TU/e
Eindhoven, March 24, 2016

USE assignment: Delivery Drone

OLAUK0
Quartile 3, 2015-2016

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List of symbols

Symbol	Quantity	Unit	Unit Abbreviation
α	Angle	Degrees	$[^\circ]$
l	Length	Meters	$[m]$
h	Heigth	Meters	$[m]$
v	Speed	Meters per second	$[m/s]$

1 Introduction

Drones can take goods that are ordered from the storage to somebodies house. The delivery is quick and orders can be handled a lot faster. This way, delivery companies can handle more orders at a higher rate. But people also get the items they have ordered really quick, which helps the satisfaction.

They say that autonomous flying is not the main problem of technology anymore, some companies already want to carry out their autonomous drone in the near future [18]. Those companies however, are using less urban areas for testing and we are curious about how their drones are going to hold in busy cities. Drones need to be more reliable, they still have a tendency to crash and run into objects. Some experiments, for example from MIT, are getting better at avoiding object autonomously [5], but this problem is still big because of unexpected events that asks the drone to react very quick. Energy consumptions could also be a problem [19]. For long flights the drones need large batteries, but bigger batteries also means less space for cargo.

Another problem with delivery drones these days is the "problem of the last meters". These last problems aren't so much about the technology, since most of it already exists, but how to implement all these technologies to make it actually work. These problems are for example: how do we deliver packages in apartment buildings and how do people (and animals) react to these kind of deliveries [15]. The article from the Washington Post gives a great start to start asking questions which aren't technical, but more to the side of users. What do we want as society?

The problem with the battery-life as given above can, for example, be fixed (maybe until there are better batteries) by changing the battery of the delivery drone in the air [14]. The concept Amazon Prime Air is the best example of the given idea [2], which is (unfortunately) still a concept and not working yet. Also Google [4] and Walmart [16] are joining the competition to get the first working delivery drones ready. These three competitors all want to be the first company that can use the drones, which means that a lot of research (and money) is involved. The problem those companies are working on is the reliability of the drones.

Our idea is to look at drones and find out what the best human interaction is when they want to land. What can we expect from buyers and how are we going to interact with them to let the landing go smooth? Also the drone should be able to find the right landing spot by itself. In further investigation the human interaction can be related to this landing procedure so the drone is able to land on the right spot in a comfortable way for the customer.

In the next section we are going to talk about the focus of our project. After this we tell -bla bla bla blabbla-

2 Focus

The focus of this paper is explained in this chapter. First, the requirements of the drone are given, so that it is clear what the drone should be able to do. After that the state of the art will be explained. Previous research, done in the second quartile of the year 2014/2015 by group 1 [3] and other companies, answered some of the questions that are related to this subject. They investigated the way of navigating and verifying. Their finding's, and some background information, will be discussed briefly in the sections below. After that the detailed focus of this paper is explained. The research that will be done in this paper is most likely going to be combined with this previous research.

2.1 Requirements

The requirements are given and explained to tell what the drone should be able to do. Small pieces of technology can be investigated, before getting to the final product.

- The drone can make a flight plan
  - The drone knows from the map where it is able to fly (course flight)
  - The drone can set a landing area for itself from a given destination
  - The drone knows what to do if the destination can't be reached
- Flying
  - The drone follows a trajectory path which is comfortable for it's surroundings
  - The drone can stabilize itself during flight
- Landing and take off
  - The drone can decided what a good landing spot is within a landing area
    - The drone can make a detailed and up to date map of the landing area
    - There is enough free space for the drone to land in the landing area
    - The drone lands on a comfortable distance of the user
    - The drone knows what to do if the local destination can't be reached
  - The drone is able to land autonomously (fine navigation)
    - The drone is able to evade inanimate objects
    - The costumer or drone won't be endangered when something doesn't go as planned, for example when the landing spot is uneven
- Localization and navigation
  - Where is the drone flying and to what destination (course navigation)
    - The drone can access a map and knows where it is on this map
- Communication and verification
  - The drone can hand over the package
  - The drone can verify that the package is at the right person
  - The drone knows what to do with emergencies
    - There is a function for the user to call the home depot
  - The drone knows how to contact the user in a good way
- Safety of the drone
  - The drone is legislated
  - The drone can an knows how to react to different weather conditions
  - The drone has procedures for safety
    - Against stealing
    - For avoiding (flying) objects
    - For something unexpected happening
  - The drone has contact with the home depot at any time
    - The connection is protected
    - The home depot can track and adjust the drone's path

Putting these requirements in a flowchart, gives a good overview and what parts are connected to other parts.

