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Abstract

The different types of drones can be differentiated in terms of the type (fixed-wing, multirotor, etc.), the degree of autonomy, the size and weight, and the power source. These specifications are important, for example for the drone's cruising range, the maximum flight duration, and the loading capacity. Aside from the drone itself (i.e., the 'platform') various types of payloads can be distinguished, including freight (e.g., mail parcels, medicines, fire extinguishing material, flyers, etc.) and different types of sensors (e.g., cameras, sniffers, meteorological sensors, etc.). Applications of different payloads will be described. In order to perform a flight, drones have a need for (a certain amount of) wireless communications with a pilot on the ground. In addition, in most cases there is a need for communication with a payload, like a camera or a sensor. To allow this communication to take place frequency spectrum is required. The requirements for frequency spectrum depend on the type of drone, the flight characteristics, and the payload. Since frequency spectrum does not end at national borders, international coordination on the use of frequency spectrum is required. Legal issues on frequency spectrum usage and electronic equipment (national and international legal matters on frequency spectrum an equipment requirements) are discussed, as well as frequency spectrum and vulnerability (an insight in available frequency spectrum and associated risks in using the frequency spectrum) and surveillance and compliance (enforcement of frequency spectrum use, equipment requirements, and the need for international and European cooperation). Finally, future developments in drone technology are discussed. The trend is for drones to become smaller, lighter, more efficient, and cheaper. As a result, drones will become increasingly available to the public at large and will be used for an increasing range of purposes. Drones will become increasingly autonomous and also more capable of operating in swarms.

Keywords (separated by '-')

Autonomy - Propulsion - Fixed-wing drones - Multirotor drones - Frequency spectrum - Wireless communication - Interference - Swarms - Miniaturization - Sensors

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Chapter 2
Drone Technology: Types, Payloads, Applications, Frequency Spectrum Issues and Future Developments

Bas Vergouw, Huub Nagel, Geert Bondt and Bart Custers

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Abstract The different types of drones can be differentiated in terms of the type (fixed-wing, multirotor, etc.), the degree of autonomy, the size and weight, and the power source. These specifications are important, for example for the drone's AQ1 cruising range, the maximum flight duration, and the loading capacity. Aside from the drone itself (i.e., the 'platform') various types of payloads can be distinguished, including freight (e.g., mail parcels, medicines, fire extinguishing material, flyers, etc.) and different types of sensors (e.g., cameras, sniffers, meteorological sensors, etc.). Applications of different payloads will be described. In order to perform a flight, drones have a need for (a certain amount of) wireless communications with a pilot on the ground. In addition, in most cases there is a need for communication with a payload, like a camera or a sensor. To allow this communication to take place frequency spectrum is required. The requirements for frequency spectrum depend on the type of drone, the flight characteristics, and the payload. Since frequency spectrum does not end at national borders, international coordination on the use of frequency spectrum is required. Legal issues on

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frequency spectrum usage and electronic equipment (national and international legal matters on frequency spectrum an equipment requirements) are discussed, as well as frequency spectrum and vulnerability (an insight in available frequency spectrum and associated risks in using the frequency spectrum) and surveillance and compliance (enforcement of frequency spectrum use, equipment requirements, and the need for international and European cooperation). Finally, future developments in drone technology are discussed. The trend is for drones to become smaller, lighter, more efficient, and cheaper. As a result, drones will become increasingly available to the public at large and will be used for an increasing range of purposes. Drones will become increasingly autonomous and also more capable of operating in swarms.

Keywords Autonomy · Propulsion · Fixed-wing drones · Multirotor drones · Frequency spectrum · Wireless communication · Interference · Swarms · Miniaturization · Sensors

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2.1 Introduction

The aim of this chapter is to provide an overview of the different types of drones currently used, their technical specifications, potential payloads and applications, frequency spectrum issues, and the current and near-future technological development in drone technology. Needless to say, this chapter is not exhaustive since (drone) technology evolves rapidly. Therefore, some overviews provided in this chapter can become outdated quickly. The main

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characteristics of drones, however, will probably remain the same for years to come. Aspects like propulsion, autonomy, and size may change in the near future but the characteristics themselves will remain important in for the use of drones nevertheless.

