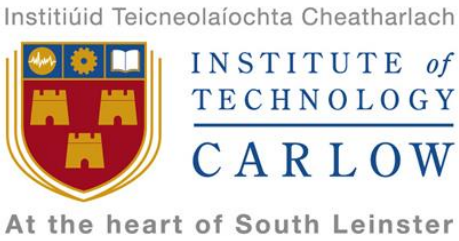

DRONE AIR TRAFFIC CONTROL SYSTEM

Research Manual

By

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Contents

Abstract

The number of drones globally in the previous few years has been increasing fast. There were 1.1 million drones in the United States as of December 31st 2017 and globally there were more than 3 million. During 2019 that number is expected to grow to 2.4 million drones. The increase in the sale of drones is largely since they are now less expensive, the camera and video capabilities are now better and because the drones are now easier to control. Drones are used commercially and by hobbyists worldwide. They have many uses such as aerial photography, aerial videos, monitoring premises, surveying land, inspecting agricultural land, delivery systems and many more uses (Sate, 2017). Drones have also been responsible for saving at least 133 lives worldwide. They have been successful in saving lives by delivering life vests to people in difficulty in water and by using the thermal imaging facility on drones to locate a person semi-conscious in a burning building (Lisb, 2018).

Section 1- Introduction

The name of the project is Drone Air Traffic Control System. It is part of a final year project in Software Development at Institute of Technology, Carlow. The project will consist of a control system for drones so they can fly on a flight plan from the source to their destination without any collisions and they will also fly unmanned. A drone is an unmanned aerial vehicle(UAV) that can be controlled by a person or autonomously(Rous, 2019). The drone that I will be using for this project is called the parrot bebop 2 drone. This research document will outline the research that took place during the project. The programming languages available during the project will be discussed to obtain the best fit for the project. All collision detection and avoidance mechanisms that are required to make the system function will be researched and determined which ones will be apt for the project. Frameworks, platforms, software development kits(SDK) and libraries will be researched to find the best fit for the project. Drone regulations will also be researched and discussed in order to see the legal infrastructure required to operate a drone in Ireland. During this research, other air traffic control systems that are currently available will be reviewed.

Section 2 - Objectives

The objective of this project is to create an air traffic control system to control drones while flying. Assuming fixed traffic routes, the system would coordinate the drones in that airspace in a safe manner. The drones would communicate their telemetry data such as GPS locations, speed, battery power and other data which is useful to the control system. The control system would then issue commands to the drone depending on what course of action needs to be taken, for example, if a drone needs to alter its speed or altitude to avoid a collision with another drone. An application must be developed which can be run on desktop computer or a mobile. Traffic routes must be defined, drone data must be received by the control system, the controller must implement a basic air traffic control algorithm and the drone must respond to commands issued by the controller. Discretionary goals are visualisation of the drone's routes in real time, access drone's onboard camera and display on screen, user interface for setting up flights and a drone that responds to commands issued by the controller. A stretch goal is to have a control system that can control multiple real drones.

Section 2- How Air traffic Systems work

Section 2.1 – US Airspace

The following section will detail how air traffic control systems work with aeroplanes concentrating on the United States. The different divisions which are involved in keeping an aircraft safe in the skies without any collisions with other planes or obstacles will be discussed. It will be discussed how the air space is split up into zones and how these zones are then split further. It will be discussed how each airport has a certain radius and that they are responsible for planes arriving and leaving in that air space

In the United States, there are about 50,000 aeroplanes in the skies each day. An air traffic control keeps these planes moving avoiding collisions and getting each aeroplane to its destination. An air traffic controller coordinates how these aircrafts fly to keep them safe in the skies. The air traffic controller keeps them safe by avoiding collisions with other planes, by avoiding dangerous weather conditions and ensuring take off and landing goes smoothly. The United States is divided into 21 zones. Each of these zones is then divided into further sectors. Within these zones there is a 50-mile diameter air zone called the TRACON(Terminal Radar Approach Control). Within this air space there are many airports, each airport further has its own airspace which measures 5 miles in radius.

The Federal Aviation Administration(FAA) overseas the air traffic control systems. There are many air traffic control systems divisions. These are ATCSCC, ARTCC, TRACON,ATCT and FSS. Air traffic controllers communicate with the pilots giving them instructions on the speed, altitude and other telemetry to keep them safe in the skies. The pilots get communications from many different controllers as the aeroplane flies through different zones. Each controller passes on information to the next controller. Pilots of commercial flights use instruments to fly which means that the aeroplane can be flown in bad weather.

