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USE assignment: Delivery Drone

OLAUK0
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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 [16]. 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 [4], 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 [17]. 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 [13]. 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 [12]. The concept Amazon Prime Air is the best example of the given idea [1], which is (unfortunately) still a concept and not working yet. Also Google [3] and Walmart [14] 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 [2] and other companies, answered some of the questions that are related to this subject. They investigated the way of navigating and verifying. Their founding'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 stabilise 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 acces 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.

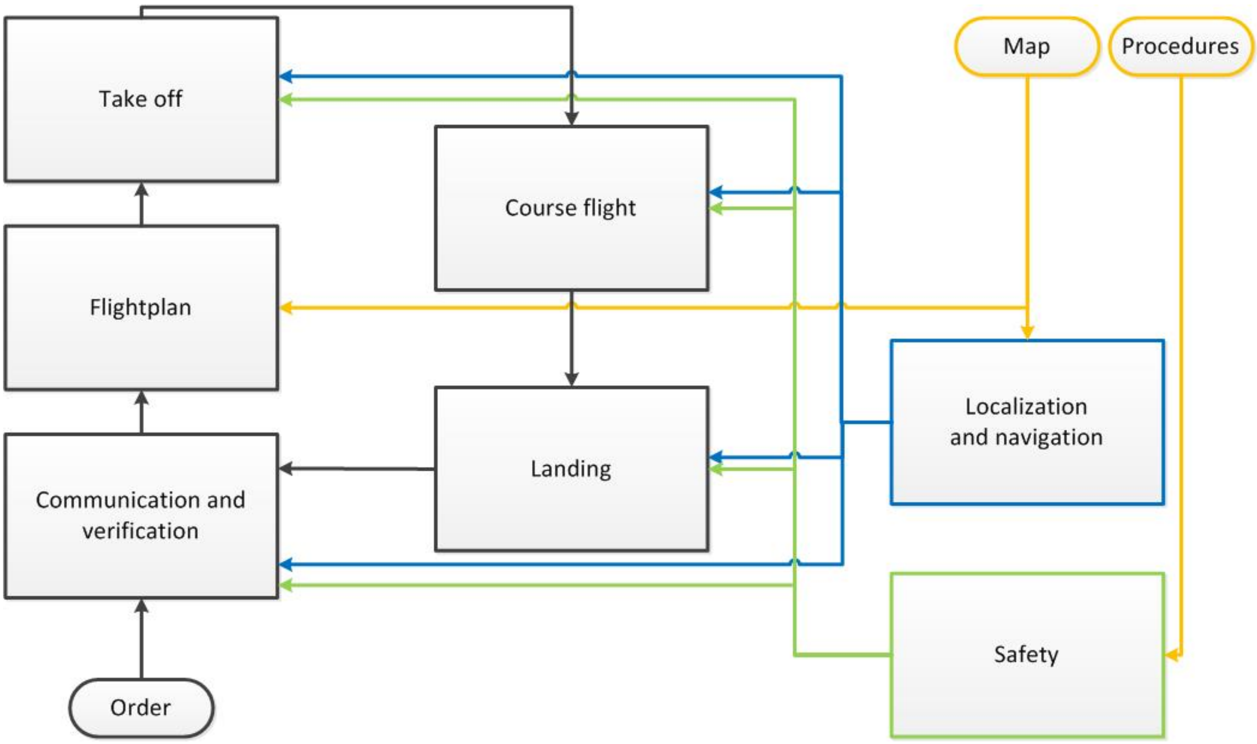

Figure 2.1: Flowchart

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 compagnies are trying to be the first to get the drone delivery a real thing.

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 focussed 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 proces 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 [9] [7] [10]. 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 [1]) 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: [5] and [19]) 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 [18], 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.

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" [8].

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 Research

Research has to be done to get the right procedure for the way of landing with a drone. How to autonomously land with a drone? Finding the right spot to land and finding the right way of approaching the customer with a drone.

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 [15]. 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 [11], 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 [6], 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.

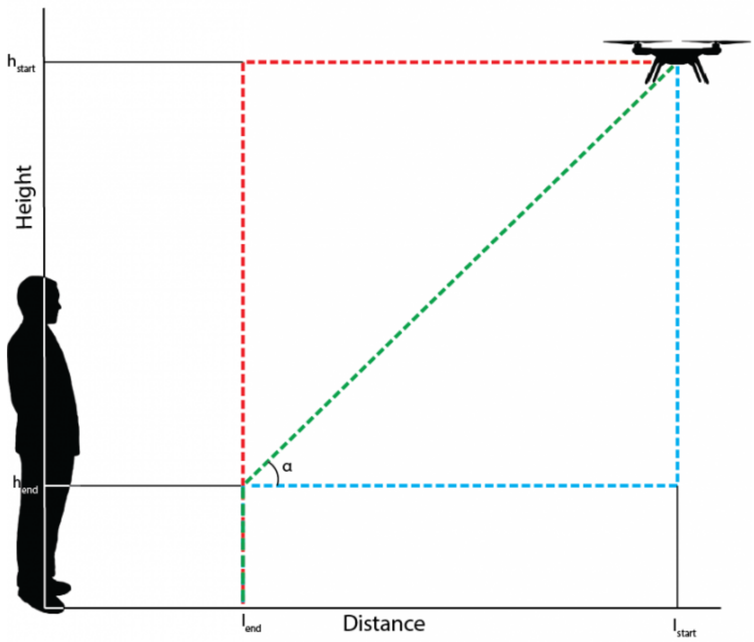

Figure 4.2: Theoretical setup

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....

4.2 Landing

Test setup
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 Technical implementation

6 Conclusion

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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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