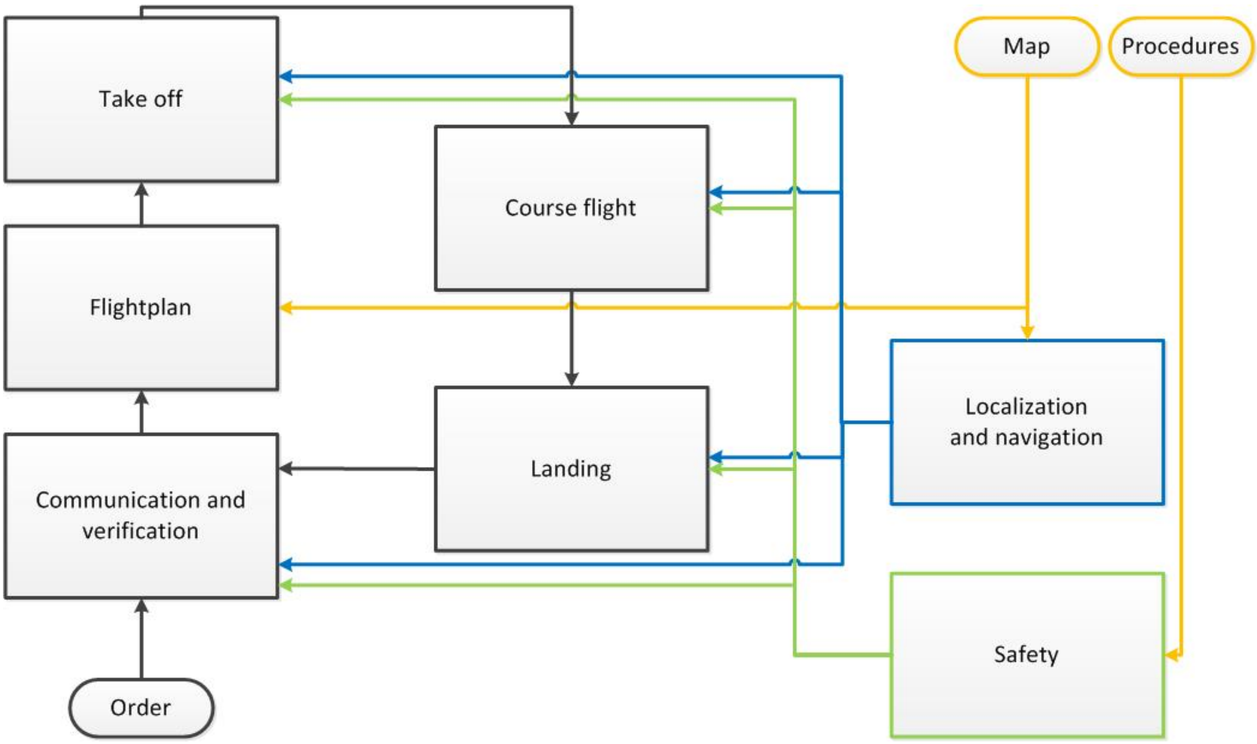

Figure 2.1: Flowchart

2.2 State of the art

The state of the art is the research that is already done. A lot of research is going on in the drone industry. A couple of big companies are trying to be the first to get the drone delivery a real thing.

Being at the brink of being introduced, drone delivery still encounters many problems. Most of these problems are not in autonomous flying however, but mainly in the implementation of these technologies. The first companies are already using less urban areas as their test-grounds. The concept is working, but remains unreliable. The drones still have the tendency to crash into objects and the endless list of unexpected events that can possibly happen ask for a high reaction speed. Also the limited battery lifetime appears to pose problems. Below Amazon's Prime Air is described, as the leader in the current developments, followed by more general current developments and points that still are being researched on.

2.2.1 Amazon Prime Air

The leader in the current developments is the Amazon Prime Air concept from Amazon. [2] Unfortunately the drones are not ready to be embedded in society, but successful flights already have been made. One of the drones they are using is small plane that has the possibility of vertical takeoff. Flying the drone as a plane increases the speed and range of the drone, resulting in a delivery time of 30 minutes or less and a range of 24 kilometers. As the drone approaches its destination, a message is send to notify the customer that the package is arriving. The drone recognizes its destination by a big 'A' that is placed on the ground. Before lowering itself, the landing area first is scanned for obstacles. After the landing, a small valve is opened releasing the package. A second drone that is being developed is a quad-copter. This drone has a range of about 14 miles and can carry packages of about 2.5 kg. This may not seem much, be around 80% of the packages delivered by Amazon falls within this weight margin, making the likelihood of this technology being introduced in the recent future rather high. Hopes are to be able to make us of this technology around 2020. [1, 6]

Figure 2.2: Amazon prime

Also Google [4] and Walmart [16] are joining the competition to get the first working delivery drones ready. These three competitors all want to be the first company that can use the drones, which means that a lot of research (and money) is involved. The problem those companies are working on is the reliability of the drones.

