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02223 Model-Based Systems Engineering

Group 19: Autonomous Drones in S&R Operations

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Report	17%	17%	17%	17%	17%	17%
Abstract	x					
1 Introduction					x	
2 Related works						x
3 Problem description	x					
4 The system modelling						x
5 The Simulation and Experiments	x	x	x		x	x
6 Cost estimates				x	x	
7 Results		x		x		
8 Discussions			x	x		
9 Future Work		x				
10 Conclusion			x			
Modelling	17%	17%	17%	17%	17%	17%
Simulation	17%	17%	17%	17%	17%	17%

May 19, 2023

Autonomous Drones in S&R Operations

Research paper on using network of drones in search and rescue missions

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ABSTRACT

Hiking has many benefits, such as being enjoyable and gratifying, but it may also be hazardous. When hikers go missing, the effort of finding them might be exceptionally challenging since the search area might be large or difficult to access. It is critical to locate the missing individual as soon as possible to limit the fatal toll. Undoubtedly, autonomous drones will play an important part in human-machine teaming in future search and rescue S&R missions. This paper will describe a search and rescue drone model-based system that uses a sensor-based embedded system to better rescue search for lost persons. To make the rescue search more successful, each drone is equipped with a thermal imaging camera and a regular camera as well as GPS location. Numerous drones are then linked together in a network that optimizes the search. The simulation trials suggest that the proposed model was successful in locating the missing individual in less time and money than the typical S&R missions. The whole process including design and simulation is documented in this report.

Keywords

Search and rescue missions, surveillance drones, model-based systems

1. INTRODUCTION

Hiking is an excellent pastime to get fit and enjoy the nature. Moreover, the hikers want to experience the wilderness in search of a remarkable adventure and magnificent views. Several studies show that walking can increase your lifespan by as much as six hours a week and improve your mental health. It lowers cardiovascular and respiratory illnesses, as well as cancer [4]. In the United States alone, the number of active hikers are almost 57.8 million, more specifically 59.4% of those hikers are male and 40.6% are female [7].

The experience of hiking could have many positive aspects such as being fun and rewarding, but it could also be dangerous at the same time. Especially if the hiker plans to go alone to an isolated and remote area without the proper precautions. Although the number changes from year to year, around 2,000 hikers get lost which leads to enormous search and rescue missions to locate these lost hikers. These lost hikers may suffer from dehydration, heart exhaustion and hypothermia that in some cases could lead to death [4].

According to the experts' calculation, there are around four deaths in the United States yearly per 100,000 hikers; and there is a greater possibility to die at the North Cascades National Park than at any other park since there are 652 deaths out of 10 million visitors [7]. There are numerous causes of death, including falling, excessive or insufficient water, lightning, high temperatures, and animal attacks [2].

Finally, search and rescue missions can be extremely costly but that depends on the duration of the rescue process, for example, the search and rescue mission for locating two teenagers in Orange County's Trabuco Canyon in 2013 lasted five days and costed around 160,000 USD which was paid from taxes [3, 12].

- Section 2 introduces the related works to the drone's simulation and the motivation of this paper.
- Section 3 describes this project problem with the potential use cases.
- Section 4 explains the design of the different system models.
- Section 5 presents the system simulations implementation with some search strategies, drone's specifications and a baseline.
- Section 6 presents a system cost estimation.
- Section 7 discusses the results obtained and their relevance.
- Section 8 summarises the main outcome of simulation and its impact on design.
- Section 9 points out the future improvements that could be applied to this project.

2. RELATED WORKS

Not many literature and research papers on drone simulation could be found. An overview of related works with the main focus on the paper's contribution to the state of art on drone simulation research are presented as the following:

- Reference [11] purpose is to implement a drone that could identify victims in the natural disasters area and that is conducted in 2019. The reference uses a Quadcopter to access these areas and with a camera attached to the drone, it could detect people. The paper's main focus is to present the implementation of the Cascaded Canny Edge and SURF. Hence these implementations improved the accuracy by 7% and the rescue time by 6%. The paper is, with 12 references, and that is good.

- Reference [6] motivation is to implement a drone with specific sensors that could detect the threat of chemical, nuclear, biological, radiological, and explosive (CBRNe) threats. It is now a mandatory requirement for the security and safety of human operators involved in emergency management. To optimize the drone's proficiency in detection, fluid dynamics numerical simulations are done to find the most optimal configurations of the sensors' position on the drone. The paper is, with 50 references, and that is very good.
- Reference [5] focus is to implement a drone to monitor the agricultural fields and that was written in 2020. So, the technological advances in the platforms and sensors have improved the quality of agricultural land monitoring needs. The paper is, with 51 references, and that is excellent.

2.1 This Paper Motivation

The main goal of the drone system discussed in this paper is to discover and rescue people who have become lost or confined due to injuries. This is done by connecting multiple drones to create an internet of things (IoT) system that can bring operational efficiency in rescuing hikers during a rescue mission. Drones can reduce the cost and risk of such missions and increase the chances of finding the target alive.

3. PROBLEM DESCRIPTION

The problem in this article is to investigate how to optimize rescue searches for lost individuals using a sensor-based embedded drone system. When individuals require search and rescue, the rescue part is usually not the issue. It is locating the individual who needs support in a short time period. This challenge will be attempted to be solved utilising a network of drones equipped with thermal imaging sensors as well as GPS position sensors. Different paths will be investigated in order to determine which is the most successful in searching for a missing individual. Efficient path planning for drones, for example, is critical in an autonomous drone system and presents significant issues due to multiple restrictions, such as limited energy, speed, and payload, and sensitivity to varied situations.

In light of the rapid progress of Internet technology, many drones may be connected to form an "Internet of Things" (IoT) system and can also be equipped with features such as a facial recognition system and a heat monitor. By connecting drones with IoT capabilities, it is possible to fulfill a range of critical activities that would be too expensive, unsafe, or impracticable for people. Furthermore, since thermal imaging on drones relies on heat emitted by the subject, the search may continue even in complete darkness.

The purpose of the drone system application designed in this paper is to locate individuals using a thermal imaging camera, regular camera and GPS.

The system makes use of unmanned drones, making modeling difficult. The challenges of the designed dynamic system with embedded computing include having each drone read data from various sensors, such as the heat camera; controlling the flight path of the drones to ensure that they are not searching in the same location; processing all of the gathered data from each drone; and ensuring that the data from each drone is sent to the main operator, who keeps track of the searched area.

Most search and rescue operations have a limited amount of time to find the missing person. As a result, it is important that rescuers locate the sufferer as soon as possible. As a result, the key question becomes: *How can we save people in dangerous circumstances in a short amount of time?* Reduced search time is especially essential for victims in critical conditions.

3.1 Potential Use Cases

Some use cases for drone-rescure search system include:

Patrol borders To boost security, the government can employ this to help refugees who run away from war area or to prevent criminals from entering the country.

Search for survivors in affected areas For example, the drone system may be used to locate more individuals who may have been injured as a result of natural disasters such as earthquakes or fires/explosions, it can even be used to rescue those who are fleeing a war.

Search for lost animals Looking for missing animals after a blizzard. For example, in 2012, numerous animals, especially horses or sheep, perished or were lost in a large snowstorm in Iceland. Following the blizzard, search and rescue teams from all over were looking for animals for the farmers in the area. This application might aid in finding animals in similar circumstances much more quickly.

