Project Initiation Document

Word Count: 3240

(Excludes title page, contents page and appendices)

OCTOBER 2019

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Contents

1. Project background and purpose

1.1. Objectives

The main objective of this project is to develop algorithms to control the flight behaviour of a swarm of CrazyFlie drones. The purpose of these algorithm is to invoke emergent behaviours whilst the drones follow a given visual trajectory. These emergent behaviours allow the drones to avoid obstacles in order to prevent damage to either their environment as well as themselves and other drones.

- Primary Objectives
    - Basic control a single drone must be established, this will start with the basic movements such as height, forwards and backwards and left and right.
    - The drones flight must be stabilised by optimising the PID (potential, integral deviation) controller which is responsible for error correction. Without this stabilisation the drone may be liable to fly off course and out of control.
    - Whilst optimising the PID controller, qualitative research will be carried out to gain insight on the performance of different configurations.
    - After gaining an understanding of how to control a drone in 3D and optimising the PID controller, effort can be made to scale this up to multiple drones.
    - A map of the swarm's environment must be created and fed to a computer system which will allow the position of the drones to be tracked as well as the position of objects in the swarm's environment.
    - With a view of the swarm having a view of its environment, algorithms can be developed and tested with the intention to invoke emergent behaviour in the swarm. Without these algorithms, the swarm will have no means of navigating its environment.
    - Qualitative research about the performance of changes to the emergent algorithm will also be conducted.

- Secondary Objectives
    - Other threats to the integrity of the swarm may come from the environment itself. Despite the drones being tested indoors, simulating weather effects like wind are an important way to make sure the drones counter measures and error correction algorithms are robust enough to stabilize the swarm.
    - Qualitative research on other research papers on certain aspects of the project may be conducted.
    - Create more challenging environments to test the emergent properties of the swarm and the robustness of the emergent algorithm.

1.2. Scope

In order to allow the emergent behaviours to take place, the swarm will have a coherent view of its environment to navigate to a given position. As the drones do not have a way of viewing their environment themselves; this will be done using the Vicon vision systems. The system utilises a series of cameras and sensors positioned around the room which will track the position and motion of objects within the environment in 3D space. This data will then be fed to a computer system to act as the eyes for the individual drones, and therefore, the swarm. This will give the swarm the ability to understand its environment and make emergent decisions.

This project will not be using drones that have the ability to map their own environment. This is due to the CrazyFlie drones not having the size or weight to carry their own sensors.

For this project, unexpected external anomalies to do with the swarm's environment and the individual drones themselves will be accounted for. This is where the error correction capabilities of the PID controllers will come in to play. It will keep the drones stable during flight with the goal of keeping the swarm relatively uniform. If a drone deviates from the followed path, the path will be corrected mid-flight. This will apply during the take-off, mid-flight and landing stages of flight. The drones must also be able to remain stabilised and finish a test flight in simulated breezy conditions with light winds.

These drones will also not be tested outside in real weather conditions. This is due to the Vicon vision system only being permitted to be used in an indoor lab. Therefore, wind effects will be simulated using a series of fans.

As the PID controller is an imperative part of the drone's functionality and subsequently the entire swarm; tests of the different PID configurations will be carried out. Qualitative research will reveal the overall performance of the different configurations giving insight into how the controller works; as well as what configuration is most desirable. This will involve tweaking with the proportional, integral and deviation calculations to see the effect on the accuracy of error correction and the rate at which the error correction occurs.

During the development of the emergent algorithms, it will be important to discover and note down what methods work and do not work. Furthermore, this will aid in understanding the advantages and drawbacks of certain methods which will be crucial to improving the swarm's reliability and integrity. Like the PID controller, by the end of a test flight, the swarm must have reached it's intended destination without any collision. This would require the emergent algorithms to be robust enough to handle most if not all test scenarios.

Qualitative research on other papers covering an aspect of this project may be conducted. For example, researching the configuration of the PID controller in other similar autonomous vehicles may shed light on the advantages and disadvantages for subjective scenarios. In addition to this, comparing their conclusions to the requirements of this project may also help to optimise this project's solution.