The first important distinction in the use of drones is between the drone itself (the platform) and the equipment attached to it (the payload). In this context, the drone itself can best be considered a flying platform which can be made suitable for different goals. These goals can be achieved in combination with the specific payload suitable for that goal. For instance, a camera can be attached to a drone to make it suitable for particular inspections. This distinction is used to define the different parts of this chapter.

In Sect. 2.2, the different types of drones and their technical properties are discussed in more detail. In Sect. 2.3, an overview of the different payloads and the possible practical applications is provided. In Sect. 2.4, frequency spectrum issues are discussed. In Sect. 2.5, future developments in the drone technology are discussed. In Sect. 2.6, this chapter is concluded.

2.2 Types of Drones and Their Technical Characteristics

To get a better understanding of drones, it is important to discuss their different technical characteristics. In this section, these characteristics are discussed and, in order to further visualize these technological characteristics, examples of existing drones with these characteristics are described.

The most notable characteristic is what we will call the type of drone. In this chapter, this term is used to define the difference between fixed-wing systems, multirotor systems, and other systems. Examples of other systems are so-called hybrid systems, which are both multirotor and fixed-wing systems, ornithopters, and drones that use turbo fans. The technology used to keep the drone flying defines the type of drone. This characteristic is also the determining factor in the shape and appearance of the drone. A second characteristic is the level of autonomy of the drone. The autonomy can vary from full autonomous operation to fully controlled by a remote pilot. Another noteworthy characteristic is the difference in size between drones. The size can vary from drones the size of an insect to drones the size of a commercial airplane. Weight is also an important characteristic. The weight of drones can vary from several grams to hundreds of kilograms. The final defining characteristic discussed in this section is the difference in energy source. Examples of energy sources are battery cells, solar cells, and traditional airplane fuel.

The importance of characteristics lies in the fact that the different drone payloads and related applications depend on (gradations within) these characteristics. Also, drones are usually categorized using the mentioned characteristics.

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2.2.1 Main Existing Drone Types

As stated above, an important technical characteristic of drones is the type of drone. The main drone types are fixed-wing systems and multirotor systems. The majority of existing drones can be defined within these two types. Other systems like hybrid systems and ornithopters are also briefly discussed.

Fixed-Wing Systems

Fixed-wing is a term mainly used in the aviation industry to define aircraft that use fixed, static wings in combination with forward airspeed to generate lift. Examples of this type of aircraft are traditional airplanes, kites that are attached to the surface and different sorts of gliders like hang gliders or paragliders. Even a simple paper airplane can be defined as a fixed-wing system. An example of a fixed-wing drone is the widely used Raven, which will be discussed in more detail later in this section.

Multirotor Systems

Multirotor systems are a subset of rotorcraft. The term rotorcraft is used in aviation to define aircraft that use rotary wings to generate lift. A popular example of a rotorcraft is the traditional helicopter. Rotorcraft can have one or multiple rotors. Drones using rotary systems are almost always equipped with multiple small rotors, which are necessary for their stability, hence the name multirotor systems. Commonly, these drones use at least four rotors to keep them flying. A popular example of these multirotor drones is the widely used Phantom drone made by the Chinese company DJI. This four-rotor drone will be discussed in more detail later in this section.

Differences between fixed-wing drones and multirotor drones are important for the different applications consumers want to use the drone for. For example, multirotor drones do not need a landing strip, make less noise than their fixed-wing counterparts and can hover in the air. Fixed-wing drones can fly faster and are more suitable for long distances than their multirotor counterparts. These characteristics determine which of these drone types to use for a specific application.

Other Systems

Some types of drones cannot be labeled as a fixed-wing or a multirotor drone. Sometimes because the drone simply is neither fixed-wing nor multirotor, sometimes because the drone has characteristics of both types. Hybrid systems are systems that have characteristics of both multirotor and fixed-wing systems. The hybrid quadcopter is an example of such a drone.[1] This drone uses multiple rotors to take-off and land vertically but also has wings so it can fly longer distances.

Drones that are neither fixed-wing nor multirotor systems are far less frequent. An example of such a drone is the ornithopter. These drones fly by mimicking wing motions of insects or birds. Most of these ornithopters are scaled to the birds

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[1] https://latitudeengineering.com/products/hq/. Accessed April 11, 2016.