Detect fires in forests The risk of a minor fire spreading out of control is especially great during a dry season. This system could patrol an area on a schedule and transmit a signal if there is a potential fire danger (smoke detector/heat sensor/camera). The person controlling the system would then receive a signal with GPS location and could promptly extinguish the fire before it spreads out of control, or contact the local authorities.

The Use case that is used for modeling the system:

Search for lost people When a hiker is reported missing who is either extremely elderly or very young and hence defenceless, every minute matters for the emergency services. Drones should be involved in the rescue effort to discover missing individuals as quickly as possible. Drones are tiny, nimble machines that can scan big regions swiftly and effectively. They can also discover individuals at night or in thickly forested places, something humans cannot.

4. THE SYSTEM MODELLING

Trying to solve the problem that is presented in this report, the team has designed a system in which a multiple number of drones using a satellite communication to connect with a base station. These drones could search an area using different search algorithm to detect a person and with various battery types and speeds. When the drone finds that person, it will send the coordinates of the target to the base station. The team wants to rescue people in a time and cost that compete the normal rescue missions. Therefore, they tried to develop a system that consist of a base station and drones that includes different subsystems. In the following sub-sections, some models will be discussed.

4.1 The Conceptual system model:

The team first designed a conceptual model to receive the initial understanding of the system and its possible simulations. Some variables that could be considered for simulation as the number of system components, nature and drone's type, battery and speed. These possible variables could be seen in the conceptual model in figure [1] :

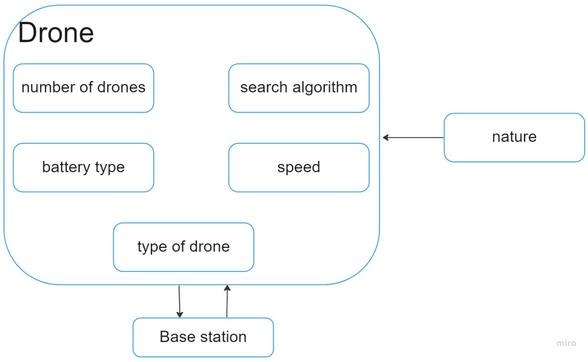

Figure 1: The Conceptual System Model

4.2 The System Environment

Generally, it includes everything the system interacts with such as the human target and the environmental aspects that is terrain, pressure, wind, overcast and humidity. More specifically it also contains a set of variables that define the system execution and the most important component in this system is the drone. This project system environment contains the base station that communicates with several drones that have multiple subsystems. These subsystems help to detect the human target even though there is the effect of the environmental factors that are presented in figure [11a] and [11b] in appendix [A.1]

4.3 The System Components:

- The drone: has many subsystems to search and detect human targets. Hence, it has some basic human detection algorithm and if the result possibility is high, it sends the information to the base station.
- The base station: has extra batteries for drones to continue searching and gets all drones data about searching to run more complicated algorithms about human detection.

4.4 The System Architecture Model:

In this model specific technologies are considered for the hardware and software and the team modelled them. The System Architecture Model includes the base station, the environmental factors and the drone with all technologies that are needed for the drone's subsystems such as the path following, communication, fight control, camera, power and decision subsystems including the image analysis.

Figure [2] presents the Drone Power Subsystem in the Architecture Model. The team created the detailed system architectural model with all main key components in appendix [A.2] figures [12], [13] and [14]

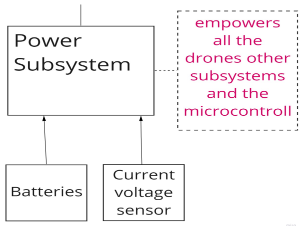

Figure 2: The Drone Power Subsystem in the Architecture Model

4.5 The System Communication Model:

In the Communication model each sending process writes to a shared variable that will be read by a receiving process. Not only that but it also includes the transmission of messages over channels.

The team created the communication model for this project system in figure [15] in appendix [A.3]

4.6 The System Application Model:

The drone application model could be identified as a set of communicating process. So, the process network may also contain timing information(ticks). The drone power subsystem is presented in figure [3] and the application model with more details is presented in appendix [A.4] figures [16], [17], [18], [19], [20] and [21]

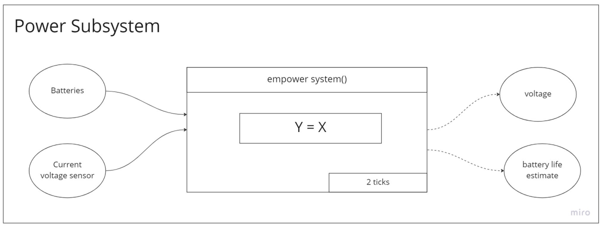

Figure 3: The Drone Power Subsystem in the Application Model

5. THE SIMULATION AND EXPERIMENTS

Simulation is a good way to test the model and gain a wider understanding of its behavior. This model is simulated so it is not necessary to invest in multiple drones that have the attributes needed to test, to control the test environment and to save time, but the simulation takes a shorter time than testing the model in the real world. It also makes a comparison between models easier.

The simulation is done using Python. It considers the search strategy of the drone, the number of drones, and different drones with different attributes e.g. price and battery range.

5.1 Base station

The base station is the starting point where the drones are released and controlled from. Images that the drones get are sent to this base station where they are evaluated by humans, this is only assumed but not simulated. The base station is also their charging station where they are refueled or batteries are swapped. The base station is implemented in the code as a separate class that has its own location and is aware of things like the drones' positions, the number of drones, and search strategies.

5.2 Search Strategies

Three search algorithms were made, but the main algorithms are the snake pattern search algorithm and the path following search algorithm.

5.2.1 Snake pattern

The depth-first-graph-search is an algorithm of visiting the states of a graph in a systematic order with keeping track of the visited states and not letting them to be repeated. The states are represented as nodes, the algorithm starts by the root node that is the base station in this project. Then this root node that is considered as a parent is expanded to get all the children nodes that are the map coordinates in this project. After that, expanding one selected child node. This operation is repeated until there are no children nodes anymore, then it moves to expand the nearest child that is not expanded yet. So, the algorithm explores the route of a drone as deep as possible [9] and [10].

The snake search algorithm depends on the previous explained algorithm. It divides the search area between the drones and then the drones scout their assigned area until they have found the missing person or all area has been searched. This search is done in a snake-like pattern, as can be seen in figure [4]. Visual representation of this search strategy can be viewed online: Snake.

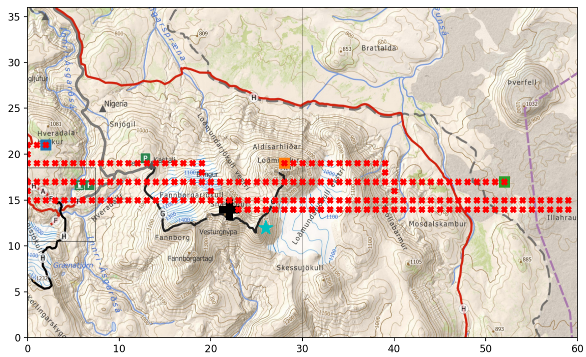

Figure 4: The snake search strategy

Implementation: Before the simulation is started, it was decided which area should be searched (length and width) and how many drones are used. The route is then decided based on the coordinates of the base station. Each drone gets an area assigned to search, but the area is divided by the number of drones. When designing the path for the drone, it is started by moving the drone to its assigned area. When the drone reaches the end of its assigned area it will go two steps forward, leaving a bit of an area that will be searched on the way back. This is done to decrease the number of times an area is searched twice.