Each pilot files a flight plan with the controller. This flight plan contains the airline name, flight number, type of aircraft, intended airspeed and altitude and the route of the flight. This information is reviewed by the fight data person and then enters the flight plan FAA host computer. A flight progress strip is created, and this strip passes from controller to controller as the flight progresses. A local controller is in the tower and he/she uses radar to plot aircraft to keep a safe distance between aeroplanes on take-off and landing. Once the plane is in the air, a transponder is activated, and this allows the flight data to be transmitted to incoming radar signals. The controller tracks the aeroplanes journey using the radar and will update the pilot with new information during the flight.

Section 2.2 – Irish Airspace

In Ireland the IAA(Irish Aviation Authority) is responsible for air traffic control. There are different types of air traffic control. There is aerodrome control which is responsible for traffic on the aerodrome ground and in the skies above it. The IAA is responsible for controlling the following airports Shannon, Dublin and Cork. Before the pilot can take off, he/she must file a flight plan similar to what happens in the US. When all of this been

approved by the controller the pilot is then cleared to take off. Once in the air the pilot then air radar controller.

The next type of air control is Approach Radar Control. In this type the controller is responsible for traffic that is around 30 to 40 miles from the airport. The traffic is lined up as it approaches the aerodrome. The aeroplanes will be separated by about 5 nautical miles. The controller separates the planes by communicating with the pilot to adjust their speed and altitude. Radar vectoring is used to separate the planes to ensure they line up properly for landing.

There are separation rules which aircraft must adhere to in Ireland too. They are for two different types of aircrafts. The two different types are IFR(instrument flight rules) and VFR(visual flight rules). IFR are all large passenger aircraft while VFR are smaller aircrafts. For IFR aircraft planes, they cannot come closer vertically to each other by less than 1000 feet and horizontally they cannot be any closer than 5 nautical miles. Aircraft cannot fly any lower than 1500 feet in built up areas or 500 feet in areas that are not built up (IAA. 2019).

Section 3-Drone Information

In this section I will discuss drones in general and the different types of drones available. I will also inform you about the specifications that the drone used in the project has and the functions that can be performed by it. I will also discuss how the drone can be controlled and discuss the frameworks which are involved in controlling the drone.

As mentioned in the introduction a drone is an unmanned aerial vehicle. Drones come in all different shapes and sizes. Drones have two types, rotor or fixed wing. Rotor types can have a single rotor or multiple rotors. Below it can be seen from figure 1 and figure 2 the differences between the two types of drones. They can range in weights from a couple of hundred grams to 5 kilograms. Drones have a GPS Module to keep track of its location, Electronic Speed Controller(ESC) to control its motor's speed and direction, Accelerometer which measures the drones speed, and an Altimeter to measure the drone's altitude and many other sensors like a thermal sensor or a sensor for measuring distance from an object (Rous, 2019).

Figure 1, fixed wing drone (Ques, 2015)

Figure 2, multiple rotor drone (Ques, 2015)

The drone used for this project is a parrot bebop 2 drone. It can fly vertically and horizontally. It can reach speeds of 37 mph flying horizontally and speeds of 13 mph flying vertically. It weighs about 500 grams and has a camera with 14 mega pixel capability and videos can be recorded in full HD. It has a GPS and visual tracking facility which can be used to return the drone to the pilot when needed. The drone can be controlled via the Freeflight app for an android phone in conjunction with the Parrot Skycontroller 2 and the cockpit glasses (Parr, 2019). The Groundsdk mobile is available to developers looking to create an app for IOS or Android. PDrAW is a video viewer for medias created by Parrot drones and Olympe which is a python framework is also available to developers. SPHINX is a tool available to developers which allows for the simulation of the drones.

Section 3.1- Drone Regulations

This section will discuss the regulations concerning drones being used in airspace. It will be discussed how the regulations differ from the UK, US and Ireland. Also discussed will be how the regulations are being currently changed to reflect the increasing number of drones in use. This section will outline registration of drones, locations in which drones can and cannot be flown and it will also be discussed what the drones can fly over and near.

In Ireland a drone must be registered if it weighs more than 1 kilogram. The drone must be registered with the IAA. In 2019 new drone regulations were published. This new regulation will be coming into effect in the next few years. Some of these regulations are no flying the drone over a group of people, for example, at a concert or a sporting event, not allowed to be flown within 30 metres of any person, vehicle or structure, not to be flown closer than 5 kilometres to an aerodrome, a drone must not be propelled over 400 feet above ground level, in civil or military airspace, over urban areas such as towns and cities and finally outside of your direct line of sight (IAA, 2019).

