A Model for Precision Aerial Drops from UAVs

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2021

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A dissertation submitted for the Degree of Master of Computer Science

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DECLARATION

I hereby declare that the thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis. This thesis has also not been submitted for any degree in any university previously.

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This is to certify that this thesis is based on the work of Mr. W.C.S Arangala under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certified by,

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Signature of the Supervisor & Date 30th Nov 2021

I would like to dedicate this thesis to my parents.

ACKNOWLEDGEMENTS

First, I would like to thank my research supervisor, Prof. G.D.S.P. Wimalaratne. This study would never accomplish without his supervision and guidance, and engagement at every step throughout the year.

I would also like to give my gratitude to my friends who have helped me a lot in different ways, especially Mr. Salika Thilakaratne, Mr. Nishan Gunawardena, Mr. Shalika Weerasinghe, Mr. Namal Jayasooriya, and Mr. Muditha Arambepola for their assistance in making this dissertation success.

Finally, none of this could happen without my family. My dearest mother, father, and sisters guide me through this study and for unending inspiration.

ABSTRACT

With the advancements of the technology world, unmanned aerial vehicles (UAV) or drones have become more prevalent in the community. It has been evolving since World War I from generation 1 to the 7th generation. UAVs have become one of the necessary items across all industries. UAVs have many practical applications, and UAVs used in humanitarian missions are one of them. UAVs have been used in humanitarian tasks such as finding trapped persons, delivering test samples to the lab, delivering medicine to remote areas, etc. In humanitarian missions, precise dropping is a crucial point. This research focuses on an autonomous and manual precision drop of payload. The precise drop is more critical when a UAV cannot land and deliver necessary items to the people who suffer from humanitarian missions. The main objective is to calculate the release point of the payload and drop it to the measured target point. Factors that affect payload drop-off are the velocity of the UAV, drag force experienced by the payload, wind, and gravity. After considering these factors, this thesis proposed an algorithm using a mathematical model for precise drop and finding the target. The pre-calculated release point was unsuitable because dynamic variables like the wind will make the error to the actual release point of the payload. To overcome those challenges using the proposed mathematical model, implemented an algorithm to calculate the release coordinates of the payload to drop to the given target on-air and another algorithm to find the target location where the payload drops from the current location of the UAV. For the first algorithm, the ground controller can configure whether the payload can be automatically dropped or not. If it is automatic, then the signal is sent to the servo motor to release the payload. If configured to manual drop, the ground controller gets a notification saying release the payload if the UAV reaches the release point. For the second algorithm, the user receives a mapped area once the user presses the configured button to request the target dropping location of the payload. This algorithm is implemented in a Raspberry Pi. There is designed hardware equipment to carry payload using fibreboard, propellor, and a servo motor. This approach was only tested in Software in the Loop (SITL) and evaluated the results but did not evaluate the real world due to the COVID-19 pandemic.

Keywords: UAV, Precise Drop, Aerial Drop, Humanitarian Missions, Drone, SITL, JPADS, Digital Elevation Model

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List of Abbreviations

UAV	**U**nmanned **A**erial **V**ehicles
IoT	**I**nternet **o**f **T**hings
UNICEF	**U**nited **N**ations **C**hildren's **F**und
JPADS	**J**oint **P**recision **A**irdrop **S**ystem
AGU	**A**irborne **G**uidance **U**nit
PWM	**P**ulse **W**idth **M**odulation
SITL	**S**oftware **i**n **t**he **L**oop
DEM	**D**igital **E**levation **M**odel
GCS	**G**round **C**ontrol **S**tation
MOCAP	**M**otion **o**f **C**apture

Chapter 1: Introduction

Unmanned Aerial Vehicles (UAVs) have been rapidly growing technology for the past few years. UAVs have many use cases, and they have become central to the functions of various businesses and governmental organizations (Statista, 2021). Using UAVs is productive and cost-effective, and it improves accuracy and decreases workload and production cost. UAVs have multiple useful features such as unmanned cargo transport, express shipping, delivery, aerial photography for journalism and films, UAVs used in agriculture, building safety inspections, etc. (Custers, 2016)

However, with recent advancements in technology, UAVs have been transforming humanitarian efforts. Today these applications are quite common in sustainable development and disaster relief. UAVs are ideal candidates as first respondents in a time-critical crisis as they can reach areas you cannot quickly get to by other means of transportation. Delivering supplies to flood-trapped victims and delivering necessities to quarantine people due to the Covid pandemic are examples of this. (LIRNEasia, 2020)

The payload drop-off approach that commercial UAVs have practiced fits well in such situations as UAVs do not need to land on the ground. Precision is critical on a payload drop-off to ensure the success of a humanitarian mission. It depends upon multiple parameters. This research aims to introduce a drop-off algorithm with high accuracy with the vision of supporting humanitarian causes.

UAV shipments have increased rapidly, and the predictions are to ship 1.3 million units by 2023. In 2019, UAV shipments made for Construction monitoring were 141100 units, and UAV shipments made for fire service monitoring were 32700 units. There were 31800 units shipped for the use of insurance investigation. Moreover, 26800 units were imported for the police. There were 12900 units shipped for retail users, and 106200 units were dispatched for the other use cases (Statista, 2020).

Forecast for the year 2023 shipments for construction monitoring will be 509500, and it is around 400% growth according to 2019 statistics (Statista, 2020). The fire services monitoring forecast will be 67000 units, and it is almost doubled according to 2019 statistics. For insurance investigations, the estimates will be 135800 units, and for the use of police evidence gathering estimates, UAV units will be 80700. The forecast for other use cases will be 356500 units. These statistics will help to understand how fastly the UAV market is growing.

1.1 Motivation

The world has changed with the development of humanity. Unfortunately, global economic growth has adverse effects on the natural ecosystem. Therefore, natural disasters are increasing over the period in the world as well as in Sri Lanka. (UNICEF Sri Lanka, 2018) According to the 2018 UNICEF report, 96% of disasters in Sri Lanka were caused by climates such as flooding, landslides, extreme winds, and droughts. According to the Global Climate Risk Index, Sri Lanka was ranked fourth most climate changed country in 2016. Further, heavy rainfall during the southwest monsoon period in 2016 and 2017 caused widespread floods and landslides in southern and western regions. Over 500 people were killed (UNICEF Sri Lanka, 2018) (including 191 people still reported as “missing” in official documents), and over 1.3 million people were affected during the two years.

At present, essentials are supplied to victims where traditional transportation can reach. Emergency units currently have no established mechanism of reaching out to a trapped survivor during a search and rescue mission. Introducing UAVs as first respondents to a crisis can positively change humanitarian missions in Sri Lanka, especially considering the varied geographical terrain making it difficult to reach certain places using traditional means during natural disasters. For emergency response, UAVs can be quickly deployed from a distance to monitor and assess incidents by flying above areas of interest, such as areas prone to floods, forest fires, and the current pandemic situation due to Covid. This precise drop-off mechanism will be beneficial for delivering items for quarantined people and delivering items to isolated areas, etc. In addition, applications of UAVs are helpful in such time-critical events and can be considered a low-cost method to provide essentials in such circumstances.

1.2 Problem Statement

UAVs (Unmanned Aerial Vehicle) are aircraft guided autonomously, by remote control, or by both means and carry some combination of sensors, electronic receivers and transmitters, and offensive ordnance. Existence of UAV dates from centuries of years. The earliest recorded use of a UAV dates back to 1849, when the Austrians attacked the Italian city of Venice using unmanned balloons loaded with explosives (Blom, 2006). Regardless of the innovative approach of this historical event, balloons are no longer considered UAVs under modern criteria.

Inspired by the incident, military research and engineering paved the road to advancement in UAVs. Looking back at many wars the world has faced, UAVs have played a significant role in strategic, operational standing on the battlefield. In 1935, the British developed “Queen Bee,” a radio-controlled target UAV that used “drone” for radio-controlled unmanned aircraft. (Vyas, 2020) Later in history, UAVs extended beyond military application and took a turn into recreational purposes. The breakthrough in UAV history was when the FAA officially issued the first commercial UAV permit in 2006. Despite the slow start of commercial applications, today, UAV usage has boomed.

UAVs today are an emerging trend in many industries such as Agriculture, Chemicals, Delivery, Mining, Filmmaking with their versatility and low cost. For example, Amazon is experimenting with Prime Air, a UAV delivery intended to deliver packages up to five pounds within thirty minutes. UAVs speed up the delivery process and cut down the delivery cost, especially in urban areas.

Beyond military and commercial applications, UAVs can also play a significant role on the humanitarian front. The mapping and monitoring, delivering supplies and medicines (particularly in high-frequency, low-volume missions to remote areas known as "last mile" delivery), and search-and-rescue activities are the most common uses for UAVs in humanitarian assistance. (Luterbacher, 2018) The main advantage of using UAVs in crisis is that they can reach challenging places for humans or vehicles. UAVs are also easily deployable and can be used instantly to assist first-line responders. Inspired by those humanitarian applications of UAVs, this project aims to look at the possibility where UAVs can be used to last-mile drop-off essentials to trapped or isolated victims in a crisis. Last-mile drop off helps to reduce the overall cost of the mission instead using a different approach such as using a helicopter, boat, truck etc. (Aurambout, Gkoumas and Ciuffo, 2019)

This study aims at UAVs for humanitarian missions, with the primary focus being on the victims who are not reachable easily via other means than a UAV. The UAV would release the package midair to a targeted location. Finding optimal release points is crucial in this exercise.

1.3 Aims and objectives

Various studies have taken place in the context of payload drop-off. This section discusses the goals and objectives of the current study.

The project's primary goal is to find accurate release coordinates that will drop to the given target location by studying the parameters that affect the calculation and developing a precise drop-off algorithm. At the same time, this will create hardware equipment for drop off the payload by using Raspberry Pi and a propeller.

Following are the main objectives focused on this research:

- Study various crises where the UAV can play a significant role.
- Understand the various UAV technologies in humanitarian causes and find the critical factors considered in payload drop off to a target location.
- Study about the sensors that can be used in UAVs to get the input data for wind, wind direction, the velocity of the UAV, height from the ground, and current coordinates of the UAV.
- Study about how much effect can change in wind speed and the direction of the wind can cause the payload drop-off.
- Identify other critical factors like the weight of the payload, density, velocity, etc., and build an algorithm using a mathematical model to determine the exact drop-off coordinates of the payload with high accuracy.
- Create a data set to test the algorithm.
- Using a simulator, SITL (Software in the loop) checks the accuracy of the implemented algorithm and improves the algorithm according to the results.
- Implement hardware equipment for the UAV using Raspberry PI and Servo motor to carry the payload and program Raspberry Pi.
- Test the hardware and Software using a real UAV and evaluate results.

1.4 Scope

The parcel drop-off model can potentially be applicable for commercial purposes. However, at this point, the model's focus is to develop an algorithmic model to find the precise drop-off location that is more focused on humanitarian missions. The model's guide assumes where the UAV controller is in line of sight of the receiver yet easily unreachable by a human, a vehicle, or any other means. For example, a person trapped in a canyon, dropping a mobile phone to a stranded person on an island in flood, delivers necessary items for isolated people due to Covid.

This study is strictly focused on UAV suitable weather conditions and does not consider extreme weather conditions that UAVs cannot take off. The service ceiling is set to a maximum of 150 feet at the highest. This height has been taken under the guidelines of the Civil Aviation Act of Sri Lanka. (CAASL, 2017). All the testing for the algorithm is done at this maximum limit and below.

The model assumes that the coordinates of the recipient are pre-known to the UAV controller, and the wind is consistent and does not change the direction after dropping the parcel. The maximum payload will be limited to the maximum load that can carry using the Tarot 680 UAV/ GAIA 160 hexacopter.

Raspberry Pi programmed for a servo motor and tests only for the Tarot 680 UAV and GAIA 160 hexacopter and taking sensor data from Cube Orange flight controller to Raspberry Pi to calculate precise drop location.