Creating specific environments to challenge the swarm's emergent properties may reveal how the emergent algorithms react in certain subjective situations. It may also serve as a way of testing the robustness of the algorithm. Different environments can be created by putting certain objects that may be found in a real-world scenario such as larger plants and other obscure objects.

1.3. Deliverables

For the project to be successful, it must meet the primary objective as well as provide these deliverables:

- The project must deliver the source code for the algorithms responsible for the emergent behaviour of the swarm.
- The source code for the PID as well as the equations used must also be included delivered as part of the source code.
- A written thesis detailing the research conducted throughout the course of the project.
- To track the progress of the swarm's emergent behaviour, test flights after changes to the source code will be documented by recording videos of their flight. These videos will be uploaded to YouTube with a description of the changes made and saved to a playlist.
- A link to the video playlist will be included in the appendices of the project report. Links to specific videos may also be referenced through the report to add context to the behaviour described in the report.

1.4. Constraints

One of the major constraints is the reliance of the Vicon vision systems to build a 3D representation of the swarm's environment. The fact that the Vicon cameras are detached from the drones and are in stationary mounts around a room means that the drones will only be able to have a view of that room. This restricts the drones to only being able to operate in locations where the Vicon vision systems are set up making outside navigation impossible.

Another constraint is regarding the limited size of the CrazyFlie drones being used and their weight capacity during flight. The size of the drone makes it difficult to attach alternative modules such as onboard computers, distance and camera sensors without designing a custom circuit board. These sensors could help with the autonomy of the drones themselves and possibly eliminate the swarm's dependence on the Vicon vision systems. Removing this dependence may allow the drones to navigate in foreign environments where the Vicon vision systems are not set up.

Considering the limited size of the room the drones will be tested in, testing the swarm's emergent behaviour at high speeds may be unachievable. Moving at high speeds is likely to reduce the manoeuvrability of the drones, therefore, regulating to lower speeds may be necessary in the smaller closed environment. This constraint means that the full capability and limitations of the configuration of the PID controller and the emergent algorithms may not be realised.

1.5. Assumptions

Vicon vision systems are used to capture motion in numerous fields such as biomechanical, sports or animal science. An array of cameras is set up around a room to capture accurate live depth and positioning data. With these capabilities, live information about obstacles can be used to help navigate the swarm to its desired goal. Moreover, theoretically, it may be possible to navigate the swarm around moving objects in the same environment due to the live depth and positioning information fed by the Vicon system.

2. Project rationale and operation

2.1. Project benefits

A successful project would require that the swarm is able to navigate towards a given trajectory without running the risk of collision. This includes random objects in the environment, other drones, and in a real-world scenario, people. This project will serve as a proof of concept for real world deployment were the drones may have the ability to map the environment using onboard sensors instead of relying on the Vicon vision systems. Without this reliance, the drones would be able to venture in previously inaccessible environments.

Examples of these benefits could be seen in exploration missions in areas potentially too dangerous to humans to venture. Unmapped caves could be mapped out without risking human lives in fields such as geology and other environmental sciences. Rescue missions where natural disasters have taken place is another applicable benefit. Onboard computation and machine learning may be able to help locate victims of a natural disaster. Furthermore, swarms maybe able to help navigate rescue workers through difficult to reach places making rescue operations much safer.

Another applicable benefit for emergent swarms could be in the entertainment industry in places like concerts and shows. The swarm could serve as a light show, displaying mesmerising patterns and shapes above the audience. This would be assuming that the drones are reliable enough to not malfunction and fall into the audience.

2.2. Project operation

Considering many of the primary objectives for this project focus on requirements that would necessitate fine tuning in order to be met, prototyping appears to be an appropriate methodology to use. One reason for this is that the nature of emergence means that incremental optimisations are crucial for making progressive improvements. Other methodologies are less suited to this as they focus on defined requirements that do not require a significant amount of research and development or trial and error to fine tune.

The type of prototype method better suited for this project is the evolutionary prototype method. The definition this variation is that a prototype is built, tested and then reworked until and acceptable prototype is achieved. This allows the developer to understand the deeper functionality of the project by taking note of what when wrong and why. What's more, the developer has no need to waste time working on a separate prototype for each iterative development.