The drone turns then to the other side and goes in that direction until it reaches the other end of its assigned area, then goes forward two steps and turns to the other direction. This will continue until the drone either can not go forward, needs to be recharged, or has found its target. If the drone can not go forward without leaving its assigned area, it will take one step backward and search the area that is missed before, doing the same snake pattern. This will continue until the target is found or all area has been searched without a success.

If the drone starts to run out of battery/fuel it will return to the base station where it will be refueled or the battery is swapped. It will then turn back to the place it previously ended its search and continue with the search.

5.2.2 Path following

The best-first-graph-search is an algorithm that is similar to depth-first-graph-search but the difference is that this algorithm depends on a heuristic function in picking which child to expand first. The heuristic function in this project is the coordinates of the hiking trail [10].

The path following algorithm is based on the best-first-graph-search that was found to be meaningful for this purpose. Search area is a reference to points of the hiking trail. This means that area close to the hiking trail is covered in first order, then search are is moved further from the hiking trail.

This approach is based on a real life assumption that any lost person would most likely deviate from the hiking path. Based on such assumption it makes sense to prioritize this area close to hiking path and continue on moving further from it.

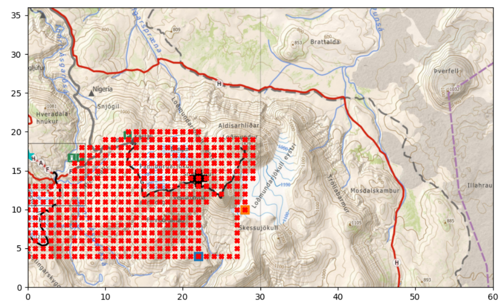

Figure 5: The path-follow search strategy

Implementation: Implementation of this search method is based on incremental point offsetting. It is using predefined offset vectors to move hiking trail reference points and redefine search areas. It is happening in such way that search area starts as small, close to the trail and moves further until all the points are covered. This concept is show in [6]. However, this visualisation is a bit simplified as search areas are defined based on individual hiking trail points, not points at the end of the trail. Visual representation of this search strategy can be viewed online: Path-follow.

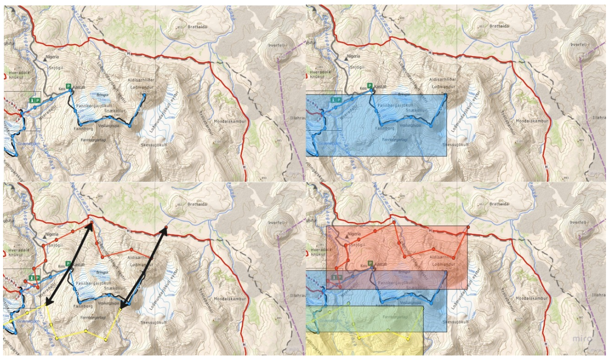

Figure 6: Visualisation of incremental point offsetting

This way of defining search areas allows many drones to work in the same area without interfering, as each of drones could have different offset vectors. Finding optimal parameters for this search strategy is another challenge. Defining direction and value of offset vectors has a big impact on the search efficiency. Moreover, a big issue with planning routes in this way involves undesired backtracking of drones (Visiting areas that has been searched again). Occurrence of this events has been minimized, but it still exist and could be optimized further in the future.

5.3 Baseline search and rescue time

In this section, the team looked for the rescue and search missions that are done with out the drones assistance to find lost people in the United States. The team will use these results as a baseline to compare the simulation results to them.

A study was conducted about Coast Guard assets on September 28th, 2017, to determine the number of search and rescue hours in each year from 1990 till 2013. The Team calculated the average time of each rescue mission in each year. The average hours spent on rescue missions from 1990 till 2013 are: (100, 98, 116, 88, 110, 122, 87, 108, 132, 159, 79, 120, 119, 93, 105, 88, 81, 87, 80, 84, 85, 91, 89).

So, the average time to recuse a lost person is 101 hour (4 days and 5 hours), and the yearly cost range between 32 to 1.141 million dollars [8].

5.4 Number of drones

In order to make the simulation as realistic as possible a different number of drones were considered. The team wanted to know if multiple drones make the search strategy more effective and if the time-wise gain outweighs the financial loss. They wanted to find out when the time-wise gain becomes insignificant or even negative.

In the implementation, the team made the number of drones a convertible parameter. The snake pattern search can use up to 60 drones (area width divided by the drone's field of view), whereas the route following search can only use up to four drones.

5.5 Specification of Drones

The considered drones are classified by their flying behavior into two main groups, fixed-wing, and multiple-rotor. The main difference is that fixed-wing drones can take off like regular airplanes thus they require a landing field, whereas multiple-rotor drones are able to execute a vertical take-off. One other difference that comes from the different shapes, is maneuverability and flying distance. Fixed-wing drones are bigger, require a landing field, and cannot change direction rapidly compared to the multiple-rotor version. A particular type of fixed-wing drone is called vertical take-off and landing (VTOL). These are kind of hybrid versions of the formerly mentioned two types. The simulator expects that in every case both types of drones can take off, although, this may clear away the advantage of vertical take-off drones.

Model	Wingspan	Battery Endurance	Max Speed
EOS Technologie Strix 400 Fixed Wing UAV	4250 mm	5h	33 m/s
Applied Aeronautics Albatross Fixed Wing UAV	3000 mm	4h	40 m/s
Elevonx SkyEye Sierra VTOL	3100 mm	3h	35 m/s

Table 1: Physical parameters of fixed-wing drones

Model	Diagonal size	Battery Endurance	Max Speed
DJI Matrice 300 RTK	810 mm	55 min	22 m/s
DJI Matrice 600 Pro	1668 mm	32 min	20 m/s

Table 2: Physical parameters of multi-rotor drones

As it can be seen from [1]. and [2]. Table fixed-wing drones can reach higher maximum speeds and can fly much longer but they require a special transportation form because of their size. Although there is a difference in the maximum speed, it is worth mentioning that the cruising-speed is about the same, 17-18 m/s for all the considered drones.

5.6 Battery and fuel range

As previously discussed, each drone has to be regularly recharged or refueled and different types of drones have varying battery or fuel ranges. Instead of recharging a drone, batteries are swapped when they run out because there is no time to lose in these kinds of missions. The battery is then recharged when not in use. To prevent drones from suddenly running out of power, drones are needed to know when it is time to return back to the base station.

Implementation: This is implemented by checking each time the drone is moved if it has enough power to continue with the search and return to the base station. If it has enough power it will continue; if not, it will put the last location into memory and return to the base station. When it has been recharged or refueled it will return to that location and continue with its search.

5.7 Width of view

In this simulation, all drones were assumed to have the same visibility range, that is 250m. This is a number that was found reasonable given the circumstances. This parameter is fixed in the implementation.

6. COST ESTIMATES

The simulator can help to calculate the efficiency of drone-based rescue searches. However, the cost of it is significant for the feasibility. The cost of this system comes mainly from the number of drones and from the base station.

As can be seen in tables: [1], [2], and [3], the multi-rotor drones are generally cheaper as well as smaller. This makes them suitable for smaller-scale fast missions. On the other hand, fixed-wing drones are unbeatable when a larger area has to be searched.

As the other part of the system, a base station with the required technologies normally cost around 10,000 USD.