In the UK drone users must register their drone with the Civil Aviation Authority(CAA) if the device weighs more than 250 grams. The pilots must also take a safety test on drone safety. These regulations start on the 30th of November 2019. Pilots can potentially face fines of up to £1,000 if they do not complete the online tests or they don't register with the CAA. Geo zones are also being programmed into drones which prevents a drone from flying in restricted areas (Tillman M. 2019).

The US(United States) differs from the UK because in the US you only need to register if you plan to use the drone in restricted airspace such as near airports, stadiums and security

sensitive airspace. Also drone pilots in the US need to register their drone with the FAA if it weighs more than 0.55 pounds. A commercial pilot is a drone user which is paid to fly their drone or a pilot who sells the media collected from their drone (Tillman M. 2019).

Section 3.2- Known Drone Air Controlled Systems

In this section, it will be discussed what drone air traffic control systems are currently developed and it will also discuss what approach and what success these companies have had in getting their systems approved by the relevant authorities in their respective countries. It will be shown what market these systems are being used for and the dimensions and specifications will also be discussed.

Alphabet's Wing is a Google company. It has developed an app to control drones in airspace. It has built an air traffic control system that is like a system which guides aeroplanes safely through our airspace. The app is called OpenSky. It has already been approved by Australia's Aviation Authority to manage drones there. The app is available for IOS and Android devices. The app can manage drones, so they won't collide with each other or other obstacles such as trees and buildings. The Australian regulator claims that the launch in April was the very first of its kind. Wing is also working with the US Federal Aviation Administration to develop a drone delivery system Kitty Hawk(a flying car company) also has permission to launch a commercial enterprise in New Zealand. Other companies like AirMap and Iris Automation are also working on air traffic control systems (Hawkins A. 2019).

Wing's drone has a wingspan of 1 metre. It has fixed wings and propellers to help it navigate the skies. It has had 80,000 test fights over 3 years. It has developed working closely with NASA (National Aeronautics and Space Administration). It weighs 4.8 kilograms and has a length of 1.3 metres. It has many redundancies like extra batteries and extra navigation systems just in case something was to fail (Wing. 2014).

Another company which is also developing a UTM(Unmanned Traffic Managed System) is a small UK company called Altitude Angel. It has designed a collision detection system which means it can fly out of sight of the pilot without colliding with other drones or other property. The system analyses the route that the drone is set to take and cross references it with the flight plan for the drone and determines if there are any conflicts and if there are conflicts it issues a new flight plan. Conflicts are not just collision courses with other drones but also considers if the drone is flying into a restricted air space such as near airports (Butcher M. 2018).

Section 4-Technology Considerations

In the following sections, the research involved in this project will be discussed. The different platforms available to create a mobile or desktop application will be researched. The market share of each platform will be shown, and each platform will be discussed in detail. The programming languages available to create a desktop or mobile app will be discussed and the differences between these languages will also be investigated. The positives and negatives of each platform and programming language will be investigated. It will be investigated to discover how each language works and performs in different environments. Frameworks will also be discussed in this section especially frameworks used to create a mobile or desktop application. The Olympe framework will be investigated to discover what operations the controller can perform such as controlling the drone and using the video on the drone. The reasons for the research and what the outcomes of the research are will be outlined.

Section 4.1 - Platforms Researched

The platforms available for this project are Windows, Linux, OSX, Android and IOS. These platforms had to be researched to discover which platform best suited the project. Android is written in java and IOS is written in Swift. Android has a greater percentage of the market than IOS. In 2017 Android held 85.9% of the market globally (Rexaline S. 2018). On researching desktop platforms, it can be clearly seen that Windows has most of the market with 79.1% of the market place. OSX has 14% of the market and Linux has about 2% of the market in 2019 (statscounter, 2019). Windows is written in C and Linux is also written in C. Linux is open source which means that its code is freely available and can be modified but Windows is proprietary and its code cannot be altered.