1.5 Structure of the thesis

- Chapter 2 deals with the literature review of the study. It represents relevant information regarding UAVs, the evolution of the UAVs, the generations it passed, and the types of UAVs. Moreover, it contains applications of UAVs. After that, it includes simulation tools that are available for simulating UAVs, UAV simulator software, Ground controller software. It talks about the physics behind the precise drop of a payload, and finally, payload drop approaches and compares relevant research papers.
- Chapter 3 described the detailed description of the methodology of research. It will discuss the design, proposed mathematical model, proposed algorithms, and the hardware equipment.
- Chapter 4 describes the evaluation of the proposed algorithm and then discusses the other approaches.
- The final chapter contains the conclusion and the future work. According to the discussion, the findings will be provided. At last, the work that has to be implemented is provided.

Chapter 2: Literature review

2.1 Introduction

The previous chapter provided an overview of the study. It described the background, problem statement, motivation, aims, objectives, and scope of the study. This chapter will discuss a detailed description of the UAVs used to deliver parcels, the mechanisms used in history and its evolution, and the physics behind finding the precise location. These factors affect when doing precise dropping, precise dropping approaches, and techniques. Also, a comparison with other research related to this study will be discussed in the latter part of this chapter.

2.2 Unmanned Aerial Vehicles (UAV)

Unmanned Aerial Vehicles or drones are commonly known as UAVs. It is an aircraft without a pilot and any passengers on board. UAVs or drones have existed for almost a century. The earliest UAV is a hot air balloon, but it is not considered a UAV because a person cannot control it. The first unmanned aircraft was built during World War I. It was the first flight of the Hewitt-Sperry(Custers, 2016) that was an automatic airplane. This airplane was made for military purposes and is considered a flying bomb. After that, those airplanes were converted to UAVs. Larynx (1927), the Fairy Queen, was the UAV created after World War I (Dekoulis, 2018). In World War II, the Radioplane company produced around 15000 UAVs for the United States Army (Dekoulis, 2018), and this was the first mass production of UAVs. In World War I and II, the purpose of the UAVs was to drop bombs. But with time, UAVs have been used in different areas other than military purposes.

As per the statistics, the commercial market size was 6.4 billion U.S dollars in 2020 (Statista, 2021). Commercial use of UAVs is getting a lot of public attraction, and it has diverged to many areas. They are cinematography and photography, sports and entertainment, industrial applications, agriculture, aerial surveying, education and research, construction, insurance, and parcel delivery.

UAV technology has changed rapidly in the past. It evolves from primary remote-controlled aircraft to complete commercial suitable, fully compliant safety and regulatory standard and enhanced intelligent piloting model. The latest UAVs are fully aware of the air space and can automatically take off the land and mission execution. There are seven generations mentioned in Figure 1, and the world's current technology is in the sixth generation (Air Drone Craze, 2018).

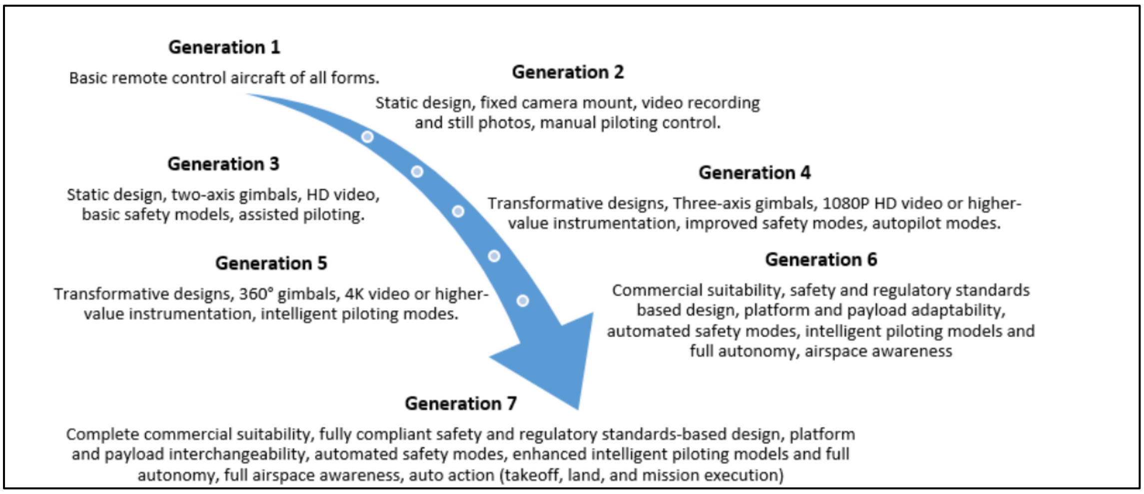


Figure 1: UAV technology evolution (Insider, 2021)

2.2.1 UAV use cases

There are many use cases other than military purposes, as mentioned above paragraph.

Cinematography and photography: UAVs can be used to capture images or display images that are hard to capture or costly to capture. DroneCast markets (Lingamaneni, Kubitza and Scheible, 2017) are used to do advertising using UAVs. It can display banners, the ability to capture stunts and ability to drop branded items, etc. UAVs are used to take videos and photos and are less expensive than the usual approach.

Sports and entertainment: UAVs have played an essential role in sports, and now it is replacing sky cameras and spyder cameras with UAVs. Using UAVs makes it easy to process and play instant replays, and these UAVs are a part of Hawkeye. UAVs can cover extreme sports moments such as skiing, snowboarding, surfing, yachting, etc. (Ayranci, 2017). Apart from that, new entertainment areas are building up from UAVs. Some of them are UAV races, synchronized light shows, UAV puppeteers, etc.

Agriculture: The use of UAVs in agriculture is one of the best use cases of UAVs. UAVs are used to gather information such as soil analysis, soil composition analysis, seeding, planting, allow farmers to monitor the entire area quickly, etc. One big issue the farmers have faced is to assess the vegetation health. Satellite images were used earlier, but it is expensive for a typical farmer, and the picture quality is not good. Using UAVs is easy, and the quality of the images is high and less expensive. Farmers use helicopters to spray seeds on their land, and it is too costly and takes time(Radoglou-Grammatikis *et al.*, 2020). Using a UAV becomes easy for farmers, and it saves their money too.

Construction: The leading use of UAVs will be construction planning, management, and inspections. Around 1.5 million UAVs are registered in the United States (Maghazei, 2020), and one-third of them for commercial use with home builders. UAV technology is used to track the progress of development sites, survey the site before starting the project, the soil analysis, security, monitoring, etc. Major companies such as Verizon (News Center, 2020) started UAV usage and management companies, which helps manage and utilize their UAV fleet. The use of UAVs in the construction process increased rapidly after COVID19 as it already promotes safety in the workplace and promotes social distancing.

Insurance: As mentioned in previous use cases, UAVs can take high-quality images and can use for inspections. UAVs can be used for motor vehicle accident inspections, post-disaster claim inspections, natural disaster monitoring, fraud detection, and many more. With UAVs, insurance companies may help reduce worker compensation, travel costs, and inspections costs. For example, if there were a major flood, hurricane, or other natural disaster, UAVs can survey and monitor the area without too many workers on site.

Delivery: UAV-based delivery systems are modern-day technology to deliver goods. The UAV delivery systems were designed to provide food, mail, medicines, and other goods. In March 2002, TacoCopter in Silicon Valley (Goodchild and Toy, 2018) publicly announced that they deliver tacos within San Francisco using UAVs. Amazon launched Prime Air delivery designed to deliver packages to customers within 30 minutes or less using UAVs (Amazon, 2017).

Using UAVs to deliver goods is one of the fastest methods, and this helps reduce CO_2 emissions and reduce traffic congestion. Using UAVs would be the most significant advantage of UAVs to make deliveries to customers. At the same time, there may be disadvantages with this method, like privacy issues, etc.

Humanitarian missions: The UAVs used in humanitarian missions are another important use of UAVs that can be used in humanitarian missions. As already mentioned, UAVs can deliver essential items such as medicine to remote and isolated locations. There are many examples that UAVs used to do such things in the past. In 2015, Cyclone Pam happened in Vanuatu(Greenwood, Nelson and Greenough, 2020), and disaster responders used UAVs to evaluate structural damages of the disaster. UAVs have also been used to deliver snake bite antivenom and blood samples to Peru in less than 35 minutes. Usually, it takes around six hours to access this region, and it saves a lot of time by using UAVs. (Tatham *et al.*, 2017). Rwanda, The African Country, was the first country that used UAVs for medical delivery. It was started in 2016 with a partnership of the Rwandan government and a Silicon Valley company called Zipline, and those UAVs deliver blood to 12 regional hospitals in eastern Rwanda(Stefan Tasevski, 2018).

During the recent COVID-19 pandemic, China became the first country to use UAVs to fight the virus. They have used UAVs to deliver testing samples to the laboratories, reducing the time and cost of transporting them using regular transportation. Using UAVs to deliver testing samples to the laboratory helps diagnose infected people quickly(Skorup and Haaland, 2020). In the pandemic time, UAVs have been used to guide and monitor people in isolated areas. Sri Lanka Police also used UAVs to monitor the movement of people in lockdown areas due to pandemics. (LIRNEasia, 2020)

This research is more focused on humanitarian missions by using UAVs.

2.2.2 Types of UAVs that can be used in humanitarian missions

Four major types of UAVs can be classified based on aerial platforms. They are Multi-Rotor UAVs, Fixed-Wing UAVs, Single Rotor UAVs, and Fixed-Wing Hybrid VTOL. We mostly used fixed-wing, multi-rotor, and hybrid UAVs for humanitarian purposes, and this topic described these three types.

Fixed Wing UAVs

This type of UAV has a two-wing design. Fixed-wing UAVs are used to cover longer distances, and they can carry heavy loads. These can be used to transport cargo over longer distances. These UAVs can be operating up to 50km/h and can stay in the air from thirty minutes to several hours, depending on the model. Most of the fixed Wing UAVs are autopilot and follow predetermined paths. The ground controller can adjust the direction when necessary. A major drawback of this is that it needs a strip of open space for landing and take-off (Boon, Drijfhout and Tesfamichael, 2017). In Figure 2, Zipline was used to deliver medical supplies in North Carolina using a Fixed Wing UAV.

Figure 2: Fixed-wing UAV used to deliver medical supplies

Hybrid UAVs

Hybrid UAVs are relatively new compared to other types of UAVs, and it is equipped with both Wing and rotors. This setup allows for vertical take-off and landing, and this can fly horizontally like fixed-wing UAVs. This type of UAV can cover far longer distances and carry heavier cargo than multi-rotor UAVs. The image for the hybrid UAV is in Figure 3

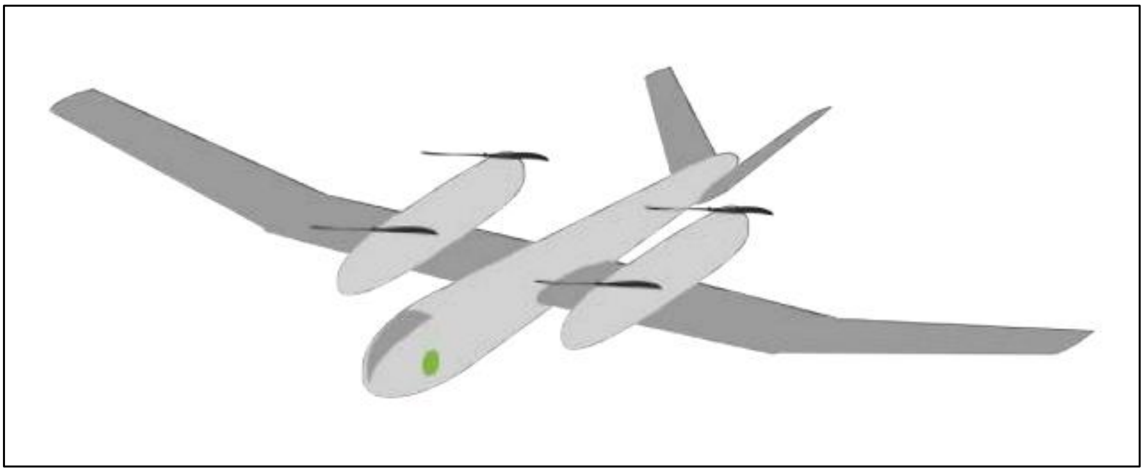


Figure 3: Model of hybrid UAV

Multirotor UAVs

Multirotor UAVs are used for shorter distances and shorter flight times. Multirotor is used to transport lightweight items. Multirotor UAVs can be further classified based on the number of rotors. They are Tricopter (3 rotors), Quadcopter (4 rotors), Hexacopter (6 rotors), and Octocopter (8 rotors). A most used multi-rotor UAV is Quadcopter. The main advantage of the multirotor UAVs is that it can take off and land vertically, so it does not need much space.