2.2.2 Can and cannot

Autonomous flying is not the main problem of technology anymore, some companies already want to carry out their autonomous drone in the near future. [18] Those companies however, are using less urban areas for testing but will not hold in busier areas. Drones need to be more reliable, they still have a tendency to crash and run into objects. Some experiments, for example from MIT, are getting better at avoiding object autonomously [5], but this problem is still big because of unexpected events that asks the drone to react very quick. How for example to cope with moving objects like people, animals (an enthusiastic dog for example) or flying objects (a football for example). Simply stuffing the drones with numberless sensors would drive up the price drastically, hopes are to be able to develop smart software that only uses few and or cheaper sensors to make the drones more attractive on the market.

A second problem is the limited battery-life of the drones. Increasing the size of the battery would reduce the loading capacity, but a small battery again will drastically decrease the range of the drone. This would require many distribution centers, which on their turn need to be supplied as well. An alternative however is given by K. Fujii, proposing to have the battery replaced without landing. [15]

Another problem with delivery drones these days is the problem of the last meters. These last problems are not so much about the technology, since most of it already exists, but how to implement all these technologies to make it actually work. These problems are for example: how do we deliver packages in (high) apartment buildings and how do people (and animals) react to these kind of deliveries [14]. The article from the Washington Post gives a great start to start asking questions which are not technical, but more to the side of users. What do we want as society? Areas where relatively less research is done, compared to the more technical side. This however is exactly what this project about, making a next step in the development of user-friendly or rather user-centered drones.

2.3 Detailed focus

As seen at the requirements above, not all the subjects can be tackled at the same time and some of them are already done by others. This project is focused on the last few meters and even more on only 2 parts. The subsections below explain the focus on the landing spot and the user approach in particular.

2.3.1 Finding landing spot

One of the problems found during the delivery process done by drone is finding where the drone can land.

Landing the drone is thought to be easy, simply ascent till you hit the ground and that's it. This however, is not that easy [11] [9] [12]. Questions arise like; how does the drone avoid objects on the ground? And how does he find the right spot to land? Is having the customer find an open space and put a printed "A" on the ground (like Amazon's Prime Air [2]) a good solution, which makes the customer responsible. Or should the drone find his own way to find the right spot?

Giving customers a lot of responsibility for the landing of the drone, is not a good idea. The company that uses the drone is responsible for the package until the customer verified that the package is in their hands. This way it gives a great risk for the company for using a printed label like Amazon wants to do. Since this is not an option, the way of finding a spot to land can be a good option. Measuring the height of the drone according to the surface below and storing this, can be converted to a height map. If there is enough space on the map on a lower area where the drone can fit, it can land there. For this a safety margin can be put for an extra 10 centimeters on the sides of the drone.

But what if, for example, the drone chooses to land in the middle of a road? Considering this is probably the largest free space available close to your front door, this will be a very likely option. How does the drone distinct places where he is not able to land?

Another thing that has to be kept in mind are the (unexpected) moving objects. This includes among others footballs, birds and children. Seeing objects with a drone is really hard. The system has to identify how far something is away, which is for example impossible if you can record in only 2 dimensions with a camera. However, a lot of research about object avoidance is done these days (for example: [7] and [22]) and besides the landing part it is not the main scope of this project.

2.3.2 Approaching the user

So far little research has been done on the field of approaching humans, when it comes to robots. Even less so for drones in specific. The behavior-based navigation architecture is one way of how robots can decide which way to approach people. Previously done research by [21], regarding approaching people with robots, gives a good insight and starting point. Based on the results of these experiments a model of a person's personal space concerning the Nao robot was made. After that a smart algorithm was made to find the optimal spot for communicating, while keeping in mind obstacles that could block certain positions and or routes.

On one hand drones give a extra dimension to this research, since also height should be implemented. On the other hand the robot used in the experiments described by Torta first approaches people and then seeks, for the user will be attending other busyness at that moment. The delivery drone we are talking about however will have the attention of the user from the start, meaning the aspect of orientation of the user can be left out.

2.3.3 Approach Torta

The model was based on two experiments, A and B. During these experiments the robot Nao approached the participant which was either sitting (experiment A) or standing (experiment B).The participants were given a button with which they could stop the robot, at the point they felt comfortable with the distance between the robot and the participant.

Three tasks were given to the participants regarding determining this distance. Task 1 consisted of stopping the robot at the optimal distance for communication. Task 2 and 3 consisted of stopping the robot at the closest and furthest distance for having comfortable communication respectively. The robot had 5 possible starting locations, each with a different angle relative to the user. These angles were -70, -35, 0, 35 and 70 degrees.

After the experiment the participants were asked to fill in an additional questionnaire, further specifying the optimal distance for communication. In total each task was preformed three times for each direction per participant, leaving the experiment at a total of 45 runs. The order of the tasks and directions was randomized.