Section 4.1.1 - Research outcome

From these investigations it can clearly be seen that windows' systems are the market leader as regards a platform. It would be advisable to have an app that can run on a Windows system. The app could solely run on a Window's system or it could be cross platform and run on multiple operating systems. If going down the mobile app route it would be wise to build an app for the android market as it has a large share of the market but once again a cross platform app could be used to run on IOS and android. For this project a desktop app would suit better because if the control system is used with multiple drones it would create a better user experience to have a larger screen to use and navigate. The platform to use initially would be Linux because the Olympe framework was tested in this OS. It can then be ported to another OS if required.

Section 4.2-Desktop/Mobile Frameworks

In this project an app must be created for mobile or for desktop. A desktop app is an app which runs completely on a desktop computer and a mobile app is an app created for a mobile device. The platform options for desktop are Linux, Mac and Windows and the options for a mobile app are android and IOS. Frameworks that can be used when creating a windows desktop app are the .net framework, Windows app development., Universal windows platform and windows forms. There are also frameworks that are cross platform, that is they work on multiple platforms such as windows and Linux. Examples of these platforms are Electron, Kivy, Haxe, NW.js, 8th and Enyo. These frameworks use different languages. For example, pyQT and Kivy both use python but NW.js uses JavaScript. Pygame is also a consideration as a cross platform framework. It is mainly used for creating games but could be useful for this project because the rendering of the map and drones is just like

the rendering of sprites in a game. The telemetry of the drone would be updated and then this updated telemetry such as GPS coordinates could be shown visually on the map using Pygame.

Section 4.2.1 – Research Outcome

From the research carried out on frameworks, there are different types of frameworks. There are frameworks for a specific OS and there are frameworks for cross platforms. It can also be seen that there are frameworks for desktop apps, mobile apps and web apps. For this project it would be wise to choose a cross platform framework to create a desktop app. A framework like PyQt, Kivy or Pygame would be apt for the project.

Section 4.3-Programmimg Languages

There are many different programming languages. There are low level languages and high-level languages. An example of a low-level language is assembly and an example of a high-level language is Java. Other popular languages are C, C#, Python and JavaScript. The most popular languages developing Linux desktop applications are C++,C#, Python, Java and JavaScript (Blair I. 2018).

C and C++ has better performance because it is a compiled language while Python is generally slower because it is an interpreted language. C and C++ are used for coding network analysis applications because speed is important for these types of applications. C and C++ also has wide platform support from Windows, Mac and Linux but C# is mostly supported only by Windows. C# is predominantly used in web, mobile and desktop applications. C# has a plus over C++ because C# has garbage collection, but C++ does not have this facility. Garbage collection is where the programming language manages the memory (EDUCBA. 2018).

Java is a high level, multi-purpose, object-oriented programming language. Java is a cross platform language and it will run on multiple platforms because it is compiled to Byte code first. Java can be executed on any computer if the JVM(Java Virtual Machine) is installed on that computer. The JVM contains the interpreter and the run time environment for execution of the byte code. Java is the programming language used in android applications.

Section 4.3.1 – Research Outcome

From the different programming languages available, Java, C, C++ and Python are the top languages currently. For this project any of these languages could be used but Python seems to be the better choice because the drone framework uses Python scripts and it would be easier to integrate the app if it was also written in Python. Frameworks which are written in Python are PyQt and Pygame. Either of these choices would seem like an ideal candidate for the job. Python is also relatively easy to learn, and it has many libraries.

Section 4.4 – Drone frameworks

Olympe is framework that provides a programming interface for the Parrot drone. This framework is written in python and it can be used to connect to a parrot drone and then control the drone's movements (Parrot 2018). The drone can be controlled via python scripts executed on a computer. Olympe can be used with physical drones or simulated drones using sphinx which is a parrot drone simulator. Olympe can be used to connect to the drone, send messages to the drone, check the current state of the drone, for example whether its landed or in flight, control the video recorder and to receive telemetry information from the drone such as speed and altitude.

Pyparrot is a python interface for the parrot drones. It was designed by Dr. Amy McGovern. It can be used to control the parrot mambo, parrot bebop and parrot mini-drones. There is a lot of information online which guides the user through installation, testing and the different functions that can be carries out through the interface (Amy McGovern. 2018).

Section 4.4.1 – Research Outcome

From reviewing the Olympe and Pyparrot frameworks, these frameworks will allow for the drone to be controlled and it will enable telemetry to be gathered from the drone such as the speed of the drone and the state the drone is in(i.e. flying or stationery). This framework could make it possible to track the drone constantly on its journey from source to destination using the GPS module. It will also be important when it comes to changing the drones flight plan if a collision is predicted to happen with the drone on its current flight path.

