CHAPTER TWO

Literature review

2.1 Overview

In this Chapter the topics related to the drones are covered. The first section explains what the drones are and how have they developed. The second section talks about the different ways to classify drones. The third section covers a specific drone type, multicopters. The fourth section features the multicopter uses and purposes. The fifth section talks about the risks related to the multicopters. And finally the sixth section discusses about the drone regulation.

2.2 Drone

Drone, Unmanned Aerial Vehicle (UAV), [4] Remotely Piloted Aircraft (RPA), many terms can be used for the same thing: “an aircraft without a pilot on board” and controlled either externally or by a computer. These terms are often extended to UA System (UAS) or RPA System (RPAS) to cover everything related to using an UAV, including controllers, Ground Control Stations (GCS) and launching pads. The term UAV includes any kind of unmanned aerial vehicle, even the uncontrolled ones such as missiles. The drone is a subcategory of UAV and narrows the meaning to either autonomous or remotely controlled (RC) aircrafts. Finally the RPA, as stated by its name, includes only the RC aircrafts. [5] On this thesis the term drone is used and chosen as the main term for several reasons. First, it fits on the modern devices which can be used with both, autonomous and RC, schemes interchangeably. Second, it has the longest history since the military use in 30s [4]. And as last, it is a short and familiar term for people. To emphasize the type and use of the drone, the term multicopter is used for the specific type of drone explained in the Section 2.3 Multicopter, and the term drone is used for any automated or remotely controlled aircraft.

UAVs have been used for over a hundred years now, but the name drone, in the modern sense, became to existence only after 1930s. In the beginning they were used only for target practice, and later in 60s also for the military reconnaissance missions. The beginning of the modern drones with live video cameras is said to have begun in the early 1970s with the surfacing of the ability to send photos to the base. From there drones have developed into the modern military class long distance multipurpose drones, like MQ-1 Predator shown in Figure 1 below, full of sensors and functionality. [4]

Figure 2.1: An MQ-1 Predator military drone

Furthermore, the technological advancements of military drones have led to the development of the civil drones. Earlier, civilians were flying UAVs in the form of airplane and helicopter models by radio controls with no autonomy on-board. Now the development of technology has made it possible to have autonomous drones at home, extending their use to other fields such as commercial use. The civilian drones are often multicopters which are piloted remotely, but they also have enough intelligence for autonomous flight with live video feed. [6]

The shape of a drone can be almost anything, like “fixed wing, rotorcraft, tilt rotor, or airship”[5]. By Merriam-Webster (2015) dictionary, a rotorcraft is “an aircraft (as a helicopter) whose lift is derived principally from rotating aerofoils”. Rotorcraft is a bit vague term, as it includes everything gaining lift from rotating aerofoils, including also the specific helicopters. To separate helicopters from the differently working aircrafts using rotors directed upwards only, a term multicopter was invented. [7] Thus, the term multicopter is used in this thesis to emphasize the specific type of the drone used. Other drones types are usually airplanes which are used for reconnaissance and long distance flying, but cannot have as big payload compared to the multicopters.

2.3 Drone classifications

Civilian drones are relatively new phenomena without much of legislation existing yet. On the other hand, to make the legislation, a classification is needed to figure out the different kinds of requirements. The civilian drone classification has not been finished yet and is still a work in progress. This chapter explains the current status of the drone classification.

The first step is to classify drones in a broad and simple way. There has already been one broad classification for drones, military versus civilian. Another broad classification would be piloted versus autonomous. [5] However, a more accurate definition seems to be hard to achieve, which can be seen from the amount of classifications listed by NASA (2015), in which they have made a good collection covering many different countries. Some parameters are take-off weight, speed, operationalaltitude, distance and environment, purpose of use and kinetic energy. The latter is important as it defines the likely damage caused by a collision. The parameters are then used in different combinations with weight being used in almost every classification. One problem on these classifications from the common civilian's point of view is that the weight classes go only from <25 kg to >150 kg, which are meant for the commercial drones. This is lacking, as it is rare for a hobbyist drone to be over 8 kg, most of them being less than 1 kg. On Table 1 on the next page, a good example of a classification is illustrated and it includes the three most common parameters and considers also the smaller drones. Furthermore, it is good to notice, that only micro and mini classes are likely to be used in civilian use.