Figure 4: GAIA 160 hexacopter

Figure 5: Tarot 680 pro hexacopter

As in Figure 4 and Figure 5, both GAIA 160 hexacopter and Tarot 680 were used to demonstrate this research project. These types of UAVs are suitable for humanitarian missions such as sending communication equipment to someone trapped, sending medical items to a person in an isolated area, etc. Another advantage is that multi-rotor UAVs are much cheaper than the other type of UAVs. The main drawback is less flying time and cannot transport items with bigger weights (Fabbroni *et al.*, 2016).

There is a comparison in famous UAV types that can be seen in below Table 1 (Vergouw *et al.*, 2016)

Table 1: Characteristics of UAV

Characteristics		Delfy Explorer (Ben Coxworth, 2013)	Parrot A.R (Parrot, 2010)	DJI Phantom (Hamdi *et al.*, 2019)	Raven (O'Young and Hubbard, 2007)	ScanEagle (Naval Technology, 2007)
Type of UAV	Fixed-wing	-	-	-	X	X
	Multirotor	-	X	X	-	-
	Other	X	-	-	-	-
Autonomy	Human operated		X	X	X	X
	Human delegated		X	X	X	X
	Human supervised	X	-	-	-	-
	Fully autonomous	-	-	-	-	-
Size / Weight	Large UAV (25-150 kg)	-	-	-	-	-
	Small UAV (2-25 kg)				X	X
	Mini UAV (<= 2 kg)	X	X	X	-	-
Energy Source	Airplane fuel					X
	Battery cells	X	X	X	X	
	Fuel cells	-	-	-	-	-
	Solar cells	-	-	-	X	-

2.3 Simulation tools used in UAV systems

UAV systems are widely used because they are capable of doing complex things. It is used in various industries, as we discussed in previous topics. UAVs are controlled by a ground control station (GCS).

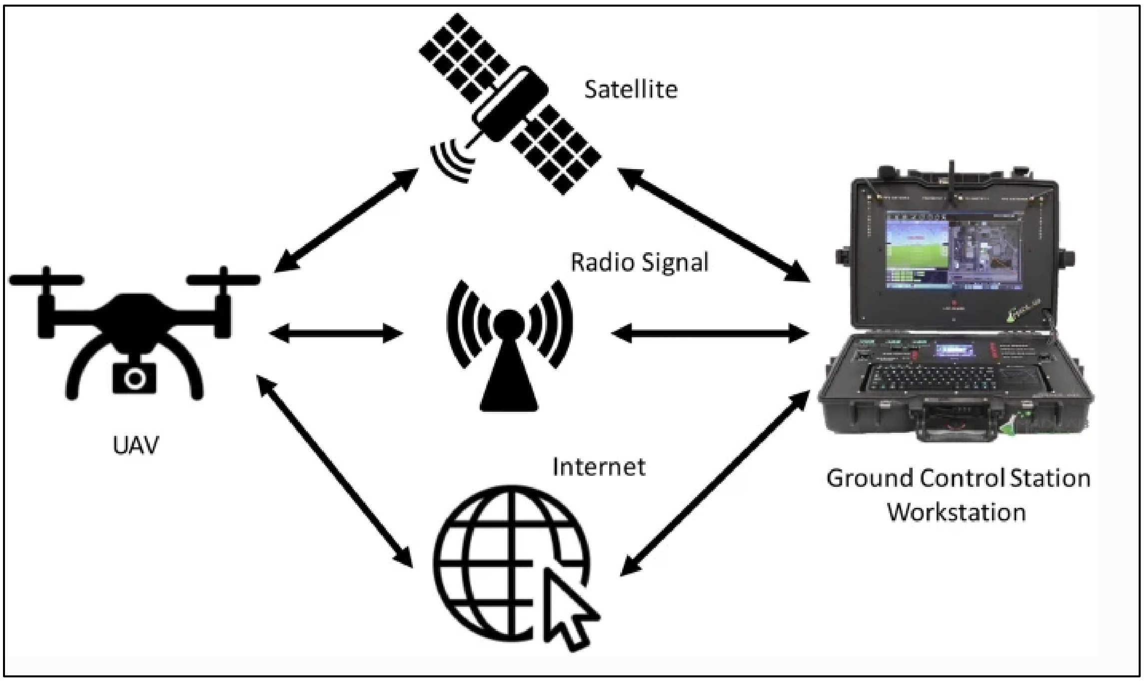


Figure 6: UAV communication with GCS

Figure 6 showing an example of how GCS communicates to the UAV. UAVs are expensive, and there should be a way to analyze UAV systems before doing an actual deployment. Many researchers (Coopmans, Podhradsk and Hoffer, 2015) have used Software In the loop (SITL) to simulate UAVs(Hodicky, 2016). Additionally, it can be used to simulate Plane and Rover without using any hardware. It builds the autopilot code using C++ language, which can be run on the computer directly for testing. The connection can be made to the SITL via UDP or TCP protocols. GCS is the other part of the UAV, and it has several features.

Mission Planning

Mission planning plans the path for the UAV by adhering to environmental and mission requirements. After that, UAV can run that mission depending on the planned trajectory.

Payload Control

There are devices such as sensors, cameras that can be added to UAVs. GCS must supervise those parameters during the mission.

Navigation and Position Control

In a mission, UAVs are placed in different altitudes to check the target area. GCS should display those movements of the UAVs to make the mission successful.

Communication and data exchange

As mentioned in Figure 6, GCS and UAV should have direct and bi-directional communication. GCS sends commands to the UAV to control it. UAV may send data like images, map data, video, etc., to the GCS.

2.3.1 UAV Simulators

The UAV simulator is used to create an environment for UAVs to fly. UAV simulator allows adding different sensors such as GPS, barometer, camera microphones, etc. There is no unique UAV simulator suitable for all aims. When choosing a UAV simulator, it is essential to check whether it is ideal for the purpose. Many UAV simulators such as Flighygear, JMavSim, Gazebo were focused on simulating the UAV physics to train the pilots. But they have limited assets and textures and did not support the motion of capture (MOCAP), allowing simulating the UAVs natural movement. Recently, UE4Sim, Microsoft Airsim supported MOCAP. They are implemented using Unreal Engine 4 (UE4).

2.3.1.1 Comparison between UAV simulators

Table 2: Comparison between UAV simulators

Simulator	**X-Plane** (XPLANE11, 2020)	**FlightGear** (Flightgear, 2018)	**Air Sim** (Shah *et al.*, 2017)
Commercial or free	Commercial	Free	Free
Vehicles	UAVs/ Airplanes/ Some multirotor	UAVs/ Airplanes/ Some multirotor	Multirotor
Sensors	Easy incorporation of sensors	Available	Depth cameras, Monocular, No lidar
Motion capture	No	No	Available
SITL-HITL	Available	Available	Available
MAVLink	Available	Available	Available

There are three major UAV simulators compared by the characteristics that have been mentioned in Table 2. Laminar Research developed the X-Plane simulator. This simulator is a commercial application, and it supports Windows, Linux, MacOS, and Android (XPLANE11, 2020).

FlightGear simulator is a free and open-source application. This simulator was implemented by the FlightGear project in 1997 and continued in development. FlightGear also supports different operating systems such as Windows, MacOS, and Linux (Flightgear, 2018).

Microsoft developed the Airsim simulator in 2017 (Shah *et al.*, 2017). This simulator uses Unreal Engine 4 to render the simulation more photorealistic. The disadvantage of this simulator is it needs a higher GPU for simulation.

2.3.2 Ground Control Station

There are many GCS software such as Mission Planner (ArduPilot Dev Team, 2016), MAVProxy (ArduPilot Dev Team, 2016), UGCS (UgCS, 2020). Comparison between the mentioned GCS in Table 3

Table 3: Comparison between different GCS software

GCS	MissionPlanner (ArduPilot Dev Team, 2016)	MAVProxy (ArduPilot Dev Team, 2016)	UGCS (UgCS, 2020)
Commercial/ Free	Free	Free	Free (Limited capabilities)
Graphical/ Command	Graphical	Command	Graphical
Support MAVLink	No	Yes	Yes
Platform for Android	No	NoYes	
Pilot	ArdupilotPX4	Ardupilot, MAVLink compatible	Dji, Innoflight, Micropilot, Parrot, MAVLink compatible

To test the implemented algorithm of this study used SITL and MAVProxy as GCS.

2.4 Physics behind precise airdrop of object

A falling object through the atmosphere is primarily subjected to two external forces known as gravitational force (weight) and air resistance (drag). If the object is falling in a vacuum (absolute pressure condition), there would be no resistance against the drop due to the absence of particles. However, an object falling through the earth's atmosphere is obstructed by the presence of gases (78 % Nitrogen, 21% Oxygen, 0.9% Argon, and 0.1% other gases). However, if the object is in the wind field and is released with relative velocity to the earth, these conditions will alter the falling path of the object.

The gravitational force expressed as the weight of the object is equal to the mass of the object times the gravitational acceleration, which is approximately 9.8 ms-2 on the earth according to Newton’s universal law of gravitation (Paul and Hinrichs, 2012). However, the gravitational acceleration can vary depending on the geographic/atmospheric location where the object is in the range of 9.806 ± 0.026 ms^{-2}. Gravitational force (Eq. (1)) acts in the vertical plane of a point location on earth and is pointed towards the center of the earth, hence, towards the earth's surface for a falling object.

$$F = \frac{GmM}{r^2} \tag{1}$$

Where F is the magnitude of the gravitational force (N), G is the gravitational constant (6.673×10^{-11} $N \cdot m^2/kg^2$), M is the mass of earth, m is the mass of the object, and r is the distance to the centre of the earth.

The vertical velocity component of the falling object will gradually increase due to the gravitational force. However, it does not vary linearly because of the presence of the drag resistance to the acceleration. The drag force acting on the falling object is proportional to the square of its velocity. Figure 7 shows the impact of drag force on the vertical component of the falling velocity of the object (Lincoln, 2020). Since the air resistance is acting against the movement of the object, the resultant vertical acceleration is expected to be lesser than 9.8 ms^{-2}. However, since the vertical velocity is time-dependent, the drag force also changes with time, hence, change of acceleration of the moving object. Therefore, the vertical velocity of the object does not vary linearly.