This sort of method works best for this project as whilst the requirements are known, the final solution, results or output can be unclear. For example, the configuration of the PID controller may produce admirable results which are in line with the requirements at an earlier evolutionary stage of development. On the other hand, improvements could still be made to improve accuracy and stability, although, the requirements for these improvements may not be clear. Methodologies such as agile and the waterfall method are best suited for projects that do not require iterative heavy development. Their progression is more linear more optimised for projects with less experimental requirements.

2.3. Options

There is a large community of developers working on the open source CrazyFlie platform. The more prevalent of these communities is Bitcraze. There have been alternate firmware implementations for CrazyFlie released on the Bitcraze site. AdaCore has implemented the CrazyFlie firmware in Ada as well as PX4 and Beta Flight. Unlike PX4 and Beta Flight, the Ada firmware is a re-written version of the original CrazyFlie firmware in SPARK instead of C. SPARK is built for high reliability software and mitigates the chances of runtime errors such as overflows and the reading of uninitialized variables. This is especially advantageous when writing software for flying vehicles like the CrazyFlie drone as software errors occurring mid-flight could prove devastating to the user as well as the environment and the drone itself. For these reasons, it is likely that this projects software will be written in SPARK with C.

The decision to use the CrazyFlie drones not only come from their modularity and open source platform, but also the community support. There have also been other projects researching large Nano-quadcopter swarms using the CrazyFlie drones. The developers have documented their justification for the use of certain methods and executions which may be referenced in this project and tested. The CrazyFlie drones open source platform and modularity make it a prime choice for developers. This is due to most other drones not giving users the ability to easily interface with their hardware and software making development a lot more open-ended.

For this project it is likely that access to a dozen drones will available to be used for the emergent swarm. This swarm count will ensure that the swarm is not small enough to give unreliable results; but not so large that the latency in communication due to the size will reduce the swarm's stability and reliability.

2.4. Risk analysis

Identifying and assessing the risks that may pose a threat to the project is crucial to finding ways of mitigating them. These risks may not be mitigated completely, but their effect on the project's progress and the likelihood of the risk occurring may be reduced. The likelihood and severity of each of risk also gives an idea of the impact these risks will have on the project. The likelihood is multiplied by the severity to give the potential impact. The likelihood is measured in three stages, for example:

- Low, Medium, High (1,2,3)
  - Big earthquake in the UK – Low likelihood
  - Hard drive failure – Medium Likelihood
  - Illness due to common cold – High Likelihood

The severity of a risk is measured in five stages and gives an estimated of how big of a consequence the risk will have on the project. Theses stages are:

- Very low – very high (1 - 5)
  - Very low – inconvenient; need to restore from backup; lose an hour's work
  - Medium – delay to project; final result affected
  - Very high – project failure

Risk	Mitigation	Likelihood	Severity	Impact
Drone Software or hardware malfunctioning causing it to fly off course and crash in to people or sensitive equipment.	• Raise safety nets around the designated air space to catch the drones if they fly off course	1	3	3
Computer failure	• Backup software to source control • Use the universities computers to continue the research	1	4	4
Illness	• Diagnosed and medicated as soon as possible	3	4	12
RSI (repetitive strain injury)	• Take painkillers to alleviate pain • time away from typing or typing intermediately • Cold packs, wrist supports, and splints can be used	1	4	4
Code becomes corrupted.	• Use source control and load from a from a previous revision • Backup code and documents regularly	1	5	5
Eye strain	• Intermediate computer uses • Reduce screen brightness • Tint screen red • Take regular naps • Sleep for a healthy amount of time • Pain killers can be used to numb the pain	2	3	6

2.5. Resources required

For the project to be able to be carried out, specific equipment will be needed.

- Computer
    - Access to a computer system, preferably a portable laptop, is a necessary tool when it comes to any software related issue in the project. It will be used for updating the drone's firmware, programming the emergent algorithms and configuring the PID controller. It will also play a crucial role in receiving the visual information from the Vicon vison system and wirelessly controlling the drones.
    - If a computer system, such as a personal laptop, is not available, access to the university's computers is available to continue research.
- CrazyFlie drones
    - These drones will make up the swarm that will be used to test the project's emergent algorithms and the PID configuration.
    - Without enough drones, the swarm's emergent properties cannot be accurately assessed. To alleviate this issue, it is possible to apply for funding from the university to acquire more drones.
- Vicon vision system
    - This system feeds visual data for the emergent algorithm to make decisions, without it, the drones would be flying blind and the emergent algorithm would not be able to make decisions.
    - If for whatever reason access to the Vicon vision system was not available or damaged, the university would need to be prompted to replace the system as soon as possible to mitigate the time lost.