Table 2.1: Example of a military classification (Weibel, 2005) Class

CLASS	Mass Range [kg]	Operating Area	Operating Altitudes [m], flight level[FL]
Micro	< 1	Local	< 150
Mini	1 – 14	Local	30 – 3000
Tactical	14 – 455	Regional	460 – 5500
Medium altitude	455 – 13600	Regional /National	5500 – FL 600
High altitude	455 – 13600	Regional /National/International	>FL 600
Heavy	>13600	National/International	5500 – FL 450

On the other hand, [5] has proposed a three category classification based on the risk for the operation of drones. These categories would be 'Open' for low risk, 'Specific' for medium risk, and 'Certified' for high risk operation. The names come from the user requirements with open being free for all, specific meaning more demanding drones and certified requiring a pilot certification. The risks addressed should be the likelihood for collision, to harm people and to damage property. The risk level would then mostly depend “on the energy and complexity of the drone”.

In addition, the military classifications seem to be different from the civilian, which is not surprising considering the operational requirements of the military use. The first way, classification by performance, resembles the civilian classifications. Some of the parameters are the same, like weight, maximum altitude and range. Still, even though these parameters are the same, their values are different.[5] For example, the most of civilian classifications define the operational weight of over 150 kg as the biggest weight class, whereas the military classifications define it as over 2000 kg [36]. Finally, the military applications require a completely different classification which would be ‘Micro aerial vehicles’, ‘Local area support vehicles’, Tactical area support vehicles’ and ‘Theatre area vehicles’.[5]

To summarize, a good legislation requires a good classification and such is hard to define. Different countries and organizations, like military and civilian, have different kinds of approach on the topic and have made different kinds of classifications. And finally, the most common way is to classify by the purpose of use.

2.4Multicopter

A specific type of drone is the multicopter which this thesis will concentrate on, partly because they are the most interesting civilian drone type nowadays, and partly because the main research tool on this thesis is the LTE multicopter. By [7] a multicopter is an aircraft which uses multiple upwards directed rotors and which is controlled by variating the rotor speeds. All of this is controlled by powerful micro-electronics and sensors. Indeed multicopters are a rather new invention in the, as it is hard to build a working multicopter without efficient electric motors, light and high capacity rechargeable batteries and microcomputers. Out of these three, the most important stepping stone for the advent of multicopter was the invention of Lithium-Polymer batteries which are light and powerful enough for multicopter use. Moreover the development of microprocessors and –chips has played an important role in the automatization required for such copters. In this section the general information on the drones will be explained.

The multicopter can have many different shapes and sizes. Usually the shape depends on the amount of the rotors attached to the ends of the arms positioned symmetrically. The amount of the rotors define the type of the multicopter, most common types being tri- (3), quad- (4), hexa- (6) and octocopter (8). Especially the quadcopter can be divided into many different styles like X, + and H depending on the orientation of the rotors compared to the front of the quadcopter. Also hexa- and octocopters have specially shaped versions with two rotors attached on each arm, making them Y and X shaped. The different layouts and rotor amounts have some differences between. In general, the quadcopters are small, light, cheap to build and easy to fly, and that is why it is the most popular for hobbyists. On the other hand, the often bigger hexa- and octocopters have much more lifting capacity and have redundancy in the motors in case of failure, and are popular for the professional use. The best multicopters for weightlifting are the Y6 and X8 which have a much higher payload compared to the other types [6]Some of the different types are shown below in the Figure 2.2

Figure 2.2: From the left to right, tri-, quad- and X octocopter.

