu 16.04'. However, it was eventually possible to navigate through the error messages and I had fully set up the environment necessary to run the simulation.

The next step was to connect the laptop to the NUC through a WiFi hotspot. When this was attempted, the laptop was unable to see the network and hence was unable to connect to the NUC. I attempted to troubleshoot this and found no solution. As a result, I reached out to one of our groups technical supervisors Dave Van Leeuwen, requesting assistance getting the NUC's hotspot to work as well as helping clarify other errors that occurred during the environment installation. Dave's advice was to install Ubuntu 18.04 on the NUC and informed me that Ubuntu 16.04 was no longer supported by most Linux programs which was likely the source of the errors during installation.

After installing Ubuntu 18.04 on the NUC, I followed the installation guide one more time in order to have the correct environment set up. After doing so, the hotspot issue was resolved, and I was ready to test the multi computer simulation. However, after following the README instructions, the simulation still did not run. We discovered that the problem was the communication between the machine running 'server_data.py' (the laptop) and the other machine running multiple drones (the NUC). In the README file, it instructs the machine running ‘server_gps.py’ to change a parameter in *common.py* (a file containing shared variables for *rx.py* and *tx.py*) to the IP address of the machine hosting the hotspot (the NUC). When the files were cloned from the 2020 git repository, this IP address was initialised as some IP address that would have been used in 2020 before pushing to the git. What we failed to realise, is that for the machine hosting the hotspot (the NUC), this IP address should have been initialised as ‘localhost’. When this error was corrected, the simulation ran as intended. In hindsight, this error could have been avoided by more carefully inspecting the source code. Why it took so long to find this error, is that we followed the README file exactly, and assumed that errors where due to our implementation and installation.

Remaining Tasks

In the remaining time, our group will work towards the completion of milestones M0, M1A, M1B, and M2. The timeline of these milestones is shown by Table 1. Each of these milestones involve a practical test flight, and they represent the culmination of work done by each of the team members brought together in a real demonstration of our progress. Milestone M0 will be a repeat of the practical tests performed by the 2020 FYP project, including performing practical flights with one, and two real drones with the rest simulated. Milestone M1B will attempt to fly at least 1 drone, with newly implemented target tracking algorithms, as well as an increase in data collection and collision avoidance techniques. Milestone M1A will attempt to fly four real drones, along a predefined path (no need for target tracking), and the final milestone M2 will attempt to incorporate the new target tracking algorithms with four real drones (only transmitter drone simulated).

I will initially focus on ensuring the simulation tools are sufficient to reach these milestones. I also intend on investigate the thoroughness of communication protocols by developing testing techniques for the network. Finally, I will attempt to investigate a better method for grouping radar readings using GPS as a time synchronisation method. Now that I can use and control the simulation software, I intend on extending the functionality and improving existing aspects. The individual tasks I have identified are improving the current plotting methods, extending the command line interface, and developing a simple GUI, and creating new launch files to extend the capability of the software.

The current plotting tool generates a scatter plot of the target position, as well each of the drone positions during the simulation. It is useful for visually verifying that simulation is working. Currently however, the plot is produced in real time using the Python visualisation tool Matplotlib. In this implementation, a new scatter plot is drawn on each run of the *Tx.py* main loop. In the 2020 final report, Reka Norman noted that the running of this visualisation tool could take up to 300ms each time it was redrawn. This could result in the *Tx.py* main loop falling behind its deadline of 1s. I will investigate methods to reduce the time taken to draw this plot including using blitting techniques and experimenting with different libraries. In addition, I will consider the usefulness of this tool and whether it is necessary to redraw the plot on every loop. Perhaps it will only be necessary to draw the plot at the end of the simulation, or at least provide options for the user to choose.

To improve the usability of the simulation, I will also work on developing a basic GUI that enables the user to navigate through setup process easier. This will include removing parts of the system that are hardcoded, for example the IP addresses of the GPS positioning server and allow them to be changed easily from the GUI. Initially, I will incorporate and test them as command line arguments, and then extend this to the GUI. In addition, the GUI will give the user options on the configuration of the simulation, this will include which launch files are used. Currently, the launch files are strict on the number of machines used, number of drones used, and number of drones simulated on each machine. Increasing the flexibility of these decisions will allow for easier testing and verification of working simulation methods.