2.3.4 Applying to Drones

A comparable model could be defined for the use of delivery drones, as they (depending on the way of delivering) could be required to approach people as well. The interaction between the drone and user will not be of the same level as the Nao robot interacts with the user, though that does not make the way of approaching less important.

Some differences between the Nao and delivery drones could be that the delivery drone will (unlike the Nao) not attempt any humanlike interaction, but rather just the needed verification and the handing over of the package. The distance between the drone and user as well might depend on different factors than for the Nao robot.

Also the appearance of both robots might play a factor. Where the Nao robot as a humanoid tries to imitate humans to a certain extent, the delivery drone will remain a 'mechanical machine', requiring a different kind of thrust of the user in the robot.

Whereas the Nao robot is the initiator of the communication, the delivery drone can be assumed to have the attention of the user from the start. Because of this the factor of direction of approach can be left out, for the user will turn towards the drone. The two factors that will be tested for comfort during this project are the distance between the user and the drone and the flying path to take for approaching a user. A more extensive description of the experiments is given in chapter 4, Approach users.

3 USE aspects

In designing a technique it is not merely about finding a technical working system that solves the problem. User preference play a big role in the success or failure of such a technique. The first question appears: What are the user preferences concerning this system? Two user preferences that will be tested for are: The distance to keep between the user and the drone, also the optimal distance for landing. And the way of approaching the user. These experiments will be further explained in the chapter 4 Research. Below the question of 'Who is this user and what are his or her preferences?' is answered.

3.1 Users

Users can be categorised into three different categories. Primary, secundary and tertiary users.

3.1.1 Primary user

Primary users are the users that the technique is aimed at, the main people to interact with. In the case of the delivery drone these are the people that will have their package handed over by the drone:

- Consumers, people who order online

3.1.2 Secondary users

Secondary users are the people who also will be making use of the technique, but have less direct contact with the drone than the primary users. Some secondary users of the delivery drone are listed below.

- Companies and shopkeepers
- Drone developers
- Drone manufacturers

3.1.3 Tertiary users

The last group of users are the tertiary users. This group often contains the users that are only incidentally confronted with the technique, people working in the same environment or people who perform maintenance on the drones for example:

- Mechanics
- Safety instances (in case of accidents)
- People walking/using the streets
- Other airspace users
- Government instances (new laws)

3.2 User needs

The main focus of the project will be interaction with the drones of the primary users. Therefor an in depth analysis of these users and their needs is needed. Other users however may play a part in this project as well, so for some their needs will be illustrated briefly as well.

General primary user needs for drone delivery are fast, trustworthy and safe delivery of their packages. Note that no discrete values can be given to what is fast, trustworthy or safe delivery. In the scope of the project these needs however are slightly different. Safety still remains a priority, the user should in no way be exposed to risky and or dangerous situation regarding the drone. Since the flight of the drone to the address is assumed to be no problem, fast delivery falls a little more to the background. Trustworthy delivery remains an user need, but its meaning changes with the context.

Here trustworthy delivery is not so much about not damaging or losing the package on the way, but rather about a being able to find a location to land no matter the environment. Last an extra user desire comes within focus, the comfortability of the delivery. This involves the drone's behavior towards the user which should not only be safe, but also feel safe and comfortable.

Companies and shopkeepers will be the ones providing the service of drone delivery. Therefor they will take a large portion of the responsibility for the drones. Their needs will lay in reliability of the drones. Another important need for companies is for the drones to be cheap, or at least affordable. A right balance between price and quality must be found. Also for they are to provide the service to the consumers, consumers needs automatically become needs for companies and shopkeepers as well.

Of course with the increasing use of drones, developers and drone-producingcompanies will be able to make money with it. Also new developments will be stimulated. For companies producing drones, the ease of producing will be an important need as well as the expense of separate parts.

Generally, taking full responsibility as the drone producer can be seen as a generous gesture towards customers and will also push the development of autonomous vehicles onto the main audience. Other autonomous machine producers have already done so: "Volvo, Google and Mercedes have now all said that they will accept full liability if their self-driving vehicles cause a collision" [10].

The primary need for mechanics is that the drones are easy to repair or preform maintenance on, as well as safety doing.

A need or wish for safety instances it to have the drones to be able to fly without accidents, for their priority is to provide a safe living environment. And in case of an accident, which will unfortunately be inevitable, the damage must be minimal.

For people walking/using the streets the main need concerning drone delivery is to be able to walk the streets safely without the fear or risk of an accident.

4 Approach users

Research has to be done to get the right procedure for the way of landing with a drone. Finding the right way of approaching the customer with a drone is one of the subjects.