It is worth a mention, the manufactures generally do not produce commercial drones of this size, resulting in difficulty finding real cost estimates.

Model	Flying distance	Price USD
EOS Technologie Strix 400 Fixed Wing UAV	320 kms	61,700
Applied Aeronautics Albatross Fixed Wing UAV	100 kms	17,000
Elevonx SkyEye Sierra VTOL	200 kms	38,100
DJI Matrice 300 RTK	56 kms	13,000
DJI Matrice 600 Pro	35 kms	10,950

Table 3: Price of the drones

7. RESULTS

7.1 Snake algorithm

Here are comparisons of results from various simulations. The program is designed to take in several variables regarding the drones, and outputs the time it takes to find a person; whose location is randomly generated.

The inputs are as follows: *<Battery range>* *<Speed of drone>* *<Quantity of drones>* *<N simulations>* *<Algorithm>*. Using these inputs it is possible to estimate a likely case of drones searching for a lost person. As mentioned earlier in Ch. [5], Python is used to generate the simulation, but then for the results, a combination of a C-program and Bash shell script is used to calculate and automate multiple cases.

First, to simulate multiple cases using the snake algorithm. For range and speed realistic specification is used from the drones in Ch. [6].

Model	**range [km]**	**speed [m/s]**
EOS Technologie Strix 400	320	18
Applied Aeronautics Albatross	100	18
Elevonx SkyEye Sierra	200	18

Table 4: Specifications used as inputs for fixed winged drones

The simulation was run for three types of fixed-wing drones, each of them with a different quantity of drones, ranging from 1-4. The graph in Fig. [7], shows that there is not much difference in the types of drones. That could be the result of a long-range, shown in table [4], but they all have the same cruise speed of 18 m/s. There is a definite correlation between more drones speeding up the process of finding a person, as expected.

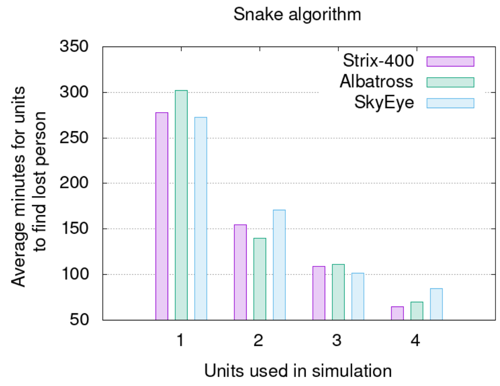

Figure 7: Average minutes for each type with different amount of drones

A baseline is included in the simulation to compare to the drones. The baseline is as if a person would be walking at the average speed of 1.35 m/s, looking for the lost person. The results in Fig. [8], show that using about ten people give as good results as using only one drone for the search.

In the graph in Fig. [9] only one type of drone is simulated to see how many units (drones) would be a possible waste of money and resources. In this case, the graph shows an exponential curve that flattens around 8 units, meaning that many drones could be used in a search and rescue mission until the results become almost identical.

7.2 Path-follow algorithm

Now, regarding the other search strategy: the path-follow system. The path-following algorithm was simulated the same way as the snake algorithm above, using specifications from drones in Ch. [6]. The main difference now is that the range for each drone is much lower than for the fixed wing drones, but the speed is similar as can be seen in table [5].

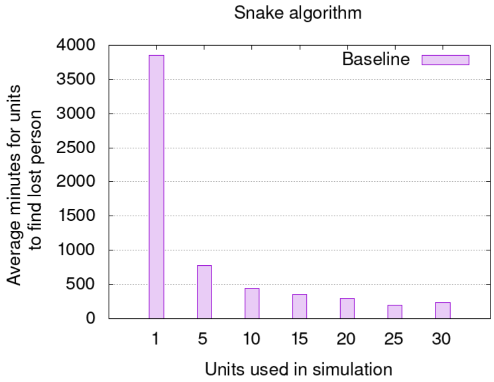

Figure 8: Simulating only the baseline

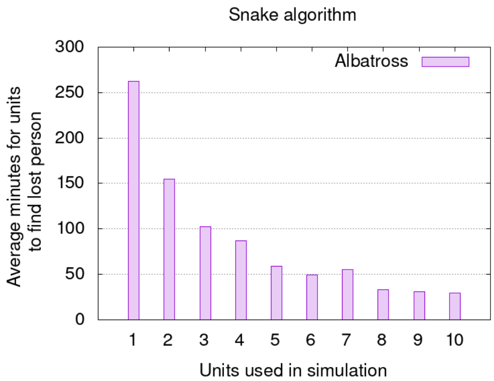

Figure 9: Simulating only different amount of drones used in search

Looking at the graph in Fig. [10], there is a clear difference between the two models. As expected the drone with higher range is able to locate the lost person more efficiently vs. the one with lower range.

There is a large difference between using one drone, with the average of 180 minutes, and using two, with the average of about 120 minutes. Although, there is a significant change using four drones in the simulation, with an average of 50 minutes. That is approx. 70% drop.

There are more plots in the appendix [A.5].

8. DISCUSSIONS AND FINDINGS

Series of simulations that has been executed provided a good portion of meaningful data for considering the use of drones in S&R operations. Resulting numbers are even more important when all factors like: cost, range, availability are taken under account.

8.1 Snake

Breaking down results shown in [7], it is clear that the number of drones used in the operation has a big impact on time of search. Difference in average time to find a lost person is halved when 2 drones instead of 1 drone is used. From 2 to 3 improvement in time spend on searching is around 30%.

Model	range [km]	speed [m/s]
Matrice 300 RTK	56	17
Matrice 600 Pro	35	18

Table 5: Specifications used as inputs for multiple rotor drones

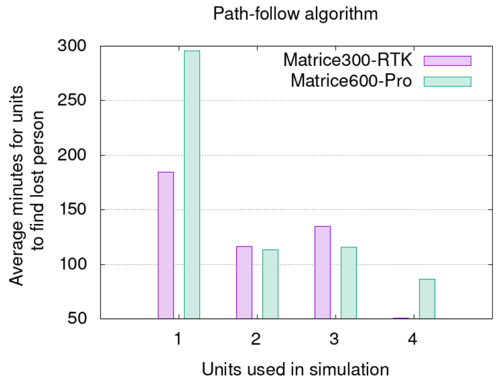

Figure 10: Average minutes for each type with different amount of drones

Generally, up to 3 drones, there is a linear trend between time spent on search and amount of drones used in search. However, as soon as more than 3 drones are involved in the search the difference becomes less and less significant [9].

Cost-wise, fixed-wing drones used in these scenarios differ in price quite significantly. As shown in [3], prices for individual drones go from 17,000 USD to 61,700 USD. This price difference seem to have no significant impact on results. Only for 4 drone scenario drone Strix-400 have quite an advantage compared to other vessels.

Compared to baseline, which is covering same distance by a S&R team on foot, any combination of number and type of drone is quite visibly superior in terms of time spent on searching. Difference is biggest for a single drone scenario, where search time is more than six times shorter.

8.2 Path-follow

Analyzing figure showing path-follow search algorithm results [10], it has been concluded that, in general, average time of the search is smaller compared to snake search. In case of one drone results differ between drones, Matrice 300-RTK it shows 30% shorter average time than Albatross fixed wing drone. On the other hand Matrice 600-Pro was slightly less efficient than Albatross with average time of search 10% longer. Interestingly, time of search does not decrease with the number of drones. Search time for 2 and 3 drones is very similar.