As we prepare for milestone M1A, it may be worthwhile investigating how the current communication system handles the increased number of machines in the network. The system runs on a 1s deadline cycle and delays in the communication of radar readings may result in a failure to meet this deadline. I plan on developing network testing tools that test the network in a number of ways, including introducing a noisy environment, moving the network at vehicular speeds, and introducing artificial delays. Depending on the results of these tests, it may be necessary to improve the existing architecture.

Towards the end of the project, I intend on investigating how to use GPS as a timestamping technique for grouping the receiver readings after they are sent to the transmitter drone. Current methods for groupings rely on basic sequence numbers, and so using a reliable source such as GPS, will be necessary to produce a robust system. The problem in this method is that the GPS module is connected directly to the PixHawk flight controller [6] rather than the Intel NUC, and so a method to allow the NUC to read the GPS timestamps will need to be discovered.

Table 1. Proposed Project Timeline

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 simulation with two physical drones being held. Full flight test with 2 drones	Improve mothership-slave UAV dependency sync correction software.
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 2 physical drones flying, look to achieve all four drones flying in formation	Account for large higher-order derivatives (inertia / drift). Axial rotation around mothership. UAV GPS coordinate double check
3+4	M1A	Perform practical test.	Perform practical test.	Perform practical test.	Perform practical test.	Perform practical test.
5+6		Integrate localisation module into improved communication and swarming	Improve tracking capability by measuring noise and reducing dropout.	Investigate methods of reading GPS timestamps to group radar readings.	Optimize landing function. Look to complete milestone 2	Improve swarming states, optimise code efficiency
Mid-sem	M2	Prepare for practical test.	Prepare for practical test.	Prepare for practical test	Prepare for practical test	Prepare for practical test
Break						
7	Prepare for Final Inspection					
8	Final Inspection – September 24th					
9						
10	Oral Presentation – October 8th					
11						
12	Final Report – October 22nd					

Sustainability Analysis

With respect to the Washington Accord Graduate Requirements [7], as a professional engineer is it necessary to demonstrate understanding of the societal and environmental impacts of my engineering work. This sustainability analysis will use the triple bottom line framework to assess the environmental, social, and economic impact of this final year project. This includes the impacts of this project in the grand scheme of New Zealand's effort to shift to increase the sustainability of our technology, as well as how our technology can be used to create sustainable solutions and alternatives to our current practices.

New Zealand is home to over 1000 threatened, and over 3000 at risk invertebrate species with more than 4900 more classified as data deficient [2]. With a total of 14,155 total species of invertebrate, the number of data deficient invertebrate is significant. This lack of information on the species, results in unknown risk with respect to the impact these species could have on the biodiversity and ecology of our country. Insects represent a large proportion of the country's biodiversity and play a crucial role in maintaining healthy ecosystems. Insects are essential links in maintaining plant communities, underground microbial communities, and detritus systems [8]. However, the full impact that insects produce in supporting the health of New Zealand ecosystems is still not understood [9]. By producing a new technology to track insects, this project is contributing to the process of animal conservation. Because of the small nature of insects, traditional insect tracking has primarily been done by trapping, and other passive tracking techniques [10]. Our project eventually aims to incorporate using harmonic radars that are capable of being fitted to insects [5]. This provides a novel solution to the problem of insect conservation and animal conservation. Moreover, the principal of kaitiaki is inherited by all of those who live in New Zealand. This principal includes the practice of environmental protection and restoration. The protection of our species and the conservation of our ecosystems is an important aspect of kaitiaki, and our project aims to fulfil this promise of guardianship.

Because this project is sponsored by the Wireless Research Centre (WRC), the incentives of this project are primarily to do with research development, as opposed to directly producing profit from our project. However, this is not to say that our project does not have an economic incentive and result. The WRC works with industry partners, and this project was initially sponsored by Scion, a Crown Research Institute company. A goal of the WRC is to "positively impact the economy and job growth" [11]. This project further supports the betterment of the New Zealand economy and our technology industry by purchasing the drones through the New Zealand business 'Aeronavics'. Supporting New Zealand engineering practices is also important for developing social growth through the hiring of New Zealanders in an expanding industry.

In addition to the potential environmental benefits, this project provides some social factors that benefit New Zealand people and businesses. As described, this project provides a new tool to help in the conservation of insects, the tool will be used by businesses and researchers. By providing people with an improved means of collecting information, this project makes a direct contribution to the people whose career and lives are spent focusing on these research areas. This project provides myself with an opportunity for learning and encourages me to explore opportunities in the development of conservation technology, as well as being a requirement to be accepted as a professional engineer. By providing me with this gain, I can produce work that is beneficial to the Wireless Research Centre without being exploited. This mutual gain can be further expanded between the Wireless Research Centre, and the New Zealand Department of Conservation. This social gain can be viewed as a chain linking me as a university student to the worldwide community through the contribution towards kaitiaki.