3. Project methodology and outcomes

3.1. Initial project plan

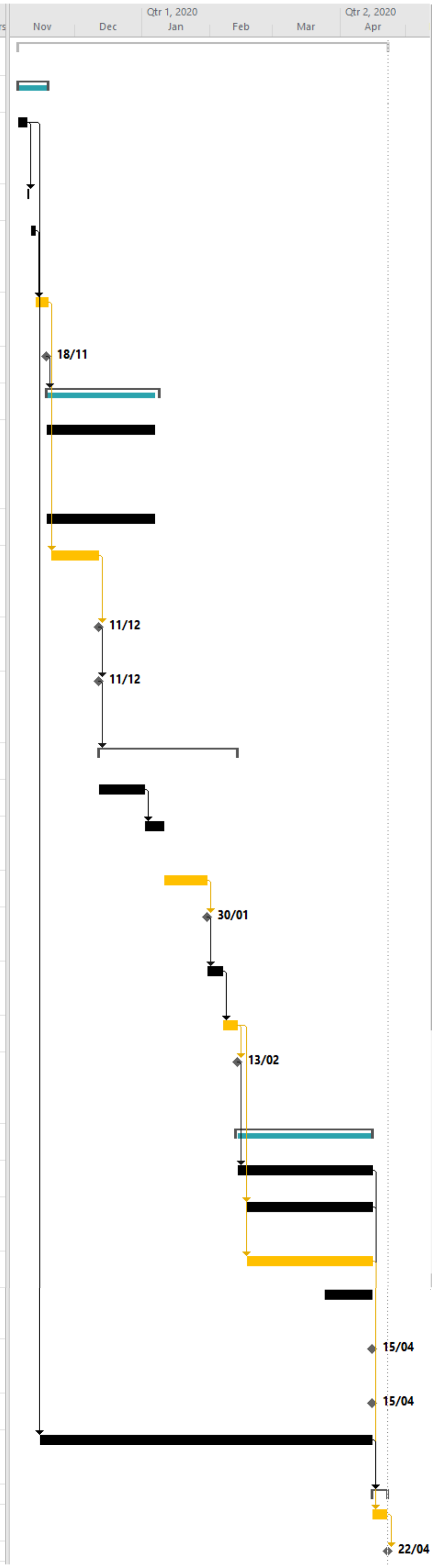
The tasks with an (M) in the are recognised as milestones.

3.1.1. Tasks and milestones

Tasks and Milestones	Detail
Install Software	• Install the firmware needed to control the drones • Install software needed for the Vicon vision system • Install the IDE needed to code the emergent algorithms • Install the software needed to interface with the PID
Create test flight air space	• Allocate a space for the drones to fly • Raise a safety net around the test flight space
Establish basic drone control (M)	• Understand how to move the drones in 3D space • Create test paths for the drone to follow
Configure the PID controller	• Whilst establishing basic control, optimise the PID controller to ensure the drones flight is stable • Whilst doing this, take note of the flight behaviour of the different configurations
Qualitative research on PID configuration	• Analyse other people's research on solutions for the PID configuration to help optimise the projects solution
Control multiple drones (M)	• Understand how to control multiple drones at once so control over the swarm can be established
Understand how to use the Vicon vision system software	• Learn how to use the system to stream the visual data to a computer • Interface the visual feed with the drone's code
Collision detection (M)	• Create collision detection code with one drone to test the Vicon vision system
Begin testing emergent algorithms	• Create basic test environment for one drone • Tell drones to follow trajectory • Gather data on algorithms performance • Scale up number of drones used
Qualitative research on emergent algorithms	• Conduct research on what makes an emergent algorithm robust and effective
Iterate on emergent algorithms (M)	• Continue development towards desirable performance
Create different test environments	• Create more challenging test environments to challenge the robustness of the emergent algorithms