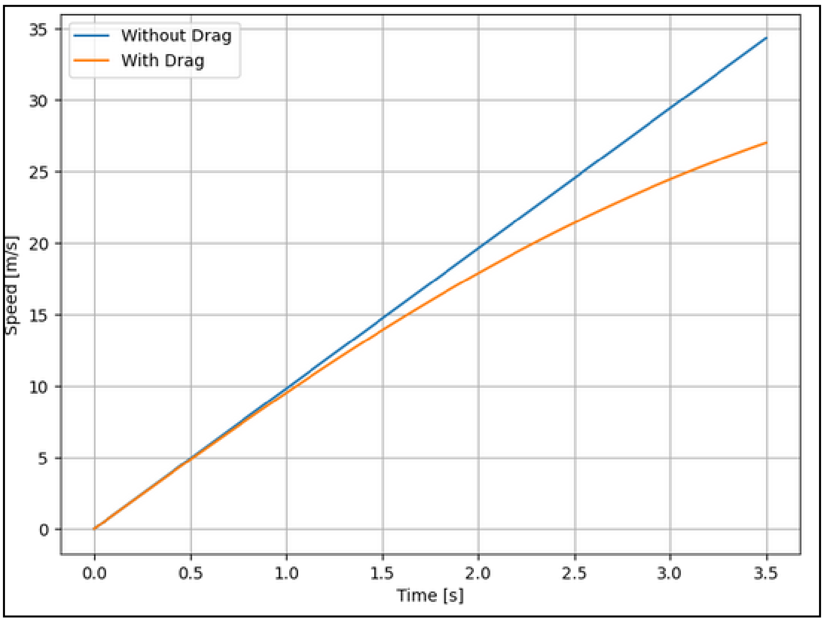


Figure 7: Vertical velocity component of the dropped object

The air resistance on a falling object which is also called drag resistance is a force acting opposite to the relative motion of the object in a fluid (gas when in the atmosphere). The drag force equation is generally used to calculate the drag force or the air resistance (National Aeronautics and Space Administra, 2015). The equation for drag force is as follows.

$$F_D = Kv^2 \tag{2}$$

Where,

F_D = Drag force
ρ = density of air
v = speed of the object
C_D = Drag coefficient
A = Cross sectional area

Above four inputs are needed to calculate the drag force (Eq. (2)). Generally, air density (ρ) varies with the temperature of the fluid (gas when in the atmosphere) and the altitude. The density of air is the mass per unit volume of atmospheric gases. The International Standard Atmosphere states the density of air is 1.225 kgm^{-3} at sea level and 15 degrees of Celsius (Helmenstine, 2020). Drag coefficient (C_D) depends on the shape of the objects and its surface. Figure 8 shows the drag coefficient for typical shapes.

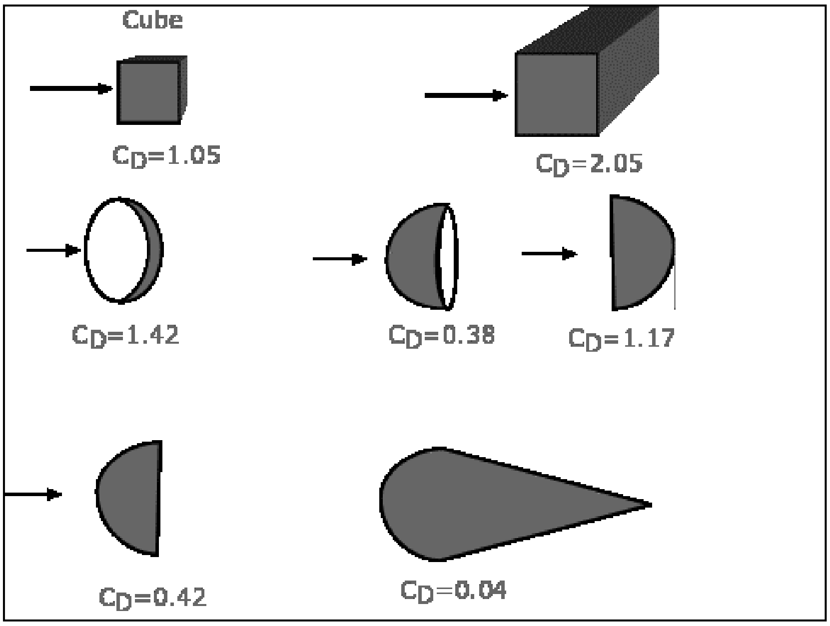
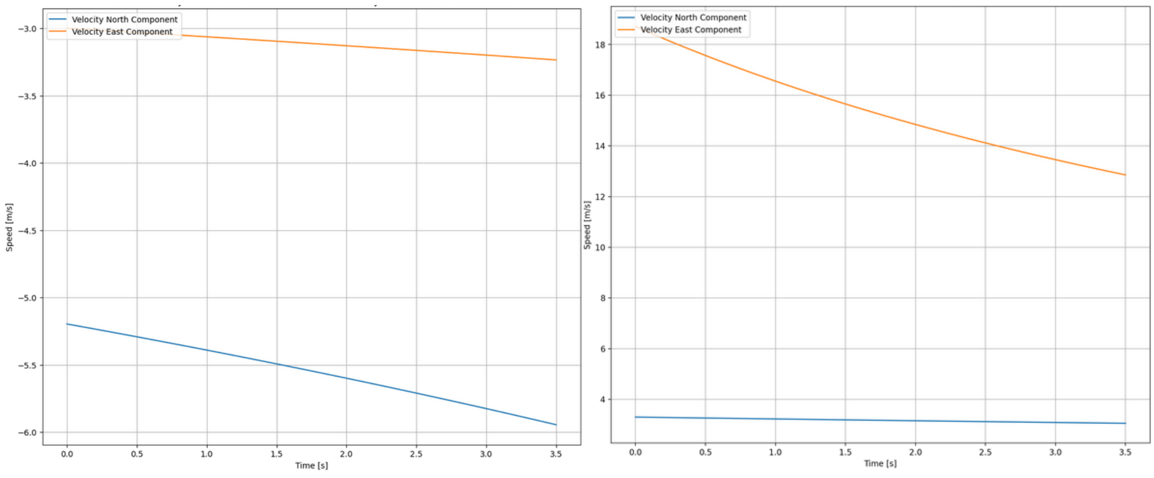


Figure 8: Drag coefficient for different shapes

Apart from the gravitational and drag forces acting on the falling object, the presence of a wind field also affects the airdrop path of the object. The wind condition of a location is typically unsteady, and it is a result of atmospheric pressure differences. Wind may act as a resistance or assistance to the falling object depending on the relative wind direction to the object. When the wind direction is allied to the movement of the object, it strengthens the velocity of the object. However, if the wind is blowing towards the airdrop object, it acts as a resistance and reduces the relative velocity of the object to the atmosphere. Many studies show the importance of an accurate wind velocity inclusion for the drop position calculations as it affects the precise drop location of the object heavily (Vicovaro, 2014). The following graphs explain the horizontal velocity profiles of an object in different wind fields.



a) b)

Figure 9: a) is an example of UAV velocity of 8 ms^(-1) 30° from North and wind velocity of 14 ms^(-1) 210° from North direction, b) b) is an example when UAV velocity changed to 10 ms^(-1) 80° from North and wind velocity of 9 ms^(-1) 80° from North dire

2.5 Payload drop approaches

There are many ways to deliver an item to a mentioned place using a UAV. Last-mile delivery is an approach that was primarily used for commercial purposes. McKunsey identified UAVs as a good option for last-mile deliveries, especially parcels to rural areas with a density smaller than 50000 inhabitants, and consumers like instant delivery or same-day delivery(Joerss, Neuhaus and Schroder, 2016). Home delivery by UAVs has been promoted and researched by many firms. Google, Amazon, UPS, DHL have tested UAV delivery for years, and Amazon will launch Amazon Prime Air in the near future. Many start-up companies like Matternet, Flytrex, and Skycart (Flytrex, 2018) also offer UAV delivery services. Lohn (Lohn, 2017) did a technical overview and the impact of this last-mile delivery, and he explored infrastructure requirements, privacy, aerial congestion, and noise. Murray and Chu (Murray and Chu, 2015) provide a mathematical programming model for optimal routing and UAV scheduling. They have talked about how the UAV works in collaboration with a delivery truck to distribute delivery items. Tavana et al. (Tavana *et al.*, 2017) discussed minimizing transportation costs by reducing waiting time for a vehicle that has to wait for the other and truck scheduling problems. Dorling (Dorling *et al.*, 2017) has discussed the energy consumption model multirotor UAV within a vehicle routing to optimize the problem.

There is another approach for delivering payload by using a precision airdrop system. This Joint Precision Airdrop System, or JPADS (Klinkmueller *et al.*, 2019), has a feature to control the canopy attached to the payload. This system has another unit called Airborne Guidance Unit (AGU) that can allow the payload to be autonomously navigate within 100m of a target coordinate, and this enhances the reliability and the efficiency of airdrop operations.

Figure 10: Autonomous airdrop using JPADS system

Figure 10 shows how the payload is delivered using the JPADS method. This is mainly suitable for the military to get their essentials. It is not possible to use this approach for commercial parcel delivery or humanitarian because the payload is sent to an unknown. There is no mechanism to return that canopy because it can be reused; otherwise, it is an additional cost to make a new canopy for every delivery. There is a lot of research done for this type of approach. Klein and Rogers (Klein and Rogers, 2015) have used unguided airdrops using parachutes. They have improved the performance of unguided drops by presenting a mission planner dependent on the desired impact dispersion, which finds the payload's optimal computed air-release position. It has also been endeavored to improve airdrop accuracy by enhancing some of the parameters that lead to the error, like optimizing the parachute transition altitudes (Gerlach, 2016) or using models to estimate optimal release points(Vandermey, Doman and Gerlach, 2015).

Mathisen (Mathisen *et al.*, 2020a) has done a closed-loop autonomous delivery system that uses machine vision to identify the target location and plan the release point path. It drops the payload to the target location. In this, a visual spectrum camera is used to capture the real-time images. It processed images based on color segmentation to detect the target and the pixel position image. Georeferencing is used to transform these pixel coordinates from a single image into more informative Earth-fixed coordinates. From that, it finds the target. This is a fully autonomous system, and it calculates the path to the target, and then it drops the payload. When calculating the ballistic path of the payload drop Mathisen used Newton’s second law to build the algorithm and assumed only air resistance and gravity acting on the object.

Williams and Trivailo (Williams and Trivailo, 2006) did a precise drop approach using an aircraft where a loitering aircraft lets a payload slide directly down to the ground along a cable. The downside of this is that a small UAV with limited payload capacity would be strained carrying a long cable.

2.6 Comparison between the related research projects

The comparison between related research projects and identified research gaps are mentioned in the below table Table 4

Table 4: Comparison between recent approaches and current approach

Reference	**Related project details**	**Research Gap**
(Mathisen, Grindheim and Johansen, 2017)	In this research, they have used autopilot mode, and they have used machine vision to identify the target. They have used wind profile power law (Touma, 1977) without taking the static wind speed when calculating the precise drop release point.	There is no option for the ground controller to do a manual drop of this approach. There is no proper way to validate the target before doing the precise drop and also, in the algorithm, the UAV changes its path against the wind before doing the precise drop. It will be a time-consuming task. This approach is for only fixed-wing UAVs
(Singh and Garg, 2016)	This approach implements both manual and automatic modes for precise dropping.	There is no proper way to validate the target before doing the precise drop, and it has no mechanism to find the area if UAV drops the payload of its current location
(Klinkmueller *et al.*, 2019)	In this project, they have used guided parachutes to drop the payload.	A precise payload approach is more efficient and cost-effective.

2.7 Summary

This chapter talked about the detailed use cases of the UAVs and the different approaches taken by recent studies to find the precise drop location of the object. Moreover, this chapter compared the recent studies with the current approach. The next chapter will focus on the methodology of the proposed mathematical model, algorithm, and hardware module.

Chapter 3: Methodology

3.1 Introduction

This chapter will describe the proposed mathematical model for precise payload drop and finding the target of payload drop. Using this mathematical model, build an algorithm for precise payload drop and find the payload drop target. Moreover, this chapter will describe the proposed hardware module to carry the payload.

3.2 Design

Despite having no onboard human pilots, unmanned Aerial Vehicle (UAV) systems currently require extensive human involvement to accomplish successful mission operations. The current UAV market is filled with innovation. At present, organizations around the world are exercising various makes and models in a humanitarian context. Selecting a limited number of such UAV models and studying their application on the humanitarian front is a primary step of this research. This study would be a part of information gathering on various technical capabilities of models and their usage in crisis response. For example, a study about the maximum payload that a UAV can take and maximum flying time per round can be beneficial in determining an ideal candidate for a humanitarian project.

This study paves the way to a technical and economic feasibility study on selected models.

Data plays a key role in this research. Identifying publicly available datasets to evaluate the generated test data to validate the algorithmic model has been identified as a critical step of the study. Validated accurate data tends to improve the model's accuracy and can be validated by using Software In the loop (SITL).

The design of this thesis can be shown in the following diagram in Figure 11. This diagram indicates that Raspberry Pi connects to the Ground Station via TCP/IP protocol, while it communicates with UAV using MavLink protocol. Ground Station communicates the UAV with a radio link. One advantage of using TCP/IP to communicate between Raspberry Pi and Ground Station is it can send the data to the controller even when radio signal misses.