4.1 Trajectory path

Multiple factors can play a role for users to feel safe and comfortable with the drone approaching them. Little research has been done regarding approaching people in a user friendly way. In order to be able to construct constrains and preferences for the approaching, four variables have been devised:

- Variable 1: Flying speed
- Variable 2: Approaching height
- Variable 3: Landing distance
- Variable 4: Flying path

The first two variables are technical constraints and thus attached to the approach. Variables 3 and 4 are coming from 2 experiments where values are computed for the optimal landing distance (relative to the user) and for a preferred flying path when approaching the user. These variables can be defined for only one drone, because users experience different drones with different feelings. For example, the size of the drone is very important for how close people want the drone to land. The drone that is used for the approaching users in this paper is the Parrot AR.Drone 2.0 is a remote controlled flying quadcopter. It was designed to be controlled by mobile or tablet with operating systems such as iOS or Android [17]. The Parrot AR.Drone 2.0 has the following specifications:

Dimensions:	451x451	(517x517 with Indoor Hull)
Weight:	380 g	(420 g with Indoor Hull)
Battery life:	12 min	(in theory)
Charging time:	60 to 90 minutes	
Interfaces:	USB and Wi-Fi	

The drone also comes with a frontal HD camera (720p, 30FPS) and a QVGA bottom camera (480p, 60FPS), both with the possibility of direct streaming. The height of the drone is measured with onboard ultrasound sensors. For this drone the four variables can be determined. There is assumed that the horizontal angle of arrival of the drone does not matter. This is because the user is waiting for the drone to come and automatically turns his/her face to the drone when it arrives.

4.1.1 Flying speed

The flying speed of the drone is important for approaching people. If the drone flies to hard, people can get afraid but if it flies to slow it would take to long. Humans average walking speed is researched to be 1.4m/s second [13], and it is assumed that it is the right speed to test with. For safety and the accuracy reasons of the experiments however, the speed of the drone has been set slightly lower; approx $v=$ 1m/s.

4.1.2 Approaching height

For the approaching height, a height of 1.0m is chosen. This is because of the following: Lower heights would result in issues with obstacle avoidance, whereas higher heights might pose danger for the user. Eye-height of possible users might vary from 1.50m to 2.20m [8], making this domain unsuitable for flight. Given the accuracy of the drone for keeping the height another 0.5m is implemented as safety feature.

4.1.3 Landing distance: Experiment 1

The variable landing distance is about the distance that users are still comfortable with the drone around. The optimal distance that users like and the nearest distance that people are comfortable with drones around are determined with an experiment. The subject (an user) stands on a given spot (l=0). The distances 0.5, 1, 1.5...7 meters are marked with masking tape (distance to test subject) on the ground. The drone will start at a distance of 7 meters (= l_{start}) as seen in figure 4.1.

Figure 4.1: Setup

The drone will approach the person at a steady speed of approximately v= 1m/s. It does so at a height of h= 1m. Whenever the test subject feels like the current distance between him and the drone is the most comfortable distance to land, the test subject will give off a sign and the drone will be given the order to land (l_{end}). The subject will redo the test to determine the nearest distance where he or she feels comfortable. Those distances are measured and rounded per 0.25m. The results of this experiment are found in Appendix B.

The mean value of the optimal distance that comes out of this experiment is ...m with an standard deviation of .... The nearest distance has a mean of ...m with an standard deviation of .... The drone should be programmed to keep these distances as boundary conditions for the landing procedure. Note again that this is drone specific and in this case it is just for the Parrot AR.Drone 2.0.

4.1.4 Flying path: Experiment 2

It's not only interesting to look at the best landing distance, but also at the way the drone approaches the user. For this, a distinction is made between three different situations. For a description of these situation see the list below. In all these situations the test person is positioned at l= 0m. The drone starts at a distance l_{start} and height h_{start} that are from experiment 1.

Situation A
The drone flies horizontally to a certain distance lend then the drone lands vertically.

Situation B
The drone flies diagonally, at an angle α, to a certain point at distance lend and height hend. Then the drone lands vertically.

Situation C

The drones lowers itself vertically to a certain height h_{end}. It then flies horizontally to a certain distance lend before it lands vertically on the ground. For the distance l_{start} a distance of 8m is chosen. The ending distance lend is chosen according to the results of experiment 1 at roughly 2.5m.

To visualise those situations, picture 4.2 is shown below.