The multicopters can be different sizes of tens of centimetres to multiple meters. The quadcopter in the middle of Figure 2.3 has diameter of only 4.5 cm [8]. The common size for a quadcopter seems to be around 50 cm, while the hexacopter used in this thesis is around 90cm. One of the most extreme cases is an 18 rotor human carrying multicopter design VC200 [9]. On the next page, in the Figure 3, the hexacopter used in this thesis is shown.

Figure 2.3: The multicopter used in this thesis

As can be seen from the figures above, multicopters are built up from all kinds of parts. Some of the important parts are the frame, motors, propellers and batteries. Some other, less visible but as important, parts are the power distribution board, Electronic Speed Controllers (ESC) and of course, the flight controller (FC). The power distribution board is used to distribute the power from the batteries to the motors through the ESCs which are used to synchronies' and balance the motors. [6] Below in the Figure2.4 some of the important parts are shown.

Figure 2.4: From left to right: ESC ,carbonfiber propellers and an electronic motor .

Less necessary, but common parts used with multicopters are radio receiver, GPS and gimbal. Traditionally the radio receiver has been a crucial part for multicopters, as there has not been any other way to control it. Nowadays other kind of options, such as automated flying and Wireless Local Area Network (WLAN), have become available and made it an unnecessary, but not obsolete, part of the multicopter.

GPS which is usually used for the automated flying has become a common part for multicopters. It is used for functions like flying through the waypoints, return home and geofencing. Return home functionality enables the copter to return back to the location where it was started in problem situations, like when the connection to the controller is lost. A simple version of geofencing prevents the multicopter flying too far from the starting point. A more advanced version prevents the multicopter from entering to areas, like airports, specified in advance.

Gimbal is a holder for the camera. It usually has its own motors for stabilization. This means, that the gimbal tries to keep the camera horizon always balanced and remove the vibration created by the moving parts. This is an especially important device for camera multicopters which are supposed to record high quality video or shoot sharp photos. Furthermore, it can sometimes be controlled by another radio controller to change the camera direction independently from the multicopterdirection. These way two persons can be used to record high quality movies and camera drives.

Multicopter is an unstable by design as it has many separate motors. Thus it needs a powerful controller and a good program to keep it balanced. To know about the forces affecting, location and the current angle of the multicopter, the FC has lots of sensors on-board.[7] They include sensors such as gyroscopes to know the tilt, accelerometers to know the inertia, and barometer to measure the altitude of the multicopter.[10] Many differences between FCs exist, with the simplest only stabilizing the multicopter and the most advanced having many different modes and automated flying. Furthermore, most of the FCs can be only used with the traditional RC controller, while some support any kind of optional controller. The optional controller, for example, can be a Nintendo Wii controller using a WLAN or Bluetooth connection. One of the important features of a research multicopter is a high quality black box which records all information during the flight. An example picture of an advanced FC is shown below

Figure 2.5: A Flight Controller

Like stated in the multicopter definition earlier, controlling the multicopter happens by the FC changing the rotation speed of the rotors, which creates the required inertias. An important factor to notice with the multicopters is that excluding some special cases, like the tricopter, the rotors are rotating to different directions always in pairs, but still giving lift. This way the copter stays at the same spot or goes up or down when all the rotors are rotating at the same speed. It tilts to specific direction, when all the rotors on one side accelerate and on one side slow down. Rotation (yaw) is created with one of the rotor pairs slowing down, while the other pair speeds up. This creates torque and rotates the craft.[7]

2.5Multicopter users and applications

The first party to use the drones was the military. In the beginning they were just used for simple reconnaissance missions and as targets for shooting practice. Later on, after the technologies advanced enough, drones became the war machines the word “drone” brings to mind. The modern military drones are still mainly used for reconnaissance, but now they are also used for straightforward attacks. The amount of the drone attacks is rising and becoming a crucial part of the air warfare. Further, the military has started using multicopters for short distance reconnaissance missions.[4] In the future it is possible that drones become the most important tool used in the war.

But the advent of technology has brought drones also available for civilian use. The amount of different use cases is growing fast with the imagination as a limit.