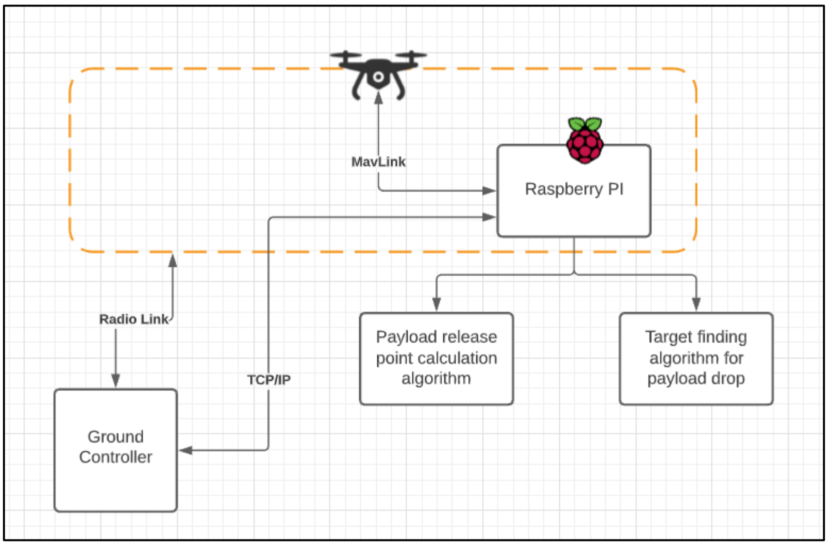


Figure 11: Design diagram

One of the main objectives of the study is to determine the precise drop-off location. Several factors come into play in the calculation.

Formulation of the algorithmic model will be based on the following factors (Henelsmith, 2016):

- The altitude of the UAV.
- Wind speed relative to the UAV.
- UAV velocity.

Above mentioned factors can vary at a given point in time.

- Mass of the payload.
- Drag coefficient.
- The density of the air.
- Target coordinates.

The above four parameters are predefined.

Ground Controller using Cube Orange (Ardupilot, 2021) and has an inbuilt sensor to get the velocity of the UAV, Coordinates of the UAV, and the altitude of the UAV. There is another sensor that should connect using PWM (Pulse Width Modulation). to identify the wind speed and direction.

Design Assumptions

The following assumptions are made while designing the algorithm,

- The wind changes according to wind profile power law (Touma, 1977) after releasing the payload.
- The wind direction is not changing after releasing the payload.
- The air density is constant.
- There are no other meteorological impacts.

3.2.1 Proposed mathematical model

This mathematical formula was created based on the drag force equation and using the second law of Newton.

Development of the proposed algorithm will be based on the drag force equation (Eq(3)) (*Small Unmanned Aircraft: Theory and Practice* - *Randal W. Beard, Timothy W. McLain* - *Google Books*, 2012)shown below:

$$F_D = \frac{1}{2}\rho v^2 C_D A \quad (3)$$

where,

F_D = drag is the aerodynamic force that opposes the motion of aircraft through the air.
ρ = density of air.
v = speed of the object relative to the fluid.
C_D = Drag coefficient
A = Cross sectional area

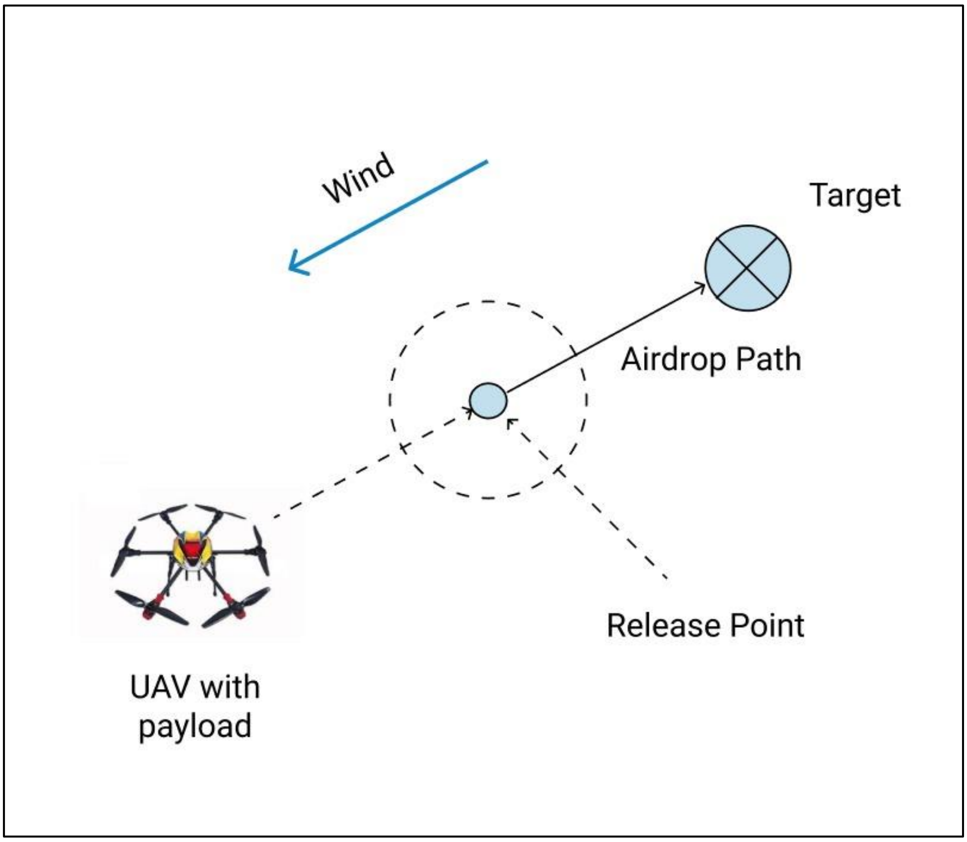
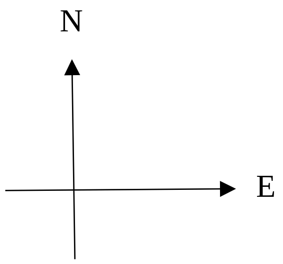


Figure 12: UAV Path to release point

As per Figure 12, to calculate the release point read wind direction and UAV direction relative to North direction and East direction.

Using Eq(3) and as per Figure 12, the proposed mathematical formula is as follows:



Θ: Angle between UAV direction and North direction.

α: Angle between Wind direction and North direction.

V_E: UAV velocity for East direction.

V_N: UAV velocity for North direction.

V_g: Velocity under gravity.

K_1: $\frac{1}{2}\rho C_D A_1$

K_2: $\frac{1}{2}\rho C_D A_2$

W: wind

Finding the velocity for both North and East directions

$$V_e = (V \sin\theta) + \delta t \frac{(-K_1)(V \sin\theta - W \sin \propto)^2}{m}$$

$$V_n = (V \cos\theta) + \delta t \frac{(-K_2)(V \cos\theta - W \cos \propto)^2}{m}$$

Find the acceleration for the z direction

$Using\ Newton's\ 2^{nd}\ law$

$$F = ma$$

$$mg - (V_n + a\delta t)^2 K_2 = ma$$

$Assume\ that\ a^2\delta t^2\ is\ too\ small$

$$a = mg - \frac{V_n^2 K}{m + 2\delta t V_n}$$

3.2.2 Proposed algorithm to find the payload release point

The flow diagram is in Figure 13 to understand the flow and, based on that, develop the algorithm to find the payload release point.

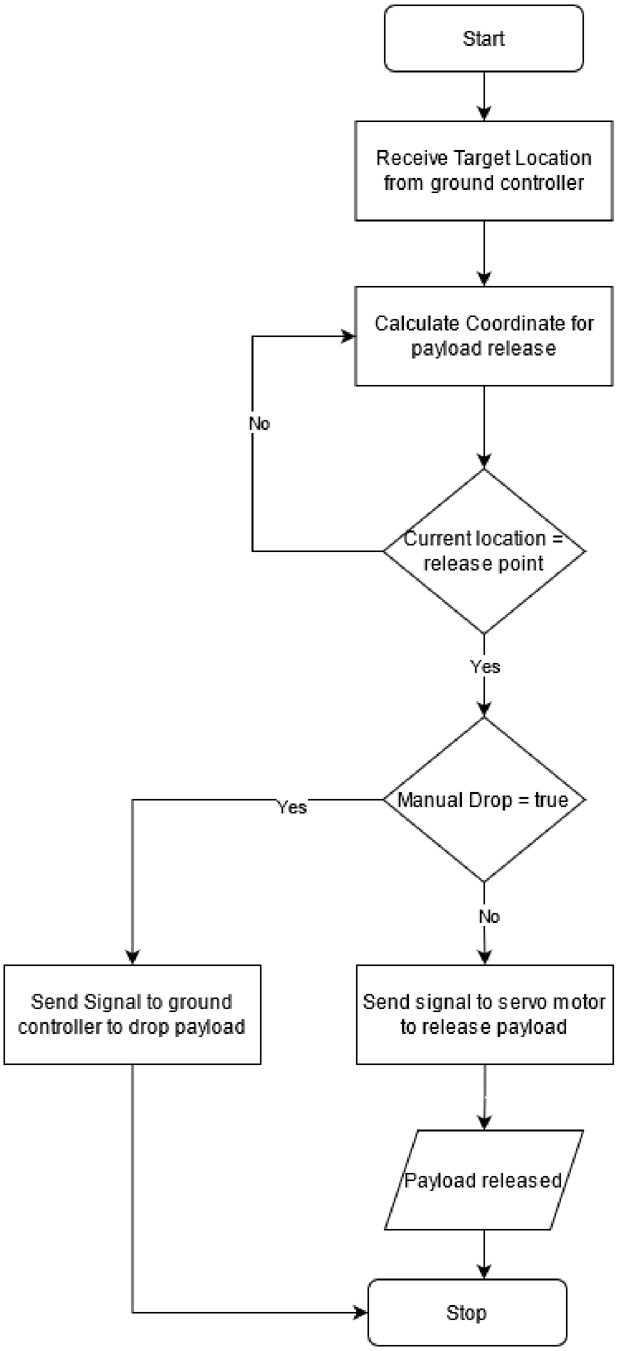


Figure 13: Flowchart for payload drop

Step 1:

Record all the following parameters at the given instant from the corresponding sensors:

- UAV altitude.
- UAV velocity is relative to the ground.
- Wind Speed relative to the air.
- Wind direction.

Mass of the payload, surface area, target location (x and y coordinates), drag coefficient, and air density are constant parameters stored in Raspberry Pi and can be changed before UAV departure.

Store target location as N_t, E_t referred for North direction coordinate and East direction coordinate.

Step 2:

Calculate the constant K in terms of the above parameters such that,

K = $\frac{1}{2}\rho C_D A$

Step 3:

Set time interval t = 0.02sec

Store the current UAV coordinates N and E referred for North direction coordinate and East direction Coordinate.

Calculate UAV initial velocity (V_e) for East direction considering wind (W) for East direction.

$V_e = (V \sin\theta - W \sin \propto)$

Calculate UAV initial velocity (V_n) for North direction considering wind (W) for North direction.

$V_n = (V \cos\theta - W \cos \propto)$

Step 4:

Iterate height (H) > 0,

Step 4a: Calculate the new components of acceleration for the East and North directions.

$$W = W_r \left(\frac{Z}{Z_r}\right)^{\alpha}$$

Acceleration (a_e) for East direction = $\frac{(-K_1)(V \sin\theta - W \sin\propto)^2}{m}$

Acceleration (a_n) for North direction = $\frac{(-K_2)(V \cos\theta - W \cos\propto)^2}{m}$

Step 4b: Calculate the new components of velocity for the East and North directions.

Velocity (V_e) for East direction = $V_e + a_e \delta t$

Velocity (V_n) for North direction = $V_n + a_n \delta t$

Step 4c: Calculate target coordinates.