3.1.2. Schedule Gantt chart

Task Name	Duration	Start	Finish	Predecessors
Research Project	**124 days**	**Tue 05/11/19**	**Wed 22/04/20**	
Set up for basic control of a single drone	**11 days**	**Tue 05/11/19**	**Mon 18/11/19**	
Install Software and firmware to the computer system being used and drones	4 days	Tue 05/11/19	Fri 08/11/19	
Create test flight environment	1 day	Sat 09/11/19	Sat 09/11/19	2
Establish host and receiver connection between drone and computer sytem	2 days	Mon 11/11/19	Tue 12/11/19	
Establish basic drone control in 3 dimensions for 1 drone(M)	4 days	Wed 13/11/19	Mon 18/11/19	4
Deliver basic drone control code	0 days	Mon 18/11/19	Mon 18/11/19	
Set up basic control for multiple drones	**38 days**	**Mon 18/11/19**	**Wed 08/01/20**	**6**
Configure PID controller's proportional, integral and deveation calculations	36 days	Mon 18/11/19	Mon 06/01/20	
Qualitative research on PID configuration	36 days?	Mon 18/11/19	Mon 06/01/20	
Establish basic 3 dimensional control scaling up the number of drones(M)	16 days	Wed 20/11/19	Wed 11/12/19	5
Deliver qualitative research on PID configuration	0 days	Wed 11/12/19	Wed 11/12/19	10
Deliver basic drone control code that can scale with the number of drones	0 days	Wed 11/12/19	Wed 11/12/19	11
Set up Vicon Vision System Control	**47 days**	**Thu 12/12/19**	**Thu 13/02/20**	**12**
Understand how to use the Vicon vision system	15 days	Thu 12/12/19	Wed 01/01/20	
Interface the Vicon vision system with a single drone	7 days	Thu 02/01/20	Fri 10/01/20	14
Collision detection code for a single drone (M)	15 days	Sat 11/01/20	Thu 30/01/20	
Deliver collision detection code for a single drone	0 days	Thu 30/01/20	Thu 30/01/20	16
Interface the Vicon vision system with multiple drones	5 days	Fri 31/01/20	Thu 06/02/20	17
Collision detection code for multiple drones (M)	5 days	Fri 07/02/20	Thu 13/02/20	18
Deliver collision detection code for a scaling number of drones	0 days	Thu 13/02/20	Thu 13/02/20	19
Develop emergent algorithms	**45 days**	**Thu 13/02/20**	**Wed 15/04/20**	
Prototype emergent properties for the swarm	44 days	Fri 14/02/20	Wed 15/04/20	20
Conduct qualitative research on emergent algorithms	42 days	Tue 18/02/20	Wed 15/04/20	19
Iterarte on emergent algorithms (M)	42 days?	Tue 18/02/20	Wed 15/04/20	19
Create different environments to test emergent algorithms	16 days	Wed 25/03/20	Wed 15/04/20	
Deliver qualitative research on emergent algorithms	0 days	Wed 15/04/20	Wed 15/04/20	
Deliver all emergent code versions	0 days	Wed 15/04/20	Wed 15/04/20	
Document data and experiments to be referenced in the thesis	110 days	Fri 15/11/19	Wed 15/04/20	2
Final submission	**5 days**	**Thu 16/04/20**	**Wed 22/04/20**	**28**
Proof read final thesis (M)	5 days	Thu 16/04/20	Wed 22/04/20	24,23,22
Deliver thesis	0 days	Wed 22/04/20	Wed 22/04/20	30



3.2. Project control

During the day to day research, the projects tasks will be kept track of using project planning software such as Trello. Tasks are displayed on software where progress can be intuitively monitored. If the deliverables are met before the deadline, project's progress will be considered successful. When it comes to source control, the code and various other deliverables will be backed up regularly. GitHub is a reliable method of source control as previous versions of uploaded software can be reclaimed. This could save the projects progress if, for example, the current source code revision becomes corrupted or is at risk of being lost. Another way to assess the successful progression of the project is by making sure the progress is inline with the Gantt Chart.

4. Appendix a

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