For some time now, the radio controlled airplanes and helicopters have been used as amusement for hobbyists. They have also been used somewhat for commercial mapping, agricultural use and video shooting, but their price, instability and low payload has limited their use.

The real change happened with the arrival of multicopters. With the multicopters having the high quality electronics on-board, the stability, easiness and possible payload have grown drastically.[11] This has made them much more approachable for normal people and hobbyists, as the price has been decreasing rapidly and the learning curve is low compared to other drones types such as helicopters and fixed-wing airplanes. Hence, another user group is the hobbyists. They use multicopters for recreational fun just flying around, taking photos or videos of their surroundings. Multicopters are also used for competing in races, so having real drone racing tournaments is possible in the future .[12]The racing is done by using specific First Person View (FPV) equipment which gives the pilot a first person view like he was on-board the multicopter.

The third user group is the commercial field. It is already commonplace to use.multicopters to shoot high budget movie scenes and beautiful scenery photographs[13] These movie drones might cost tens of thousands[14],and have equipment worth of thousands of euros on-board .[15]Still they are much cheaper to buy, easier to use and require much less space than a real full-sized helicopter. Furthermore, in Finland electricity

Power companies have started using multicopters to map broken power lines. [16] But a lot of room for new application ideas still exists.

Figure 2.6: DHL delivery drone

Many of the use cases are still on the drawing board or in the test phase, but many of them are soon going to be possible. A good example is postal companies after they saw the possibility of drones for delivering mail. First it was Amazon developing a quadcopter for such purpose, then Google using fixed-wing planes and then Deutsche Post AG (DHL) made the first regular delivery service with a multicopter shown above in Figure 2.6[17]And now Finnish Posti has done collaboration with the verkkokauppa.com to deliver packages to Suomenlinna, even though it was just a couple of days of testing .[18] One more way could be using multicopters for warehouse logistics .[19]

The fourth user group is the emergency services. Firemen are using drones in fire control missions, using live video on the progress from above.[20] And now, as the newest news on the drone field, North Dakota police has gotten permission to use drones as non-lethal weapons, shooting tear gas or Tasers from the air[21].There has also been some research for using multicopters for rescue operations, like locating avalanche victims [22] and defibrillator drone delivering fast aid for heart attack patients

As last, multicopters have a great research potential. By Google Scholar they are used for all kind of research, like computer vision and video development, extending cellular networks and collaboration of multiple multicopters.

Common for all of these use cases is that they work either over radio control or over automated waypoints in Visual Line Of Sight (VLOS) distance. As the amount possibilities already with VLOS multicopters are so tremendous, they can be extended even further with the much longer range of LTE drones.

The LTE connection can be used also for other purposes than the controlling. As it will be explained later on, it is possible to get live status information from the drone to the pilot. This connection could also be used two ways sending information, such as geofencing data, to the FC. It could be further developed into an air traffic control system for drones.[23]

2.6 Multicopter Risks

Multicopters Similar problems have existed before, but because of the steep learning curve they have not been so common. The easiness of multicopters has made them popular and common. In addition flying devices are always full of risks. Some of them are purely technical new technological advancements never come without problems, and same applies for the such as the flight controller malfunctioning and the drone escaping from the user. [24] Some are human mistakes or ethical problems, for example, flying around high security locations such as nuclear power stations. [25] This section covers different kinds of problems related to the drones.

One of the most common problems with hobbyist drones is the already mentioned "fly-away" which means the drone going out of control and flying too far to be recoverable. It is especially problematic, as the fly-aways can occur for multiple reasons such as bad calibration, GPS signal loss and radio signal loss. Such cases have already been numerous. [26] GPS signal can be lost easily when flying in an area with bad reception or under structures, like a heavy bridge. Radio signal loss can occur when the pilot flies too far away, or the radio receiver breaks. No matter what the reason is, the lost drones can fly anywhere crashing on buildings, aircrafts and humans. [25] Even though multicopters commonly have a "return to home" functionality which should make sure the device returns back to the pilot in the case of signal loss, it does not always happen either because the GPS is messed up, or because an obstacle is on the way, like happened to [27] In other words, the "return to home" functionality is still too simple and should be developed more. Furthermore the motors or related electronics might fail, making a quadcopter to fall uncontrollably. In fact, some solutions already exist for such problem such as parachutes. [28] As last, the multicopter might have a power loss, either by technical malfunction such as fire on-board, or just simply running out of battery.