Considering costs of two drones used in this scenario of the simulation, Matrice 300-RTK is a clear winner as it's cost is 20% more [3], and seems to have better results when it comes to average time spent finding the lost person. It has a smaller range: 56km, compared to 35km for Matrice 600-Pro. This difference in range does have a significant impact on the results of simulation.

8.3 General

General observation regarding the results is that searching using drones is always more effective than assumed baseline. This means that choosing any type of drone is going to improve search efficiency and increase the chance of survival for lost hikers.

Speaking about the results itself, it need to be clearly addressed that this conclusion is based on initial assumptions regarding visibility range of drones, range, speed etc. These variables are crucial for simulation to be real-world relatable. For instance, visibility tend to be very limited during rough hiking conditions and this is the time when many hikers get lost. There are many scenarios to investigate in the simulation, however time constrains of the project made it demanding to go that much in-depth.

9. FUTURE WORK

The subsections that follow address areas where further effort is needed to improve this system.

9.1 Add a bluetooth signal sensor to the drone

A sensor that detects a bluetooth signal from a nearby phone should be incorporated in the drone to make the system more efficient. Because most individuals currently carry a phone, integrating this in the design would make the rescue search much more efficient. By attaching this sensor to the drone, the cell phone becomes a beacon capable of directing rescue crews to its position. The instrument has enormous potential for saving lives in calamities such as earthquakes, when people may be trapped beneath debris or soil, or in avalanches. It might also be useful in locating persons who are concealed beneath a dense canopy, such as in a forest, where the heat sensor could possibly not detect the lost person [1].

9.2 Simulation with more environmental factors

To make the simulation as precise as possible environmental factors need to be considered. These factors can be pressure, electromagnetic fields, wind, overcast, humidity, etc. These factors can affect the drone significantly; for instance, the wind may cause the drone to lose power more quickly.

9.3 Simulation with more drone attributes

Different drones have different features, some might have a better camera or the camera's width of view is narrower. These are features that would be useful to add to the simulation.

9.4 Make each drone capable of detecting trees and other obstacles.

AI software can be used to do this. If the drone's camera sensor detects something in front of it, it should avoid it.

10. CONCLUSION

In this paper, a concept for a model-based search and rescue drone system that employs a sensor-based embedded system to aid in the search for a missing person was proposed.

As previously said, locating a missing person as early as possible is critical in order to lessen the danger of the person being discovered fatal. As a result, a simulation was created to examine the efficacy of each search algorithm that was developed. The snake pattern search algorithm and the path following search algorithm were created as search algorithms. The typical walking pace of a human was used as a benchmark to assess how successful the drone route algorithm was against individuals on foot attempting to find the missing person without employing drones. The average human walking rate was deemed to be noteworthy as a benchmark because rescue searches are now almost completely done by people without the assistance of drones.

Having this in mind, drones are very likely to play a crucial role in S&R operations. While this simulation wasn't very detailed, it showed that the use of drones has always a positive outcome when it comes to searching for a lost person at the hiking trail. Basing this statement on numbers, using even a single drone can reduce the time of search more than six times [8], [9] and [10]. Strategy of search, number of drones and exact type of drone seem to have much smaller impact on the search time. This means that any drone that took part in this study is a good fit for S&R operation on a hiking trail or any other application with open space, e.g. water bodies, nature parks. On the other hand there are arguments against using drones in these scenarios, such as relatively high price of some solutions and questionable reliability in harsh conditions. However, these challenges could be optimized with further development of knowledge and technology.

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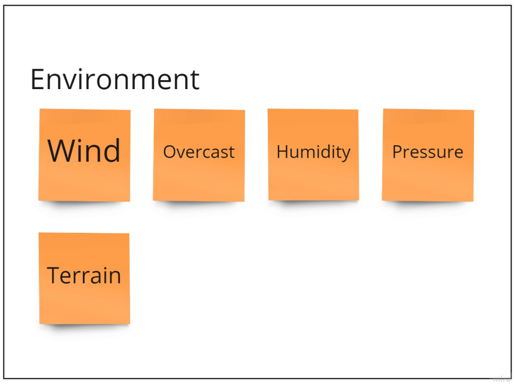
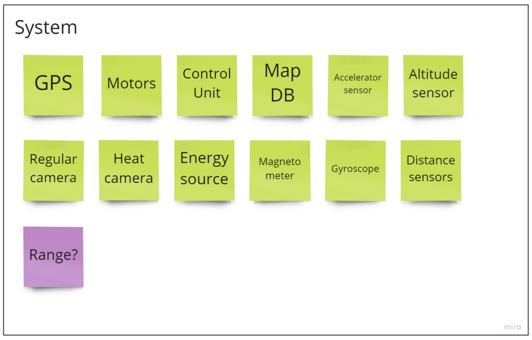
APPENDIX