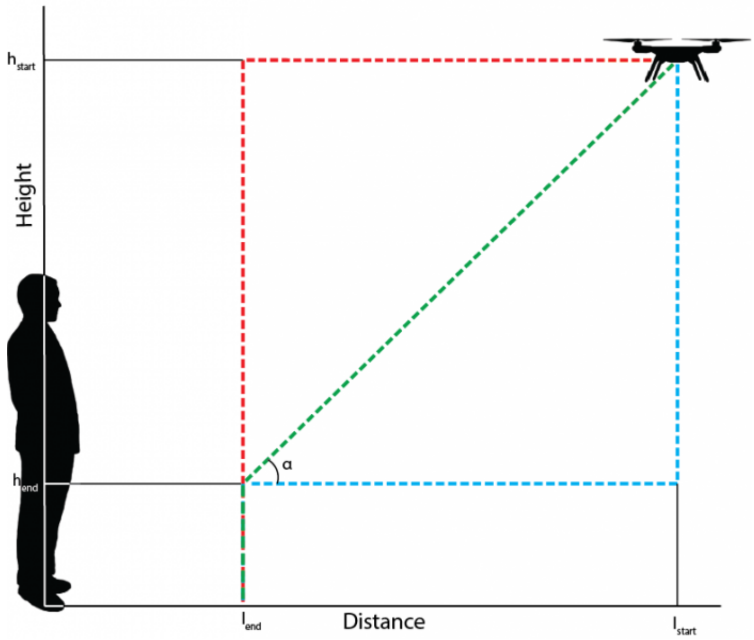

Figure 4.2: Theoretical setup

After each test variation the test person is asked to rate the experience with the values very bad/bad/neutral/good/very good. The participants need to fill in the values without seeing the others results. This for preventing the participants to get influenced by other participants. The participants were also asked to enlighten their findings and feelings to explain their choices. Some of these explanations were also reflecting on the first experiment. After a couple of experiments it was noted that the time that is consumed by this experiment is a lot. Because of that, more participants can stand next to each other at the same time to speed up the proces. It was also noted that the results were turning to one side. By looking at facial expressions, it helped to verify these results. The results of this experiment are found in Appendix C.

Those results show that there is a lot of variation of choice. Most of the participants felt good with the drone at a low height. Participant 6 told, that flying with only 1 degree of freedom at the same time felt safer. This was confirmed while looking at the expressions of the participants. Also when doing a T-test on the data, the outcome tells that....

5 Landing phase

A major problem during the autonomous landing phase is that the drone needs to know where it is on the map it is creating. It's not wise to assume that the drone flies at a constant speed, since it doesn't. Doing so would create an error which can result in complete disaster. Since the test setup has been moved inside, the situation created won't be realistic, but very controllable. Determining the location of the drone will be done with markers placed on the ground or objects which the drone can detected with its down facing camera. These markers will be placed 0.5m from its neighboring marker. In the first situation the system will be developed in a two dimensional world. Their will be height differences and the drone can be front- and backwards. No movement to the left or right will be possible. If the drone succeeds to land in such a randomized environment their will be looked at the second situation. In the second situation a third dimension will be added, the left and right movement. This will be a more realistic environment, but far from the environment a drone will encounter in a real world scenario. In both the situations their will only be objects the drone can detected from the height it uses to scan the environment. Since the markers are used to determine the location of the drone, they will be placed on a level surface. This could be an object or the ground. Their will also be enough space to land the drone in a user friendly way.

5.1 Introduction

In this project, we focus on creating an implementation which allows the drone to find a good landing location near the user. This will ensure that the drone does not land on inconvenient locations such as edges and unstable terrain. In order to achieve this, we create a map that contains information about the terrain in which we then find the best candidate area to land on.

5.2 Height map

Initially, we make sure that the software creates a 2D map with coordinate points it receives from the drone. Each point will contain information about that specific area. Currently, we limit ourselves to only the height of the area since the drone is not capable of measuring more useful data. With these altitude points, we can create a so-called height map. This map shows an overview of the changes in heights.

Figure 5.1: Mapping points

To find the perfect area, one could cluster these points to create a platform with relatively equal altitudes. However, this would require too many measurement points to get an accurate result. Our implementation tries to optimize this by creating a Voronoi diagram out of the measurement points.

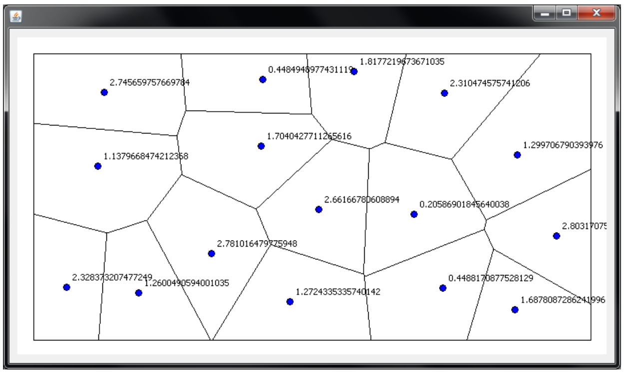

Figure 5.2: Create Voronoi diagram

With a Voronoi diagram, a point could represent a whole polygon area. With this in mind, our algorithm will set the altitude of the whole area to a single number. Using this method, it will no longer be fully necessary to create a point for each unique coordinate and thus prevent probing time. Working with areas has the following benefits:

1. It saves probing time due the fact that it requires less points to find a good location for landing
2. It makes sure that the altitude probing errors are smoothed out since it is averaged over the area

Once the algorithm has a set of probing points with the desired Voronoi diagram, it can search for landing candidates. This works by comparing each individual area with its neighbors. If the altitude of the neighbors is similar to the tested area, it will become a possible landing candidate. Below is an example of a landing candidate. To get the best possible landing area, the candidates are being sorted based on difference between neighbors, in case two areas have the same differences, one with the highest number of neighbors will gain priority due a higher amount of probing accuracy.