Cordinate for North direction

$N = N + V_n * \delta t$

Cordinate for East direction

$E = E + V_e * \delta t$

Step 5:

Check if $N = N_t$ and $E = E_t$, then exit the loop. Else continue

Step 6:

End

After returning from the above calculation, the servo motor will release the payload to the target.

3.2.3 Proposed algorithm to find the target

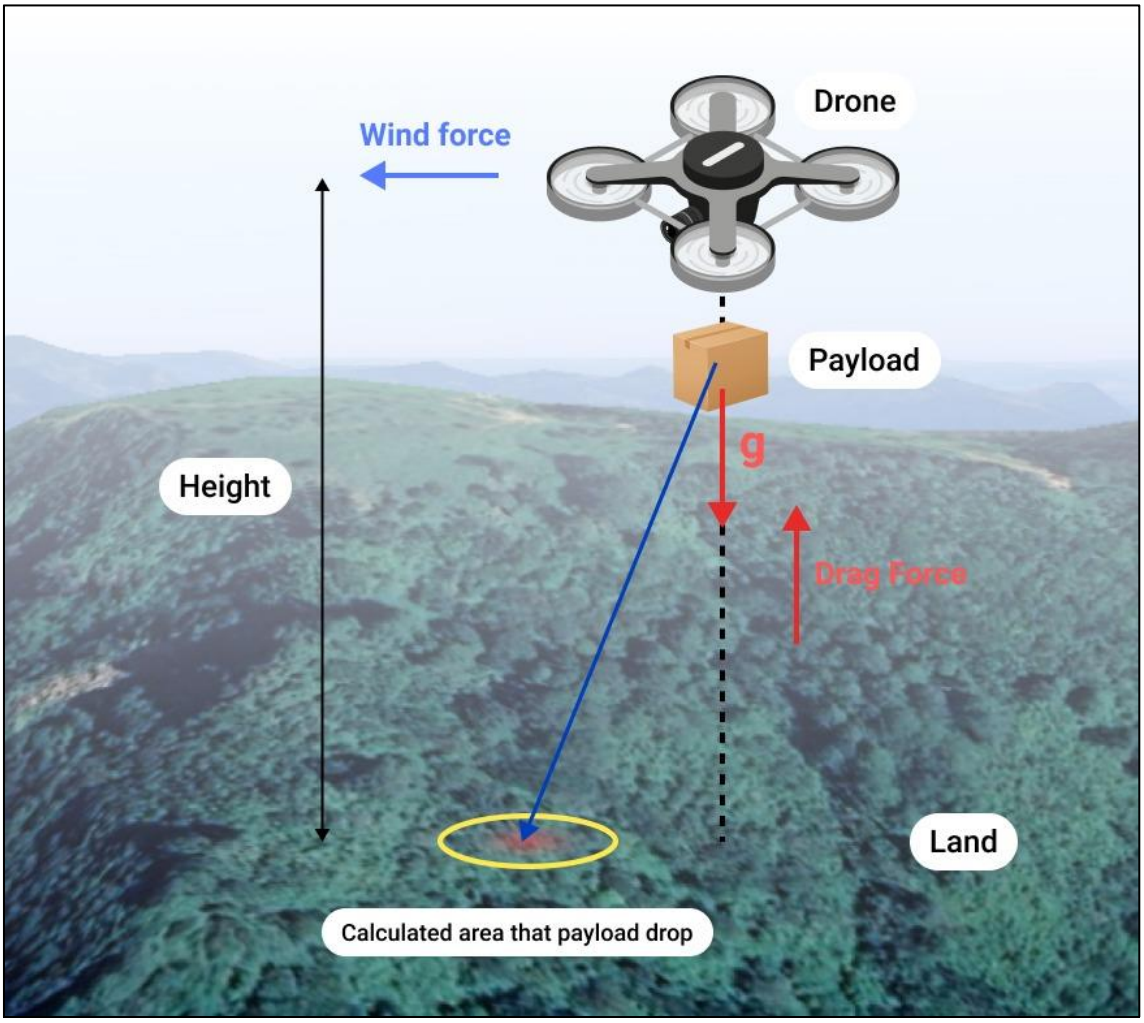


Figure 14: Diagram for target drop

Using the above mathematical model, find the target of the payload if it releases from the current UAV location (Figure 14). In this scenario, assume that the UAV is stabilized, and it does not have a velocity, and the height is constant. To identify the target location is the land or not, need to use the DEM

Step 1:

Record all the following parameters at the given instant from the corresponding sensors:

- UAV altitude.
- Wind Speed relative to the air.
- Wind direction.

Mass of the payload, surface area, drag coefficient, and air density are constant parameters stored in Raspberry Pi and can be changed before UAV departure.

Step 2:

Store the current UAV coordinates N and E referred for North direction coordinate and East direction Coordinate.

Step 3

Calculate initial velocity (V_e) that creates from wind for East direction considering wind (W) for East direction.

$$V_e = W \sin \propto$$

Calculate the initial velocity (Vn) that creates wind for the North direction, considering wind (W) for the North direction.

$$V_n = W \cos \propto$$

Step 4:

Iterate height (H) > 0,

Step 4a: Calculate the new components of acceleration for the East and North directions.

Acceleration (a_e) for East direction = $\frac{(-K_1)(W \sin\propto)^2}{m}$

Acceleration (a_n) for North direction = $\frac{(-K_2)(W \cos\propto)^2}{m}$

Step 4b: Calculate the new components of velocity for the East and North directions.

Velocity (v_e) for East direction = $V_e + a_e \, \delta t$

Velocity (v_n) for North direction = $V_n + a_n \, \delta t$

Step 4c: Calculate target coordinates

Cordinate for North direction

$N = N + V_n * \delta t$

Cordinate for East direction

$E = E + V_e * \delta t$

Step 5:

Send new N, E values to the Digital Elevation Model (DEM) and check if the coordinates are ground or not. If it is ground, then exit the loop. Else continue

Step 6:

End

After exits, the loop Model will draw a possible target area that payload drops in the map and send it to an open API that can be accessed from the internet via the ground controller.

3.2.4 Hardware equipment

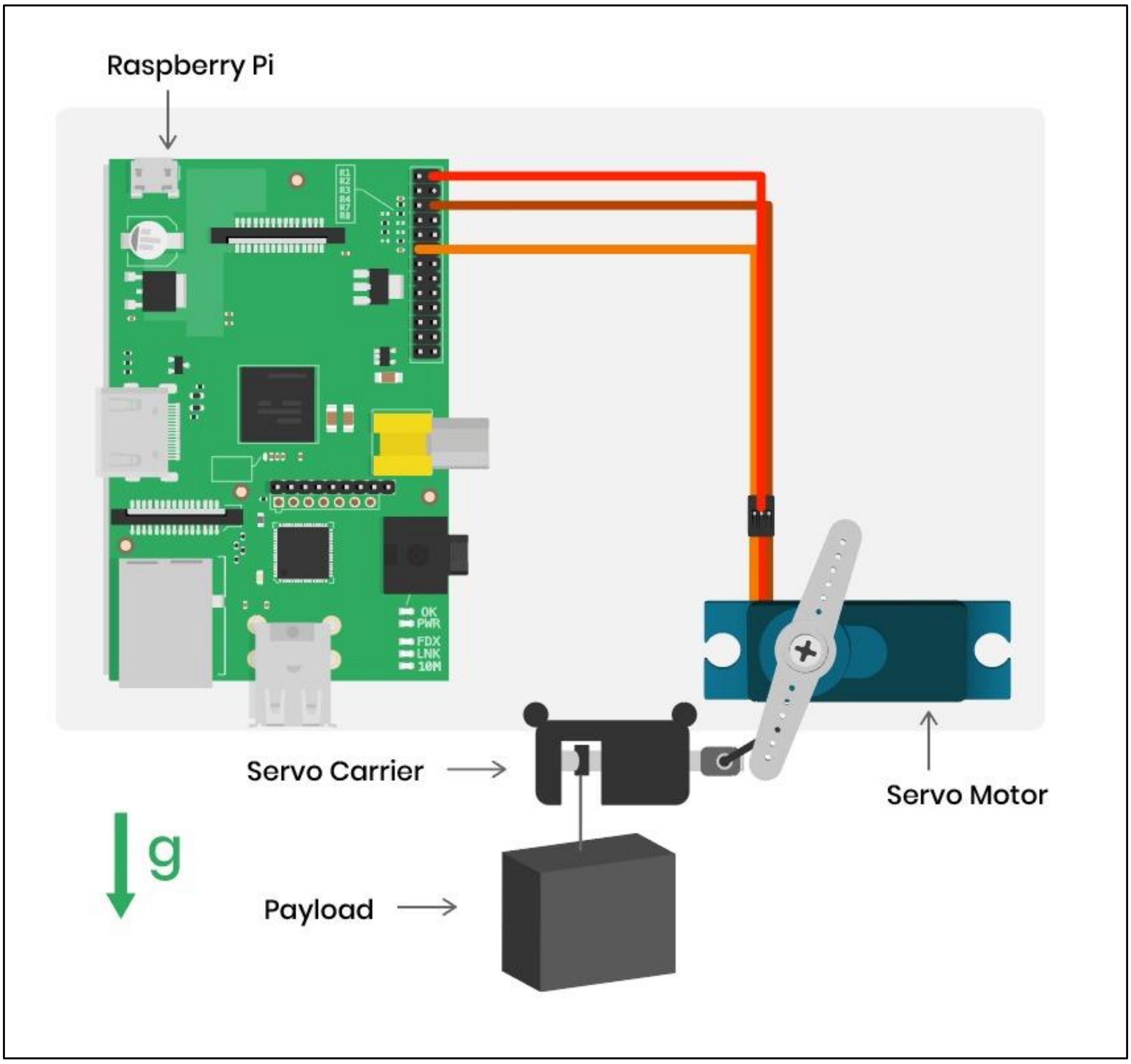


Figure 15: Payload carrier

As per Figure 15 Payload carrier is designed as follows. Carrier is made of fiberboard and mounted to a UAV. Servo motor is on the side, and it has a slider rod to lock and unlock. Raspberry PI is mounted on the UAV, and Raspberry Pi is connected to the servo motor. When the algorithm finds the release point, Raspberry PI gives a signal to the servo motor to unload the payload.

3.3 Implementation

To implement the designed algorithms needs to get input from the different sensors that are in the UAV. The Cube Orange Flight Controller specification (PX4, 2021) was used in this implementation. It has four built-in sensors. They are Accelerometer, Gyroscope, Compass, and Barometric Pressure Sensor. Additionally, there is one sensor that needs to ad to measure the wind speed and the direction of the wind.