A. THE SYSTEM MODELS

A.1 The Environmental Factors



(a) The Environment Factors



(b) The system

A.2 The System Architecture Model

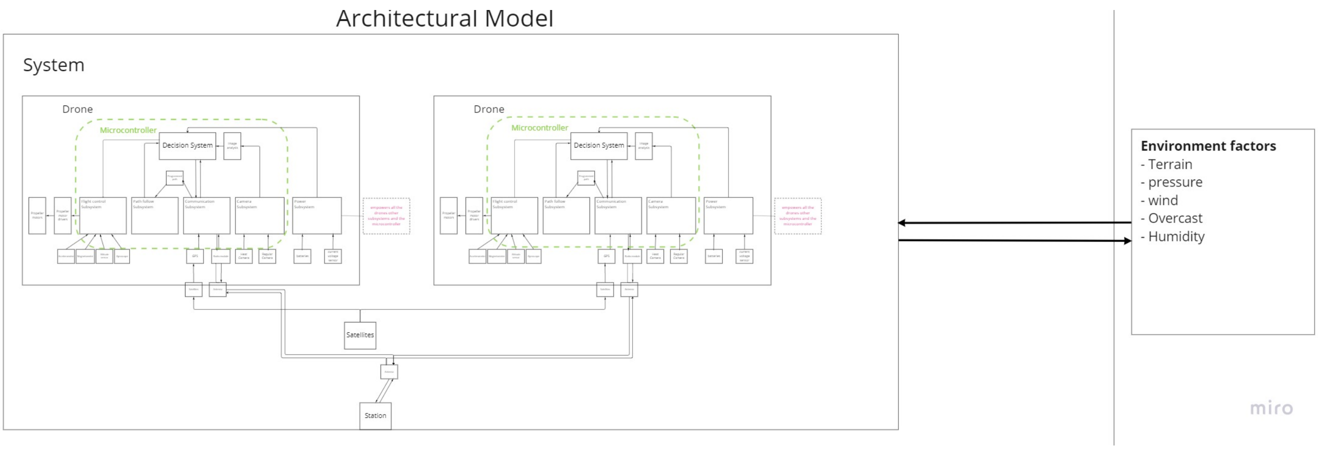


Figure 12: The system Architecture Model

System

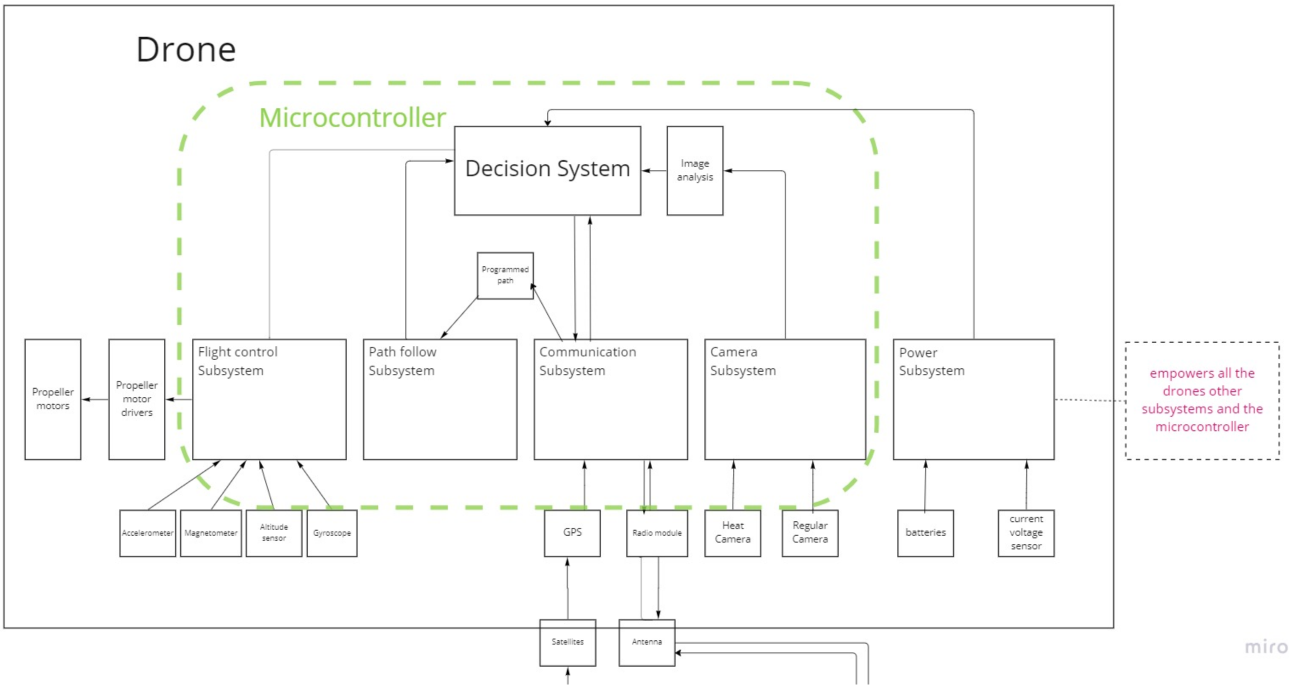


Figure 13: The Drone's Architecture Model

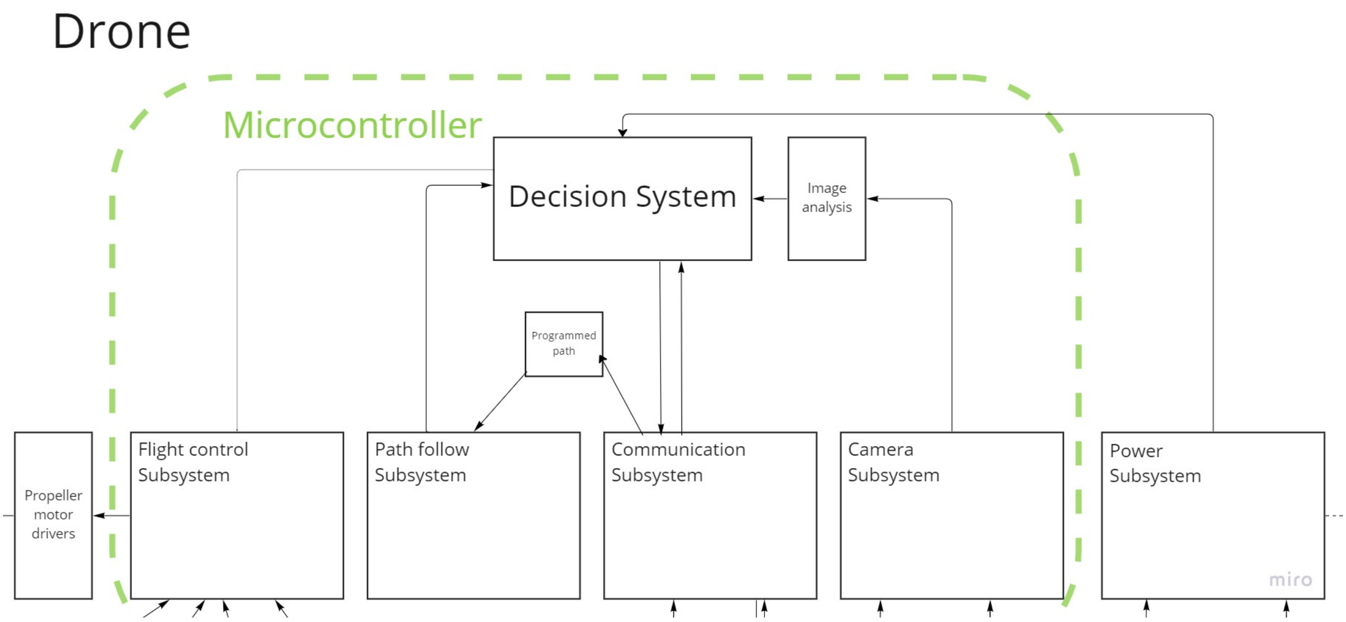


Figure 14: The Drone's Microcontroller Architecture Model

A.3 The System Communication Model

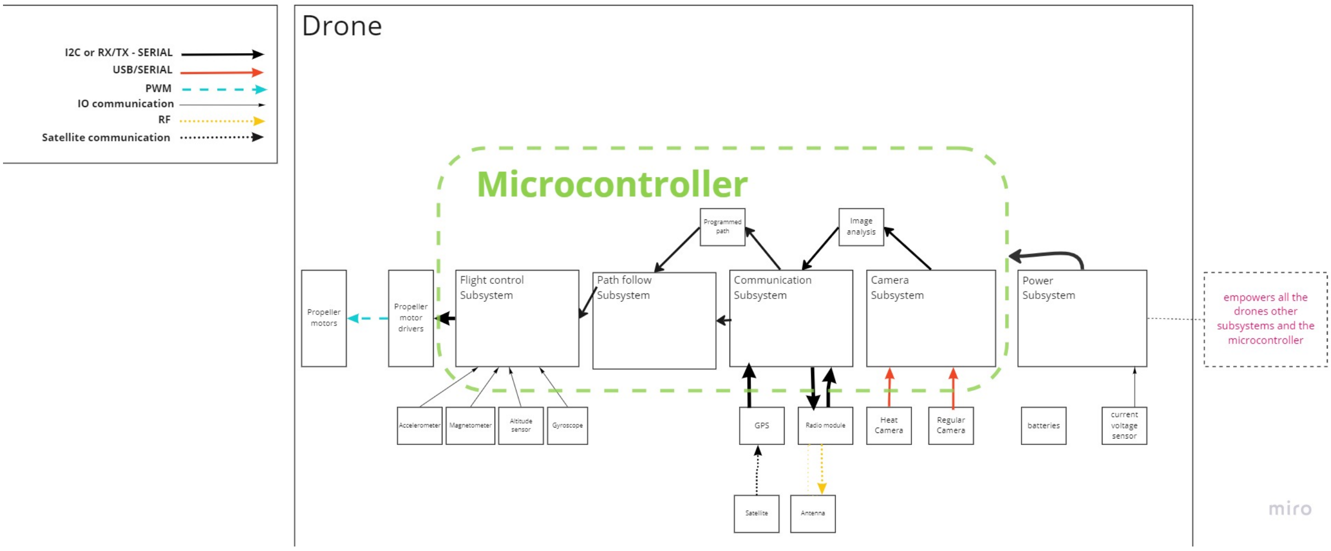