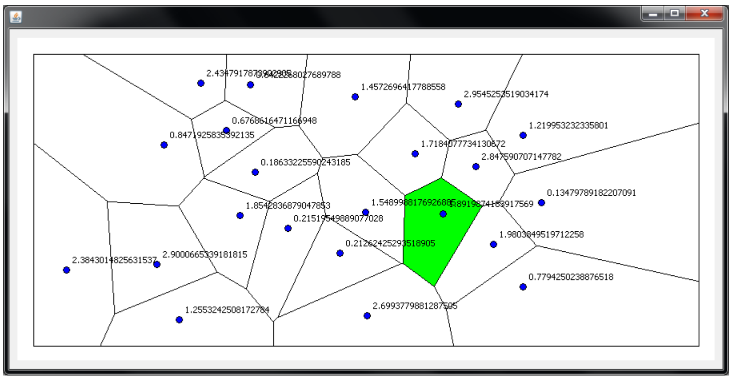

Figure 5.3: Candidate selection

After the selection process, one could re-run the algorithm on the specific selected area for greater results. This step could be repeated until the area is at least as big as the drone itself and can assure that the final area is flat.

5.3 Optimal exploration strategy

Mapping the possible landing area can take quite a long time if no flat and safe area can be found. To do this as fast as possible an optimal exploration strategy has to be used. To cover a random determined area the best strategy to use is to zigzag over the area [20]. There are two possible directions the drone can sweep the area, along the short or long side as is depicted in figure 5.4.

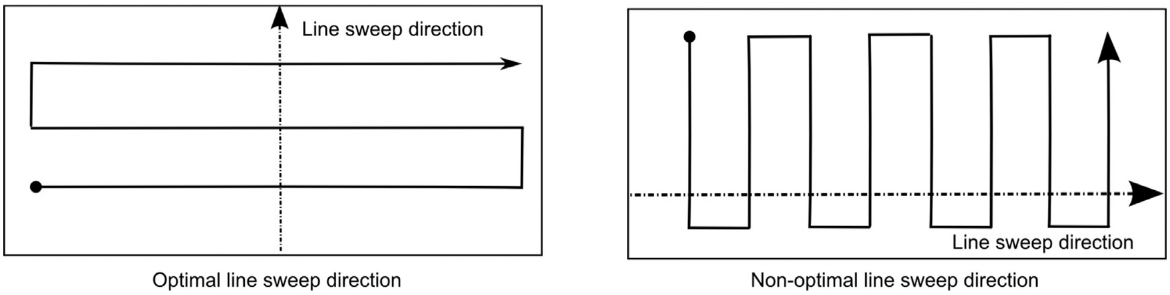

Figure 5.4: Two possible sweep directions

Since making turns takes some time the amount of turns needs to be minimized. This can be done by choosing to fly parallel to the long sided edge of the area.

6 Conclusion

The goal of this paper was finding an user friendly approach and landing procedure of the last few meters. The approach itself is not universal, because of a lot of different drones. However, the way of determining this approach is. The practical outcome is the autonomous landing script for a drone.

First, the research field is investigated to find a not invented part of drone-delivery. After that, the focus of the research is determined with a detailed focus for this paper. The USE aspects are investigated and then the research started. With experiments, the user friendly approach is determined for a specific drone and this verified with a T-test. Meanwhile, the landing procedure is made, to find a landing spot autonomously.

The final outcome of this paper is an universal way to find the user approach. Also, the used drone can scan an area and can find its own landing spot to land.

7 Discussion

The approaching technique of the drone could be improved by investigating a bigger and a more diverse group of participants. According to the obtained results, the conclusion of the experiment will only be valid for Dutch males, aged between 20 and 25 years and who have a technical background. When using more participants with a more diverse background, the results are more reliable for use in common area's. When investigating more sorts of drones to verify their way of best approach, a more universal approach could emerge by combining all the data.

The implementation of the autonomous landing could be improved by implementing the approach technique. At this moment this is not possible, because there is a need for scanning the area. The used drone and its components were not optimal. These components (or the whole drone) could be improved so that the mapping can be improved. Eventually the scanning of the area is optimized, so that approach can be used immediately and that there is no special scanning manoeuvre needed anymore. The landing procedure can also be improved for different kind of area's. For example, the drone can not see the difference between land and water. For that, the procedure needs to be improved.