Section 4.5 Reasons for researching and perceived relevance to project

The reasons for researching programing languages, frameworks and platforms are to discover which language will be best used for coding the app, to find which framework will work best with the project and to evaluate which platform would best suit the project.

Section 4.6-What was discovered during research

During the research many different things were discovered. From the research Windows is the platform that has the greatest market share for a desktop application, Python is one of the most popular languages currently and that it can be used for a variety of purposes such as creating desktop apps and is used extensively in data science. During the investigations of frameworks, it was found that there are many frameworks in existence. There are frameworks that are solely for one platform and there are other frameworks which can be for multiple platforms such as Kyiv, Xamarin, QT, and Electron.

It was also discovered that the regulations differ from the UK, Ireland and the United States. In the United States drones only need to be registered if they are to be used in a restricted space such as near airports or military airspace but in the UK the drone needs to be registered if it weighs more than 250 grams. It was also found that new regulations are coming in 2019 and that they will be enforced in the coming years. Some of these regulations prohibits the use of drones near airports and the drones must not be flown within 30 metres of a vehicle or structure.

From the research, other companies were developing drone air traffic control systems. Two other companies which are developing a system are Wing and Altitude Angel. Wing is a Goggle company which has developed an app called Opensky. Opensky has been approved

by the Australian Aviation Authority to use their app to control drones in the Australian airspace. It has currently had 80,000 test flights in 3 years. Altitude Angel is a UK company which is also currently developing a drone air traffic control system.

Furthermore, I also discovered the Olympe framework which is a framework that provides a programming interface for the Parrot drone. This framework is written in Python. Through investigations, it was found that the install instructions for Olympe have been tested in Ubuntu 18.04 and higher. Olympe will enable the drone to be controlled and it will also make known the state of the drone, (i.e. whether the drone is flying or parked).

Section 4.7 - Investigation Outcomes

From investigations it has been discovered that a desktop application would be a good fit for the project. From investigating other air traffic control systems, it has been apparent that the controller will need constant data sent from the drone. With aeroplanes the controller is in constant communication with the pilots of the aircraft updating them on any changes in their flight plan that needs to be taken. These controllers monitor the planes location using radar. It is not possible to use radar with the drone, but GPS coordinates can be used to track the drone's location. This application will be used to control the drone, it will be used to set up flight plans and will also be used to receive telemetry from the drone. Through the drone framework it is possible to control the drone and it is also possible to receive the telemetry required. This project will aim to mimic an aeroplane air traffic control system. It will keep the drones moving in a safe manner with no collisions. The drone will need to be in a fit state to be added to the system. It will have to be able to get to its destination on the battery life it has, and it will also have to be controlled from the system. Linux seems to be the best choice for this project as the drone framework has been installed and tested successfully in Linux. The desktop app can be ported to another OS later if required . A framework could be used too create the desktop app. A cross platform framework such as Kivy, PyQt or Pygame would be a good choice for this project. The preferred language for the drone project would be Python as it would work well with the drone framework as it run s Python scripts.

Section 5- Collision Detection and Avoidance

Collision detection and the avoidance of the drones colliding is a large section of this project. Drones need to be added to the air control system and the paths need to be verified so they do not cross another drones flight corridor at the same time and thus a collision would occur. It would be logical for the drone with the greatest battery life to be the drone to alter their path as to avoid a collision. From figure 3 below it can be seen how the air traffic system will operate. The system will get constant updates from the drones on their position, altitude, speed and any other relevant data required. The air traffic control system can make changes to the flight of any of the drones if a collision is going to occur. The system controls the drones using the drone framework.

Already in practice in the aviation industry is a collision avoidance system called traffic System Avoidance System(TCAS) which all aeroplanes should be equipped with as a measure to prevent collisions. The system informs the pilot if the air craft is on a flight path

that would cause a collision with another aeroplane. If the distance between the planes drops to a certain distance the alarm is enabled and the pilots act to avoid a collision. This type of system could be implemented in the drone project if two or more drones' distance between them, with them on a collision course reduces to a set distance, a command can be given from the controller system to a drone or drones to take avoidance measures such as increase altitude. Aeroplanes utilise transponders to use the TCAS system. An aeroplane can ping another plane and this will give how close the plane is to the other plane (Engber D, 2006). Smaller planes can also use the VFR(Visual Flight Rules) system. It is a system which the pilot uses by simply being able to see other aircraft. When there are aircrafts on a collision course pilots must take certain procedures to avoid the collision (Plane finder, 2019).