Figure 15: The System Communication Model

A.4 The System Application Model

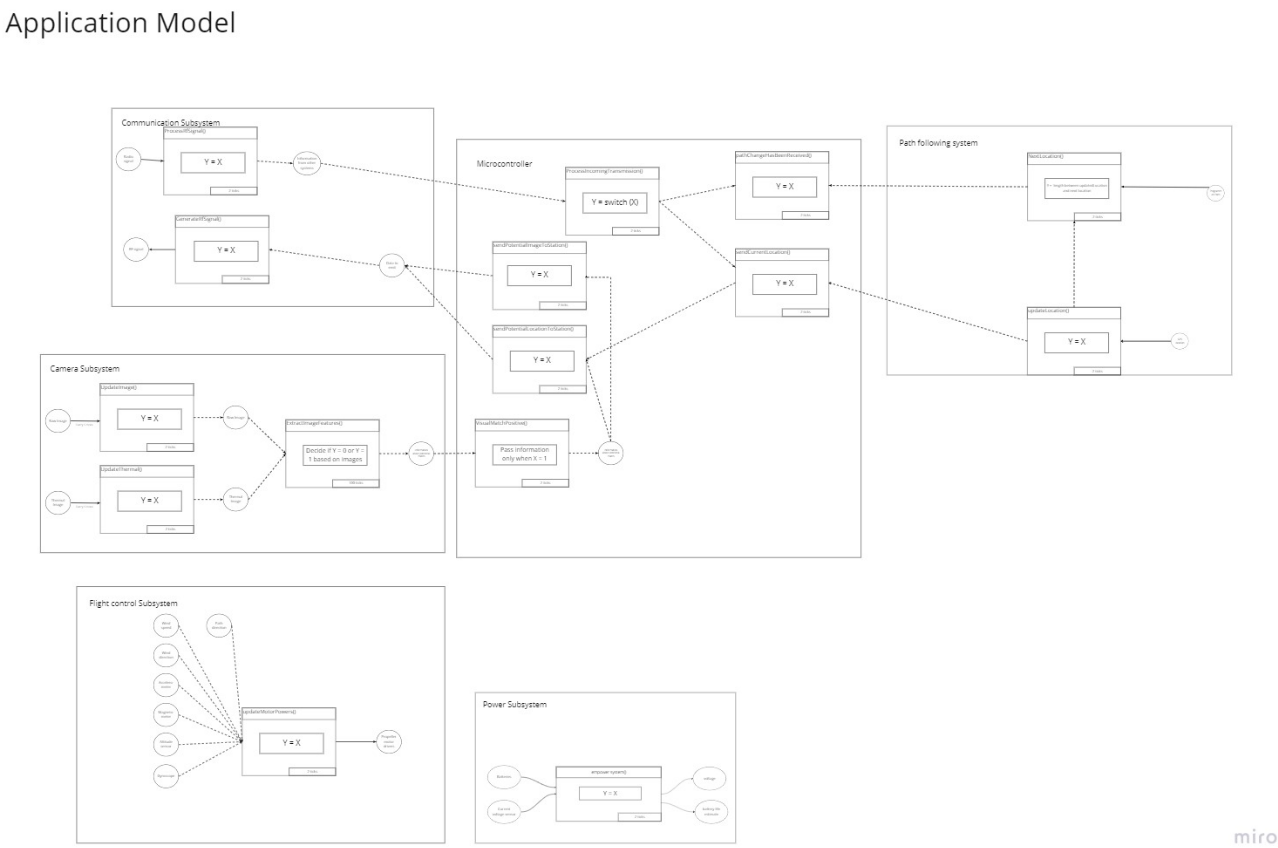


Figure 16: The Drone's Application Model

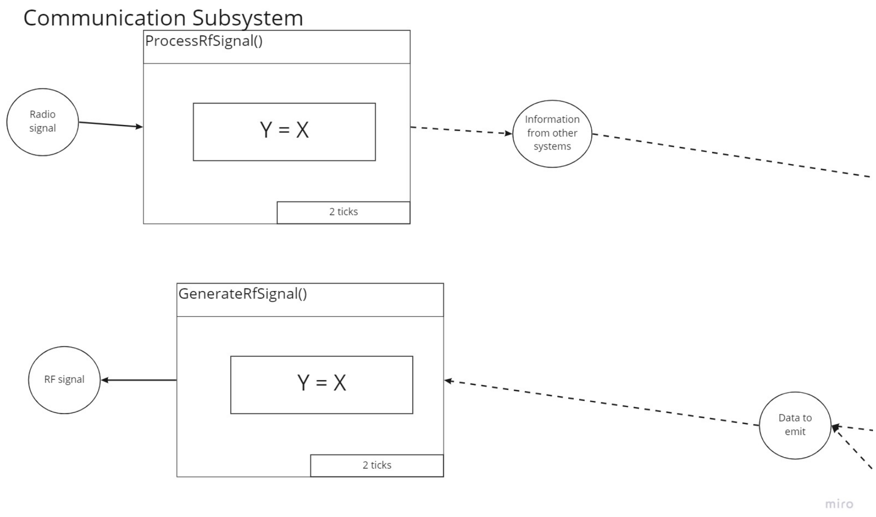


Figure 17: The Drone's Communication Subsystem in the Application Model

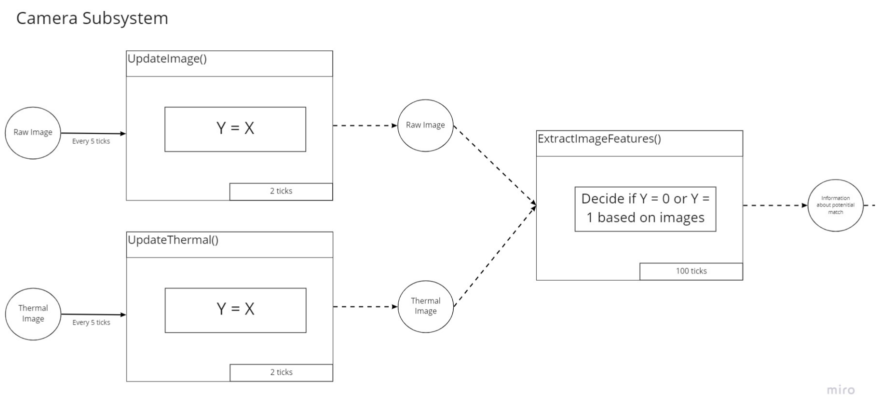


Figure 18: The Drone's Camera Subsystem in the Application Model

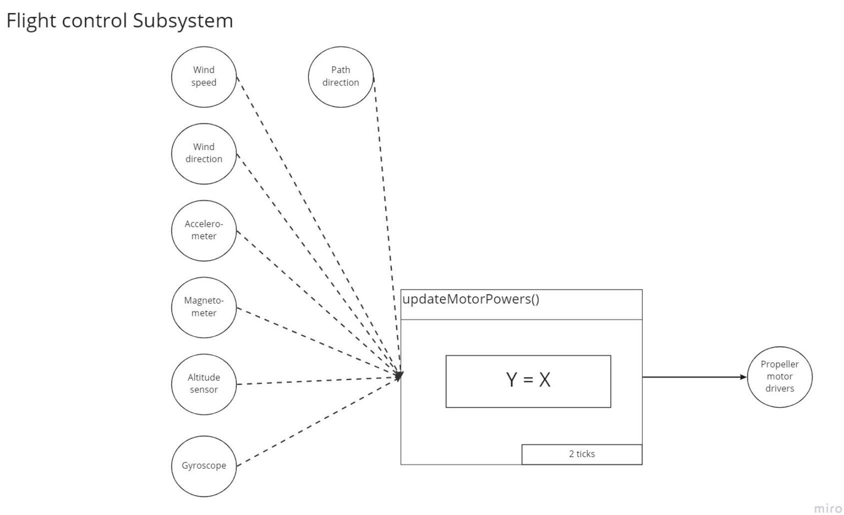


Figure 19: The Drone's Flight Control Subsystem in the Application Model