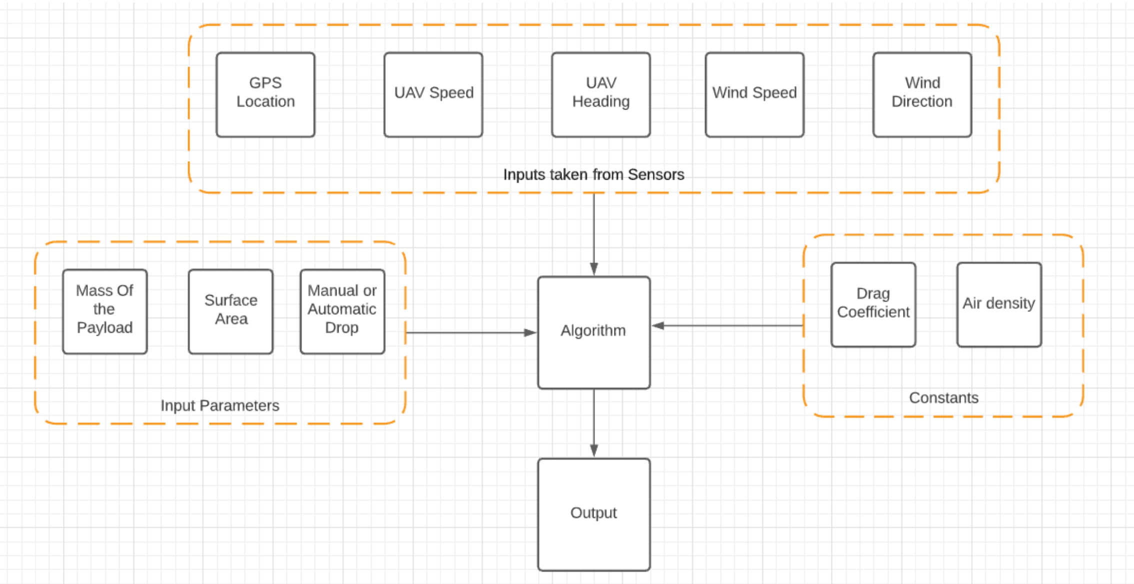


Figure 16: Algorithm process

As in the above-mentioned Figure 16, inputs have been taken from the sensors, user inputs (Configuration before flying the UAV), and constants. These sensor inputs can be accessed via the MavLink protocol, as seen in Figure 17.

```
import time
import math
import timeit
from dronekit import connect, VehicleMode, LocationGlobalRelative, Command, LocationGlobal
from pymavlink import mavutil
```

Figure 17: Libraries that are needed for the algorithm implementation

After taking the inputs from sensors as mentioned in Figure 17, send those inputs, constants, and user inputs to the algorithm developed.

```
while H > 0:
 ae = -k/m*(Ve-W*math.sin(alpha))**2
 an = -k/m*(Vn-W*math.cos(alpha))**2

 N = round(addMetresToLatitude(N , Vn*timeInterval),20)
 E = round(addMetresToLongitude(E ,N, Ve*timeInterval),20)

 Vn = Vn + an*timeInterval
 Ve = Ve + ae*timeInterval

 ag = (m*9.81 - Ug**2*k)/(m + 2*0.0001*Ug)
 H = H - Ug*timeInterval
 Ug = Ug + ag*timeInterval
 print(N,E,H)
 distance = disBetweenLocation(N, targerNDir, E, targetEDir)
 print('Distance: %s'%float(distance))
 if distance <= 0.5:
     return True
 else:
     return False
```

Figure 18: Code snippet to measure payload release

The code mentioned in Figure 18 runs every one second and measures the release point. This code checks the target coordinate, which is matched after releasing the payload of the current location of the UAV. If it is matched, the algorithm checks the ground controller configuration, and it sends back a message to the ground controller or drops off the payload. Figure 18 is the example for algorithm one and algorithm two. It sends the target location marked in the map for the current UAV location to the ground controller.

3.4 Summary

Implement the algorithms by using the proposed mathematical equation and coded it into Raspberry Pi. The payload carrier is created using a servo motor. The proposed algorithm waits for the target location coordinates to the Raspberry Pi from the ground control station. The proposed algorithm accounts for the following factors to execute an accurate drop: UAV velocity, UAV altitude, wind velocity, UAVs current location coordinates, and target coordinates. The weight of the payload and its approximate drag coefficients have been hardcoded into the Software.

Chapter 4: Evaluation and results

4.1 Introduction

The evaluation was planned to do with the actual data by performing UAV payload drop-off for 20 rounds and checking the accuracy of the algorithm since there was no actual data set to test the algorithm. Due to the COVID-19 pandemic, it is not possible to test this algorithm in the real world. Hence evaluation was only done by using SITL.

Evaluation for the proposed algorithms was done by using SITL Figure 19. SITL allows running ArduPilot on the computer without the need for any special hardware. SITL can simulate copters, rovers, and planes. MAVProxy is used as a GCS to communicate with the UAV. MAVProxy is a full-featured ground station application for the ArduPilot open-source autopilot project.

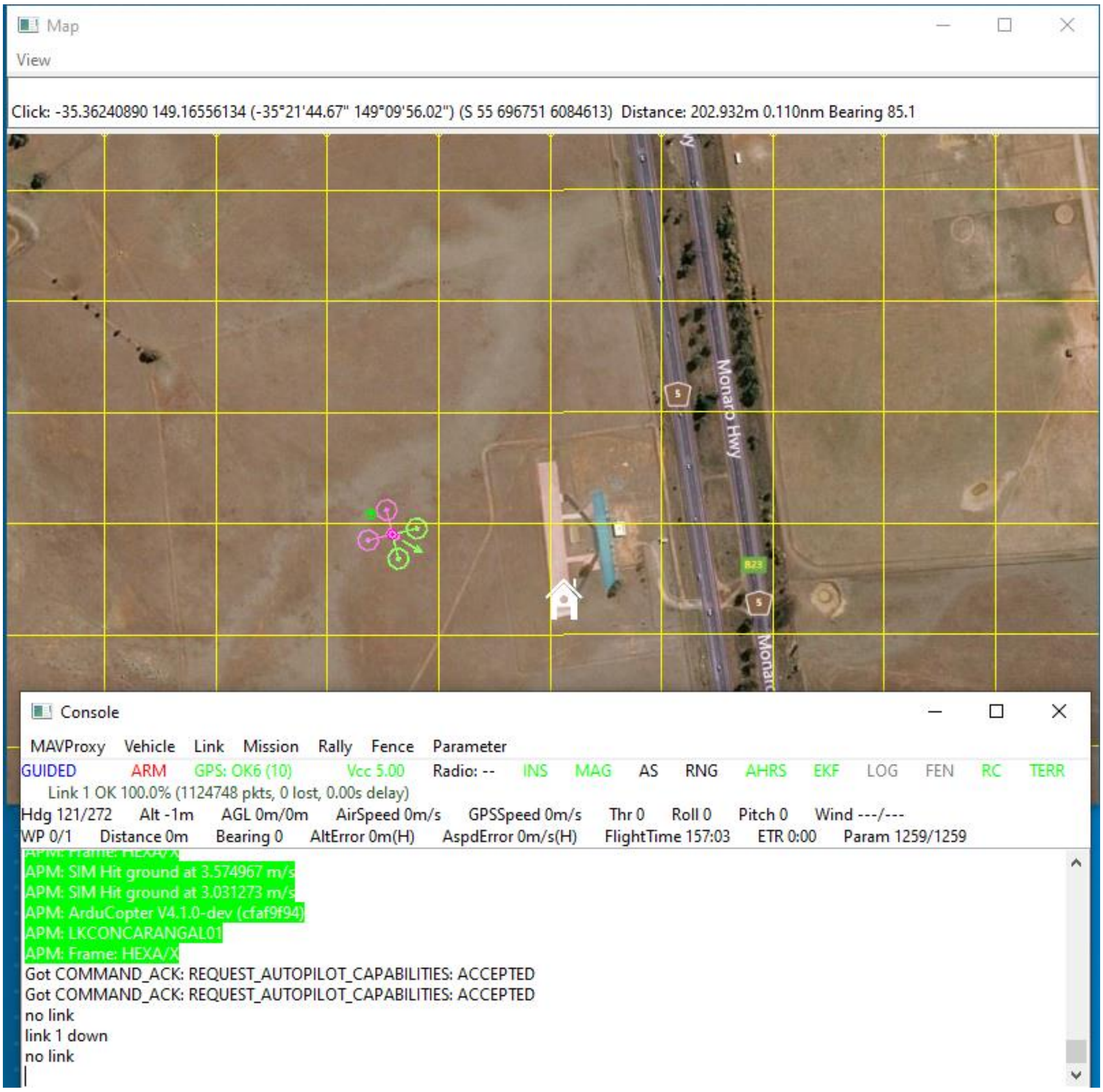


Figure 19: Software in the Loop (SITL) Window

4.2 Evaluation

MAVProxy connects to SITL. The required attribute values have been taken through MavLink protocol to find the precise drop location in a natural environment. Generate a real dataset to compare the results. After generating the dataset, simulate it using the SITL and check the UAV payload precise drop by giving the dataset values as inputs and plot the expected target coordinates against the actual target coordinates. After plotting this data in a scatter plot, calculate the error using linear regression.

E.g., Creates two separate graphs for the North coordinate actual and expected values, and West coordinates actual and expected values.

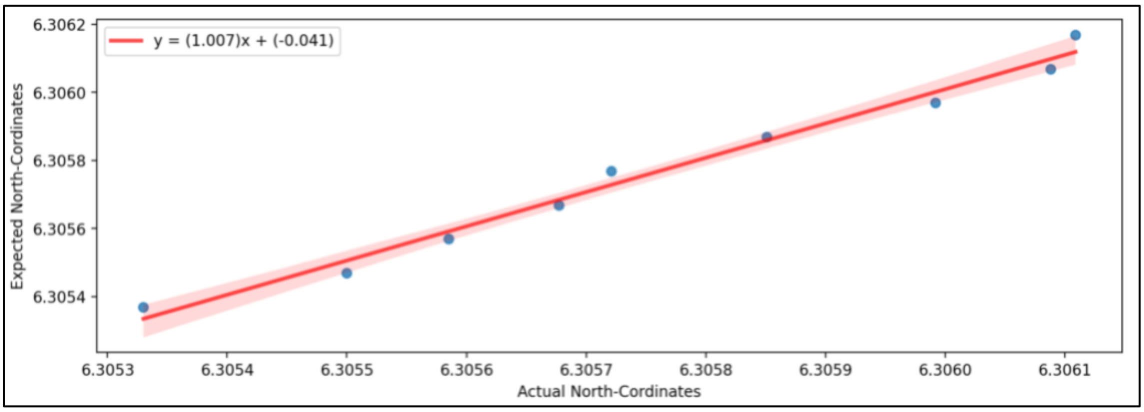


Figure 20: Sample Plot diagram for North Coordinates

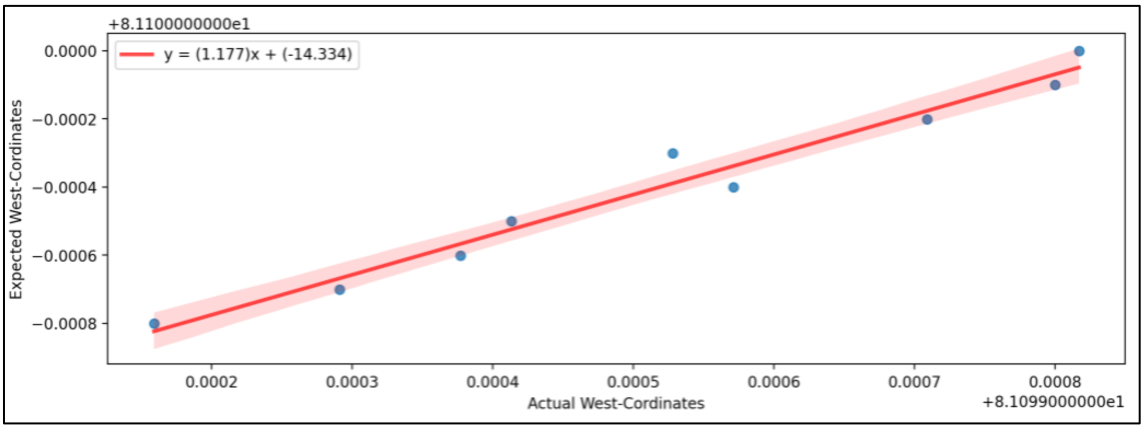


Figure 21: Sample Plot diagram for West Coordinates

Using this plot diagram mentioned in, Figure 20 and Figure 21, find the R-squared and check whether it is above 0.6, and if not, modify the algorithm and improve its accuracy. Then run the simulation again and recheck the R-squared and check the algorithm is up to standard.

4.3 Results

Evaluation 1

Run the first algorithm by changing the wind speed and wind direction by making UAV velocity zero.

The following table shows the results after running the first algorithm ten times by changing above mentioned conditions in SITL.

Assume that drag coefficient for a rectangular box (payload to drop) is 2.1, air density at sea level 1.225 kg/m^3, gravity is 9.81 m/s^2, area of the payload surface is 0.001 m^{2,} and mass of the payload is 1.5 kg. The altitude of the UAV is 30m.