A Scenario

The scenario starts with the customer buying a package in 2025 from the best-selling company in the Eindhoven. The customer lives in the so called "Parklaan". Within 20 minutes after payment, the drone with the package is in a radius of 100 meters of the destination.

When the drone is nearby it switches to a more accurate way of orientation, to find the exact location of the front door where it needs to be. The customer lives in a flat, so because of laws he still has to come out of the apartment to the front door of the building. That drones are flying arround with cargo is very special, this is because in the beginning of the drones they weren't allowed to do anything.

While the drone evades 2 birds and 10 rocks (that children threw) and 1 other drone it flies smooth and quick to the front door of the flat. The customer gets 2 minutes before the drone arrives a message on his phone that the drone arrived and he comes to the door. At this moment the company is still accountable for the package and this is staying this way until the customer accepted the package. The customer can identify himself by showing his member card from the company or by showing the QR-code of the order together with his id-card. After the drone verified this data with the data that is attached to the package, the package can be released. The customer has to tell if he wants the package on the ground or in his hands and the drone easily does so. If the customer has the package, the drone verifies that it is done and it can leave after exactly 26 minutes after payment.

While gaining altitude, a person tries to grab the drone. The drone can react fast and can just get away of this persons hands. If it would be grabbed, the drone makes pictures of the person and sends all the information to the headquarters. The headquarters would immediately call the police and the special drone squad will track the robber down. Luckily this time is not that time. This picture is only kept for several months for evidence. Now the drone is at a safe distance from bad people, it can return back to the base. It is still not allowed to go over gardens, which is a rule since the beginning of the drone-age. The drone just uses the air above the streets, just as it is told to do.

B Results experiment 1

The results of experiment 1 are seen below.

Experiment	Optimal distance (m)	Nearest distance (m)
1	2.25	1.0
2	2.75	0.75
3	2.5	1.0
4	2.25	0.75
5	2.0	0.75
6	1.75	0.5
7	3.5	2.0
8	3.5	1.75
9	1.75	0.5
10	2.0	1.5
11	2.5	1.5
12	2.25	1.25
13	1.5	0.5
14	2.5	0.75

C Results experiment 2

Results approach A

Experiment	Very bad	Bad	Neutral	Good	Very good
1A		X			
2A	X				
3A		X			
4A				X	
5A			X		
6A				X	
7A			X		
8A				X	

Results approach B

Experiment	Very bad	Bad	Neutral	Good	Very good
1B				X	
2B				X	
3B				X	
4B			X		
5B				X	
6B	X				
7B	X				
8B				X	

Results approach C

Experiment	Very bad	Bad	Neutral	Good	Very good
1C				X	
2C					X
3C				X	
4C		X			
5C			X		
6C				X	
7C				X	
8C			X		

Explanations participants

Participant 3's opinion was that he likes to look to top of drone. If he could see into the rotors, it felt a lot safer than if he looked from the bottom and saw the rotors coming down.

The 5th participant felt the best when he saw the drone going down while coming to him. He felt that the drone was not going to run into him and that it knew what it was doing.

Participant 6 told that 2 degrees of freedom scared him. If a drone does only action at the time, like moving horizontal or moving vertical, it felt a lot safer.

Participant 7 said that as long as he could see the drone, it felt right.

As was already put in the report, participant 8 told that flying on eye-height was not nice to encounter. The drone didn't fly on eye-height, but probably it felt this way because of the flying was by hand and not autonomously. (So there were small height changes)

D Laws

Rules from the Netherlands, category light (4-150 kg)

Private * Stay under 120 meters * Keep direct sight on your drone during the whole flight * You can only fly during daylight, with an environment that allows for clear sight * Avoid people and animals * It is not allowed to fly above cities, towns (150 m), railways, roads and docks(50 m) * Stay away from airfields * No flying within no fly zones

Commercial As a company it is obligatory to have a ROC (RPAS operator certificate) for flying drones. (Since 2015 1st of July) This means the following: * The drone pilot has a certificate for flying drones * The drone has a BvL (bewijs van luchtvaardigheid, 'prove of airworthiness') * You are in the possession of an approved operations manual

Also: * Keep direct sight on your drone during the whole flight * You can only fly during daylight, with an environment that allows for clear sight * Other airspace users will have precedence at all times

Concerning privacy Besides the normal privacy rules: * Not allowed to (systematically) gather data about people, including public * Not allowed to use advanced camera like infrared, night-vision, heat-camera, camera with built-in analytic techniques or cameras which do nothing but monitor * Not allowed to gather information that is publicly published Filming through windows or looking in buildings is direct infringement of privacy.

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