As well as supporting fields of conservation, the project may contribute towards better biosecurity information with respect to the exportation of timber. Methyl Bromide is used in the fumigation treatment process necessary for our timber export industry [3] . Methyl Bromide acts as an Ozone depleting gas and its use is currently being phased out in New Zealand with accord to the Montreal Protocol [4]. The technology produced by this project with provide an awareness of the movement patterns, survival, and dispersal techniques of invasive species and may provide insight into what fumigation techniques are necessary to remove the threat of exporting contaminated timber. In addition, providing technology for increasing the biosecurity of the country's export business creates social gain by increasing trust between New Zealand and its trade partners. Finally, this may also provide an economic incentive for international trade due to increased confidence in the biosecurity of the country’s timber export business.

Conclusions

My project contributions so far have been limited to working with the simulation software. Although I have felt that this progress has been slow and could have been avoided, now that I have successfully been able to run the simulation, I feel confident that I can make improvements to lift the effectiveness of simulation system.

These improvements will begin with developing improved visualisation tools that minimise the risk of missing the 1 second main loop deadline in *Tx.py*, removing the dependence on hardcoded variables, developing launch files to increase the flexibility of the simulation when running with multiple machines, and generating a GUI for the programs to run from. It is my hope that through these improvements, the simulation will be easier to control, and will allow for more thorough testing of launch scenarios involving more than two machines. In addition, improving the simulation software will also make it easier to integrate and test the work done by the other students, with respect to improvements in the multilateration and swarming logic that controls the flight paths of the drones. As the group approaches milestones M1A and M1B, I also aim to provide evidence that the current communication system is capable enough to support a network larger than two drones. This will include the variability of network latency, as well as how the system is able react to unexpected network delays. Finally, I wish to experiment with ways of integrating the drone's GPS module with the Intel NUCs in order to provide timestamps as an accurate means of grouping the receiver drone's range readings as they arrive at the transmitter (master) drone.

References

[1] S. M. B. L. David Mech, “A CRITIQUE OF WILDLIFE RADIO-TRACKING, A REPORT TO THE U.S. NATIONAL PARK SERVICE,” 2002.

[2] D. o. Conservation, *New Zealand Threat Classification System,* 2021.

[3] N. W. I. G. J. A. Stephen Pawson, “Reducing biosecurity business risks for logs and timber,” *NZ Journal of Forestry,* vol. Vol 29, no. No. 2, 2014.

[4] Ministry for Primary Industries , “iInformationon the biosecurity use of methyl bromidein New Zealand,” 2019.

[5] B. L. G. W. S. P. A. Lavrenko, “Design and Evaluation of a Compact Harmonic Transponder for Insect Tracking,” *IEEE Microwave and Wireless Components Letters,* vol. 30, pp. 445-448, 2020.

[6] A. D. Team, “UBlox GPS + Compass Module,” [Online]. Available: https://ardupilot.org/copter/docs/common-installing-3dr-ublox-gps-compass-module.html. [Accessed 30 May 2021].

[7] International Engineering Alliance Secretariat, *Washington Accord,* vol. REF 10175, 2014.

[8] C. G. Louie H. Yang, “Insects as drivers of ecosystem processes,” *Current Opinion in Insect Science,* vol. 18, pp. 1-7, 2014.

[9] Threatened Species Unit, Department of Conservation, “Threatened Terrestrial Insects: A Workshop to Advance Conservation,” *Threatened Species Occasional Publication No.6,* no. ISSN 1170-3709.

[10] A. Evans, *Introduction to Inverebrate Monitoring, Version 1.0,* Department of Conservation, 2016.

[11] W. R. Center, “About us,” [Online]. Available: https://www.canterbury.ac.nz/wrc/about/. [Accessed May 2021].

Progress Report Marking Sheet

Project Name: E25 Object Tracking using Drone Swarms

Student Name: Nicholas Ranum

All Individual Marks

Item	Weight	Mark out of 100
Executive summary	15	
Project overview	10	
Progress to date	30	
Remaining tasks	10	
Sustainability analysis	10	
Conclusions	15	
References/support	10	
Total weight	100	

Comments:

Overall Mark:

/100