Table 5: Release point distance from UAV current location using algorithm 1

No	Wind speed (ms^{-1})	Wind direction (degrees)	Target point and UAV location	Payload release point distance (m)
1	5	25	6.30533, 81.09915	0.06
2	6	30	6.30543, 81.09925	0.09
3	7	60	6.30553, 81.09935	0.11
4	8	120	6.30563, 81.09945	0.12
5	9	150	6.30573, 81.09955	0.15
6	10	270	6.30583, 81.09965	0.26
7	11	220	6.30593, 81.09975	0.32

Evaluation 2

Run the second algorithm by changing the wind speed and wind as same as in Experiment 1. To run this algorithm velocity of the UAV should be zero. Assume that all the other factors are the same as in Experiment 1.

Table 6: Target locations and distance using algorithm 2

No	Wind speed (ms^{-1})	Wind direction	UAV location	Target point	Distance (m)
1	5	25	6.305330, 81.099159	6.305329, 81.09915	0.06
2	6	30	6.305430, 81.099259	6.305429, 81.09925	0.09
3	7	60	6.305530, 81.099359	6.305528, 81.099358	0.11

4	8	120	6.305630, 81.099459	6.305628, 81.099458	0.12
5	9	150	6.305730, 81.099559	6.305729, 81.09955	0.15
6	10	270	6.305830, 81.099659	6.305827, 81.099658	0.26
7	11	220	6.305930, 81.099759	6.305927, 81.099758	0.32

The results in Table 5 and Table 6 were taken after simulating SITL seven times. It shows that both the results are matched perfectly for the given inputs. Comparing the results taken from the simulator needs a real data set, which was not possible due to the COVID-19 situation.

4.4 Discussion

This section will discuss the results and approaches used in this research thesis and other relevant research.

UAV technology has been emerging since World War I. There are many studies about precise dropping techniques and approaches. The algorithms that find the release point and the target point proposed in this thesis have continuously been calculated on the fly. That helps to make the error minimal.

Algorithm one is used to find the precise payload release location for the given target. This location finding is challenging due to the various conditions. One of the crucial factors is changing wind and the direction of the wind continuously. Singh and Garg (Singh and Garg, 2016) did a manually and automatic payload drop. In that approach, they stated that wind is constant during the fall of the payload. Since the wind is a more crucial factor the accuracy of the precise drop will be low. To overcome that issue, the algorithm calculates a new wind speed for each iteration of the loop by using wind profile power law (Touma, 1977). This helps to reduce the error that can happen from the wind. That is being addressed from the solution given in this thesis. Another problem addressed in this thesis is payload drop can be done manually. The ground controller gets a notification after the UAV reaches the release point. The primary use of this thesis is to serve in humanitarian missions. There may be situations like the UAV is in the release point, but the target cannot be reached because of the disturbance between the target and release point. The research of Mathisen (Mathisen *et al.*, 2020b) has done an autonomous precise dropping, which is not practical for the scenarios mentioned above. This research paper overcame that situation by giving a configuration to the ground station to configure whether the precise drop is done automatically or manually.

Algorithm two is developed to find the target drop location from the current location of the UAV. UAV should be in a stabilized mode to run this algorithm. Algorithm two sends an image to the ground station with a marked location in a map that predicts the target drop-off position for the payload. The challenge of this approach is that it is not enough to get the altitude of the UAV to calculate this. Because the target location may not be flat land, hence the algorithm uses a DEM to identify whether the generated coordinate is actually land or not. The correctness of this approach highly depends on GPS accuracy.

The advantage of this algorithm is that it can validate the target location before doing a precise payload release.

4.5 Summary

This chapter discussed the evaluation of proposed algorithms. Results that were obtained after running algorithm one and algorithm two and compare the results. Discussed the challenges while implementing the algorithm and how to overcome those challenges. Finally discussed the research gaps that are addressed in the thesis.

Chapter 5: Conclusion and Future work

5.1 Conclusion

This thesis represented a detailed description of the use cases of UAVs and proposed a mathematical model to find the precise drop location of the payload to the given target. Using that mathematical model, proposed an algorithm to find the release point of the payload to drop to the given target and another algorithm to find the dropping location from the current UAV position.

UAVs are emerging, and it is changing rapidly. It was used in the military in the early days, but now it is used in almost in every industry. UAVs play a significant role when it comes to humanitarian missions. It can reach the places where it is hard to reach from regular transport. UAVs can respond quickly. Precise drop mechanism is a valuable technique for UAVs where they cannot land. This thesis proposed two algorithms. One algorithm is to find the precise payload drop location to a given target. The crucial point of this is it has dynamic variables that keep changing. As an example, wind velocity and wind direction. Overcome dynamic variable problem, the algorithm mentioned above runs in one second and continuously calculates the precise drop location. By adding the wind profile power law, the algorithm became more accurate. After the UAV came to where the precise drop coordinate was mentioned, it had two options. It can drop the payload automatically, or it can send a signal to the ground controller. The configuration for manual/automatic payload drop should be configured before the UAV flies.

The other algorithm can send the approximate target to the ground controller if the payload drops in stabilized mode. This algorithm uses a digital elevation model to find the target location. Using these two methods, the ground controller validates the target before doing a payload drop-off. This thesis described more about the hardware equipment called 'payload carrier' used to carry the payload. It is built with Raspberry Pi that embeds the above algorithms. It can drop the payload autonomously, and if the ground controller configures it to a manual drop, it sends a signal to the ground controller when it reaches the drop point. The other proposed algorithm can be used to determine the target of the payload drop when the UAV is in stabilized mode. It will send the marked area of the map where the payload will drop through an open API.

5.2 Future work

First and foremost, this algorithm should be tested in the real-world using UAV, and possibly it will explore more enhancements that can be done to improve the accuracy of the algorithm. In the current approach to find the payload release point and find the target point of payload drop from the current UAV position, the payload should be a square shape. This approach can be further enhanced to drop more shapes other than squares. This algorithm does not calculate the error, and the algorithm can be more accurate after adding an error correction using a machine learning model.

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Appendix A: Implementation of payload release point

```
import time
import math
import timeit
from dronekit import connect, VehicleMode, LocationGlobalRelative, Command, LocationGlobal
from pymavlink import mavutil

dragCoefficient = 2.1
airDensity = 1.225
area = 0.001
timeInterval = 0.0001
targetE = 6.2972979
targetN = 81.1046362
mass = 2

vehicle = connect('udp:127.0.0.1:14550')
def arm_and_takeoff():
    while True:
    print('Global Location (relative altitude): %s'% vehicle.location.global_relative_frame)
    print ("Local Location: %s" % vehicle.location.local_frame )
    print "GPS: %s" % vehicle.gps_0
    uav_location = vehicle.location.global_relative_frame
    if preciseDrop(vehicle.airspeed,vehicle.heading,uav_location,targetE,targetN,
                   vehicle.location.global_relative_frame.alt,vehicle.wind,mass):
        break;
    time.sleep(1)


def preciseDrop(vSpeed,vHeading,uav_location,targerNDir,targetEDir,vHeight,WSpeed,payLoadMass):
    print(vSpeed)
    start_time = timeit.default_timer()
    t = 0
    Ug = 0
    V = vSpeed
    W = WSpeed
    theta = vHeading
    alpha = 25
    m = payLoadMass
    k = 0.5*dragCoefficient*airDensity*area

    H = vHeight
    N = uav_location.lat
    E = uav_location.lon
    Ve = V*math.sin(theta)
    Vn = V*math.cos(theta)

    while H > 0:
        ae = -k/m*(Ve-W*math.sin(alpha))**2
        an = -k/m*(Vn-W*math.cos(alpha))**2
        N = round(addMetresToLatitude(N , Vn*timeInterval),20)
        E = round(addMetresToLongitude(E ,N, Ve*timeInterval),20)
        Vn = Vn + an*timeInterval
        Ve = Ve + ae*timeInterval
        ag = (m*9.81 - Ug**2*k)/(m + 2*timeInterval*Ug)
        H = H - Ug*timeInterval
        Ug = Ug + ag*timeInterval

    print(N,E,H)
    distance = disBetweenLocation(N, targerNDir, E, targetEDir)
    print('Distance: %s'%float(distance))
    if distance <= 0.5:
        return True
    else:
        return False
```

```
def disBetweenLocation(lat1, lat2, lon1, lon2):

    lon1 = math.radians(lon1)
    lon2 = math.radians(lon2)
    lat1 = math.radians(lat1)
    lat2 = math.radians(lat2)

    # Haversine formula
    dlon = lon2 - lon1
    dlat = lat2 - lat1
    a = math.sin(dlat / 2)**2 + math.cos(lat1) * math.cos(lat2) * math.sin(dlon / 2)**2

    c = 2 * math.asin(math.sqrt(a))

    # Radius of earth in kilometers.
    r = 6378.137
    # calculate the result
    return(c * r * 1000)

def addMetresToLatitude(lat,value) :
    earth = 6378.137
    m = (1 / ((2 * math.pi / 360) * earth)) / 1000
    return lat + (value * m);

def addMetresToLongitude(long,lat,value) :
    earth = 6378.137
    m = (1 / ((2 * math.pi / 360) * earth)) / 1000;
    return long + (value * m) / math.cos(lat * (math.pi / 180));

arm_and_takeoff()
```

Appendix B: Implementation of payload release target

```
def findTarget(vSpeed,vHeading,uav_location,vHeight,WSpeed,payLoadMass):
    print(vSpeed)
    start_time = timeit.default_timer()
    t = 0
    Ug = 0
    V = vSpeed
    W = WSpeed
    theta = vHeading
    alpha = 25
    m = payLoadMass
    k = 0.5*dragCoefficient*airDensity*area

    H = vHeight
    N = uav_location.lat
    E = uav_location.lon
    Ve = 0
    Vn = 0

    while H > 0:
        ae = -k/m*(Ve-W*math.sin(alpha))**2
        an = -k/m*(Vn-W*math.cos(alpha))**2
        N = round(addMetresToLatitude(N , Vn*0.0001),20)
        E = round(addMetresToLongitude(E ,N, Ve*0.0001),20)
        Vn = Vn + an*0.0001
        Ve = Ve + ae*0.0001
        ag = (m*9.81 - Ug**2*k)/(m + 2*0.0001*Ug)
        H = H - Ug*0.0001
        Ug = Ug + ag*0.0001

    print(N,E,H)
    distance = disBetweenLocation(initialN, N, initialE, E)
    print('Distance: %s'%float(distance))
```

Appendix C: Implementation of the UAV keyboard controller

```
def handleUAV(altitude):
    while not vehicle.is_armable:
        print("waiting to be armable")
        time.sleep(1)

    print("Arming motors")
    vehicle.mode = VehicleMode("GUIDED")
    vehicle.armed = True

    while not vehicle.armed: time.sleep(1)

        print("Taking Off")
        vehicle.simple_takeoff(altitude)

    while True:
        v_alt = vehicle.location.global_relative_frame.alt
        print(">> Altitude = %.1f m"%v_alt)
        if v_alt >= altitude - 1.0:
            print("Target altitude reached")
            break
        time.sleep(1)



def set_velocity_body(vehicle, vx, vy, vz):

    msg = vehicle.message_factory.set_position_target_local_ned_encode(
            0,
            0, 0,
            mavutil.mavlink.MAV_FRAME_BODY_NED,
            0b0000111111000111, #-- BITMASK -> Consider only the velocities
            0, 0, 0,        #-- POSITION
            vx, vy, vz,     #-- VELOCITY
            0, 0, 0,        #-- ACCELERATIONS
            0, 0)
    vehicle.send_mavlink(msg)
    vehicle.flush()


def key(event):
    if event.char == event.keysym: #-- standard keys
        if event.keysym == 'r':
            print("r pressed >> Set the vehicle to RTL")
            vehicle.mode = VehicleMode("RTL")

    else: #-- non standard keys
        if event.keysym == 'Up':
            set_velocity_body(vehicle, gnd_speed, 0, 0)
        elif event.keysym == 'Down':
            set_velocity_body(vehicle,-gnd_speed, 0, 0)
        elif event.keysym == 'Left':
            set_velocity_body(vehicle, 0, -gnd_speed, 0)
        elif event.keysym == 'Right':
            set_velocity_body(vehicle, 0, gnd_speed, 0)
```