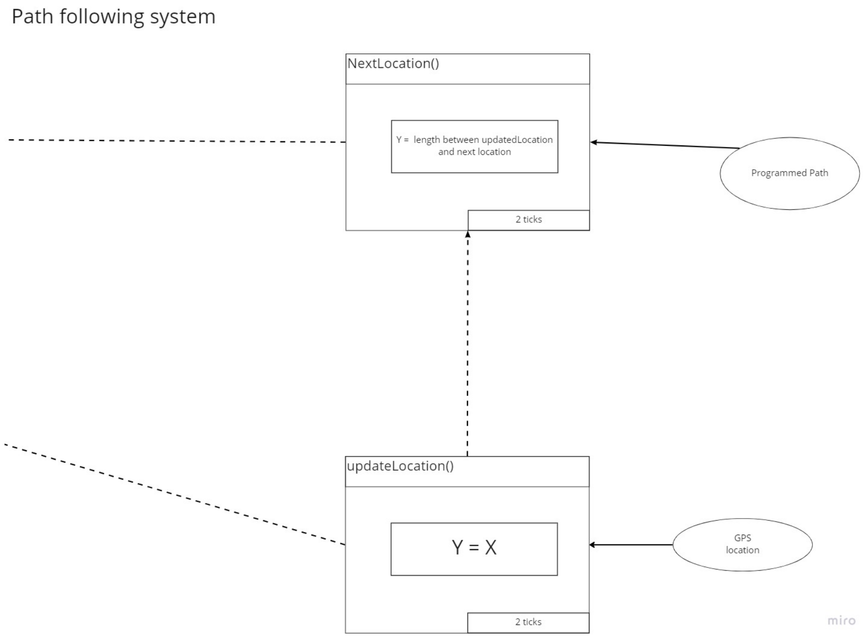


Figure 20: The Drone's Path Following Subsystem in the Application Model

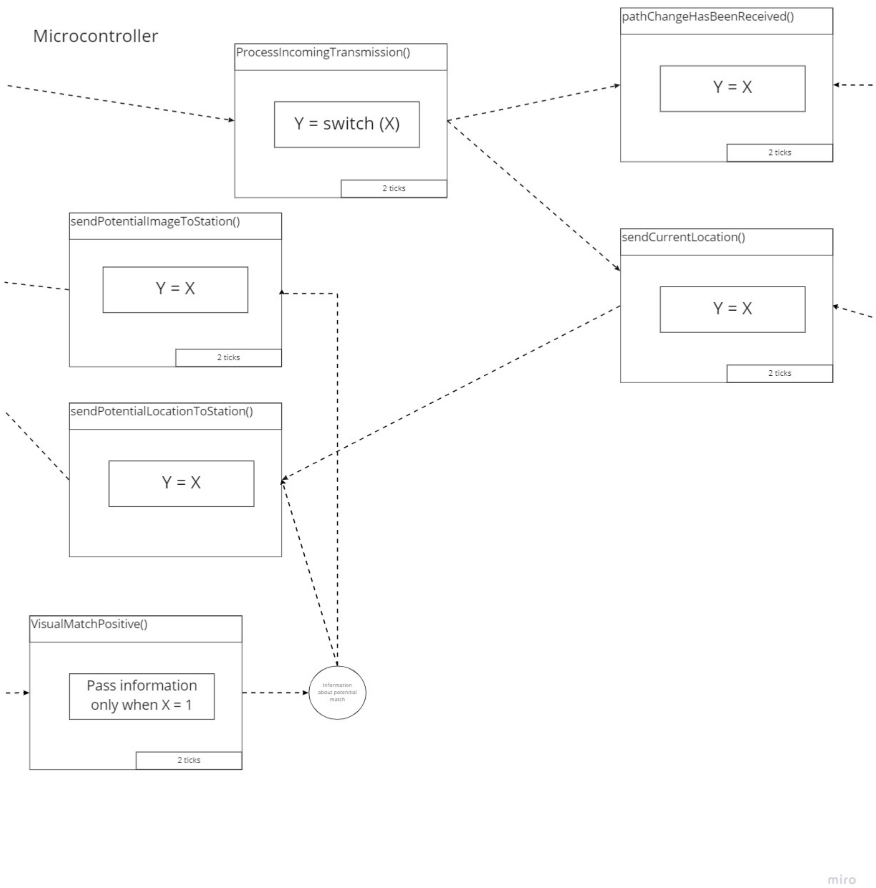


Figure 21: The Drone's Microcontroller Subsystem in the Application Model

A.5 More plots from simulation

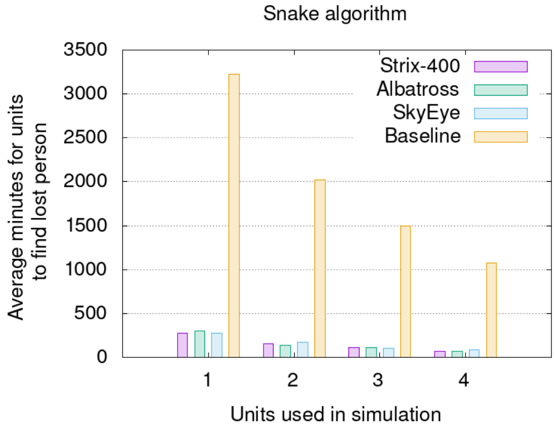


Figure 22: Same results as for the plot in Fig.7, now including the baseline

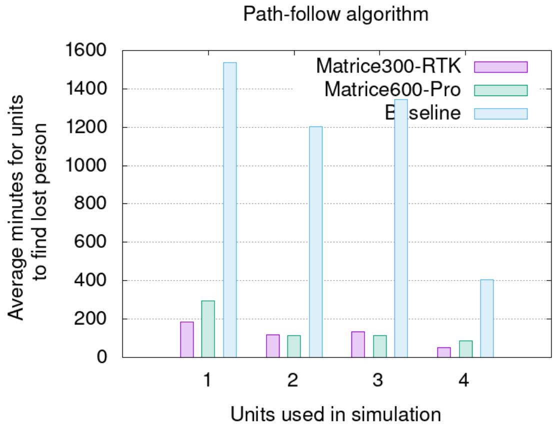


Figure 23: Same results as for the plot in Fig.10, now including the baseline