Other big problems brought by multicopters are the misuse and vandalism. They are easy to get, cheap, easy to fly, have high payload and have a camera on-board, which makes them good tools for misuse. Starting from the lighter side, such misuse can happen because of lack of knowledge, for example, by flying nearby airports endangering the airplanes taking off [29] or flying while being drunk around the White House [32] and painting walls, like in New York City [30]. On a bit worrisome side, they can be used by activist movements flying around sensitive areas such as nuclear power stations like mentioned already earlier. Or they can be used for smuggling drugs over the border, like has happened between U.S. and Mexico border. These cases do not sound that bad, but it is easy to see how serious problems the

Multicopters can create, if they are used for terrorism by attaching bombs on them [33]

No matter what the reason for the drone hitting unintended targets is, it can be imagined what kind of damage a 20 kg device, falling from the sky or hitting a passenger airplane, can do. This has been modelled for example by Weibel and Hansman (2005). And this is why regulation is needed.

2.7 Drone Regulation

Traditionally the Radio Controlled (RC) aerial vehicles have not created lots of trouble, as it has not been possible to fly beyond line-of-sight. This is because without the modern camera and telecommunication technologies, the only way to control them has been by seeing them with your own eyes. This has limited the possible flight distance a lot. Fixed-wing airplanes have easily flown out of the range of the controller, and helicopters have been too unstable to fly far away. Furthermore, their lifting capacity has not allowed much of extra equipment on-board. This has made the regulation easy, or even almost unnecessary. Thus the current drone legislation is loose, allowing almost anything with a couple of specific rules.

But now, the rapid development of customer electronics has enabled multicopters. Because of the intelligence in the Flight Controller (FC), they are stable enough to stay at the same spot without human intervention. With GPS they can fly by themselves through the pre-set waypoints, making it possible for the multicopter to fly relatively long distances unattended, with any outer threat closing by unbeknownst to the device. Multicopters having enough lift to carry even heavy payloads such as digital cameras and video cameras have made them a popular tool to shoot videos on top of audiences, which is dangerous. And the latest trend, using first person view (FPV) setups, allows the user to pilot the drone seeing where to fly as long as the radio works with a limited view and information about the surroundings.

The new ways of piloting these aerial vehicles has changed the need for legislation completely. Multicopters are becoming common, the pilot needs almost zero knowledge to fly them, they have lots of sensitive equipment prone for breaking, and they are heavy and have lots of moving parts. This worries the regulators, who are scared and worried for the first risk group, human lives. Furthermore EASA lists two more risks groups for drones: “mid-air collision with manned aircraft” and “damage to property”. These kinds of worries have created a need for regulating the usage of drones all around the world. FAA has already started legislating and restricting the use. In China they have already started requiring licenses for the drone pilots [35]. And of course, Trafi has already made a draft of the regulation too.

By the drafts around the world, generally the use of drones for delivering packages, flying over audiences, flying nearby airports etc. would be forbidden. Additionally it seems to be common plan that small drones, like toy multicopters and model airplanes, would be allowed to be flown without any licenses for recreational use
[36]. In the Table 2 FAA (2014) separates recreational use from the non-recreational use. This recreational use would also have strong limitations, like flying distance limited to the visual line of sight, and restricted flying nearby specific areas, like airports or power stations. [34] [35] On the other hand, some special cases have also been made. For example Amazon, amongst already 128 other companies, have gotten an exemption to test the drones for mail delivery [37]