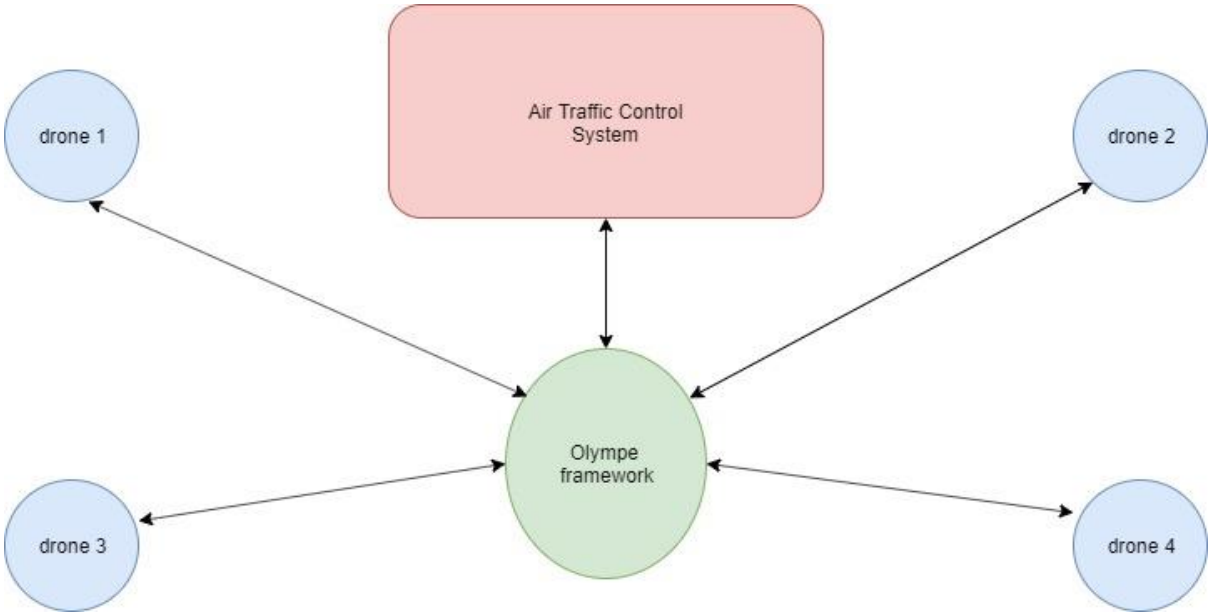

Figure 3 Proposed system layout

Section 6-Conclusions

Through the research carried out there are many different languages which could be used, possibly Python ,Java, JavaScript or C++. There are also many different frameworks that could be used depending on the programming language used. For example, if using Python Kivy, PyQt or Pygame could be used as a framework. If creating an application using JavaScript Electron could be the choice. Whichever framework is chosen to create the app, it needs to be able to be integrated with the Olympe framework which will be used to control the drone and this framework will also be used to collect telemetry from the drone. From the research carried out, a desktop application seems to be the better choice over a mobile application because the greater screen size would make it easier to manage multiple drones.

From the research, it was also concluded that the most suitable platform would be Ubuntu as the Olympe framework was tested successfully installed on that platform. From research it was also determined that a suitable detect and avoid algorithm is required so the drones to navigate the airspace safely. Currently aeroplanes use the TCAS system as a detection and avoidance system. A distance is kept from other aeroplanes and if this distance is reduced to a certain distance an alarm sounds in the cockpit of a plane to warn the pilot. A similar system could be used to alter the drone's path when they come into a certain range of another drone. There are many types of editors which could be used during this project. Visual Studio Code is familiar to the author and has many extensions that can be added so it might be reasonable to choose Visual Studio Code.

Glossary

SDK-A software development kit (SDK or devkit) is typically a set of software development tools that allows the creation of applications for a certain software package, software framework, hardware platform, computer system, video game console, operating system, or similar development platform.

OSX-Operating System developed by Apple Inc.

IOS-Internet Operating System

ATCSCC-Air Traffic Control System Command Centre

ARTCC-Air route traffic control centres

TRACON-Terminal radar approach control

ATCT-Air traffic control tower

FSS-Flight service station

FAA-Federal Aviation Administration

IAA-Irish Aviation Authority

CAA-Civil Aviation Authority

TCAS-Traffic Collision Avoidance System

VTR- Visual Traffic Rules

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