Table 2.2: differences between recreational and commercial use

Hobby or Recreation	Not Hobby or Recreational
Flying a model aircraft at the local model aircraft club	Receiving money for demonstrating aerobatics with a model aircraft.
Taking photographs with a model aircraft for personal use.	A realtor using a model aircraft to photograph a property that he is trying to sell and using the photos in the property's real estate listing. A person photographing a property or event and selling the photos to someone else.
Using a model aircraft to move a box from point to point without any kind of compensation.	Delivering packages to people for a fee.
Viewing a field to determine whether crops need water when they are grown for personal enjoyment.	Determining whether crops need to be watered that are grown as part of commercial farming operation

In Finland the aerial vehicle legislation is done by the Finnish Transport Safety Agency, Trafi. Like mentioned already, the current legislation is loose, as the only limitations are 20 kg weight limit, 150 m height limit and a VLOS to the drone as recommendations [38] This is why the Trafi, after the other legislative organizations like European Aviation Safety Agency (EASA), has started creating a new all covering legislation for the aerial vehicles, also touching up some hobbyist model aircraft rules. The first draft was published by [40].It raised opposition, as the hobbyist could not agree on some of the laws proposals [39]. However, the Trafiis understanding and they are asking for public opinion before the final version, coming in the end of 2015.

The most important part of the first draft is differentiating between the professional and hobbyist use of drones. Professionals fly over audiences and Beyond Visual Line Of Sight (BVLOS), so it makes sense to require more strict rules and higher familiarity with the equipment. On the other hand, hobbyists are using the multicopters on open fields less often compared to professionals.

The draft does not actually affect multicopter hobbyists much, as the biggest change for hobbyists is forbidding anything else than Visual Line Of Sight (VLOS) piloting. The VLOS means that the pilot has to be able to follow the multicopter continuously with his own eyes, instead of devices like cameras, First Person View (FPV) equipment or other person. There has been a growing audience for FPV 15

flying [12], where the pilot does not have VLOS to the vehicle while wearing the video glasses. Interestingly, the draft does not allow using a spotter for recreational use compared to commercial use, where it is allowed. This forbids the FPV racing completely. Furthermore, multicopters are not allowed to be used above audience. Finally, the draft does not include a requirement for any kind of drone license. [40]
The draft affects more on the professionals and is much stricter on them. For example, the pilot needs to be at least 18 years old, the drone has to be registered, it needs to have pilot name and contact details attached, and the pilot needs to keep a log book for every flight done. The Finnish draft does not require a drone piloting license, compared to the American draft by [34]. But the professionals would also need to take good care of the drone, for example going through a status check-up before every lift-off. The VLOS rule affects the professionals too, making the automated waypoint flying forbidden without a temporary license. Compared to the recreational use, in commercial use the use of a spotter is allowed, who must also be over 18 years old. The pilot and spotter must have two separate communication devices available all the time. This restricts the drone use as the most beneficial use cases for automated flying would be something like going somewhere far away, for example taking a video of a LTE mast and returning to starting point. Moreover, special limitations for flying over the audience have been defined. For example, the multicopter should weight at most 7 kg, the flight height should minimize the possible damage caused to the people and their property and there has to be plans for the use. [40]
Finally, the regulation affecting both the recreational and professional users is covered below. The basic rules, like maximum flight height and distance have stayed the same compared to the current legislation. The maximum weight would rise to 25 kg. In addition, it has been stated that flying in the night would not be allowed, except for the civil safety like police and firemen. This makes sense, as it is hard to keep the orientation of the drone in the night. Moreover, the drones are not allowed to be flown nearby specific areas, like airports or power stations. [40]
A big problem is how to prevent pilots from entering these areas. As a solution a system called geofencinghas been suggested. [5] It would require the restricted areas to be preconfigured in the FC which would stop in the border of the area. One problem in this is, that most of the FCs cannot support such functionality. As last, the drone has to avoid all the other aircrafts. Some more obvious points are minimizing noise and property damage to other people, and not disturbing governmental agencies, like police. On the other hand, it has also been stated, that it is possible to make exceptions over these rules. [40] The final version of the

[40]regulation came out in the end of the year 2015 and it is practically same with the draft.