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or insects they represent. These small drones are mostly still under development and are not widely used in practice. Examples of ornithopters include the Delfly explorer,[2] a drone that mimics a dragonfly, and the micromechanical flying insect,[3] a drone under development that is eventually going to represent a fly both in size and movement.

Another example of drones that are neither fixed-wing nor multirotor are drones using jet engines. The T-Hawk drone is an example of such a drone.[4] This drone uses a turbo fan, making the drone look more like an unmanned (hydro) jetpack than fixed-wing or multirotor.[5]

To give a more complete picture, unmanned balloons (filled with for example hot air, helium, or hydrogen) are mentioned here as well. These balloons can fly by heating the air inside. Unmanned balloons are a special kind of unmanned aircraft, but are not commonly seen as drones. The same goes for rockets and jetpacks.

2.2.2 Level of Autonomy

Because of the absence of a pilot, drones always have a certain level of autonomy. An important distinction within the concept of autonomy is the difference between automatic and autonomous systems. An automatic system is a fully preprogrammed system that can perform a preprogrammed assignment on its own. Automation also includes aspects like automatic flight stabilization. Autonomous systems, on the other hand, can deal with unexpected situations by using a preprogrammed ruleset to help them make choices. Automatic systems cannot exercise this ‘freedom of choice.’[6] In this chapter, the focus is on autonomy in flight routes and operations (i.e., focusing on drone use and applications) rather than on automation like flight stabilization (i.e., focusing on technology).

The United States Department of Defense distinguishes four levels of autonomy in their roadmap for unmanned systems.[7] The most basic level of autonomy is a human operated system in which a human operator makes all the decisions regarding drone operation. This system does not have any autonomous control over its environment. A higher level of autonomy is a human delegated system. This system can perform many functions independent of human control. It can perform tasks when delegated to do so, without further human input. Examples are engine controls, automatic controls, and other automation that must be activated or

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[2]http://ww.delfly.nl/explorer.html. Accessed April 11, 2016.
[3]Wood et al. 2003.
[4]http://aerospace.honeywell.com/thawk. Accessed April 1, 2016.
[5]Ackerman 2011.
[6]USDoD 2013.
[7]USDoD 2013.

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deactivated by a human controller. The third level of autonomy is a human supervised system. This system can perform various tasks when it is given certain permissions and directions by a human. Both the system itself and the supervisor can initiate actions based on sensed data. However, the system can only initiate these actions within the scope of the current task. The final level of autonomy is a fully autonomous system. This system receives commands input by a human and translates these commands in specific tasks without further human interaction. In case of an emergency, a human operator can interfere with these tasks.

2.2.3 Size and Weight

Other important characteristics of a drone are its size and weight. Clarke (2014) distinguishes large drones and small drones, but divides the small drones in multiple subcategories. Clarke also adds minimum weight indicators to the drone categories. The lower weight limit of large drones is 150 kg for fixed-wing drones and 100 kg for multirotor drones.

Many countries distinguish large and small (or light and heavy) drones. For instance, the Dutch Human Environment and Transport Inspectorate (ILT) makes a distinction between light drones and heavy drones. Light drones are drones lighter than 150 kg and heavy drones are drones of 150 kg or more.[8]

Custers et al. (2015) make a distinction between large and small drones but with different criteria than mentioned above.[9] The development of drones is currently focused on making smaller and lighter drones for the general public. Large drones are mainly used for military purposes. Therefore, a shift can be observed from large drones to smaller drones. This calls for changing the reference categories and the category parameters. Therefore, they suggest to use the term large drones for fixed-wing drones between 20 and 150 kg and multirotor drones between 25 and 100 kg. Small drones are fixed-wing drones up to 20 kg and multirotor drones up to 25 kg. Within the category of small drones, they suggest to use a subcategory of mini drones. Mini drones can vary in weight from several grams up to several kilograms. These mini drones are mainly suitable for indoor applications and recreational applications. Examples of such drones are discussed later in this section.

2.2.4 Differences in Energy Source

The final drone characteristic discussed here is the energy source. There are four main energy sources: traditional airplane fuel, battery cells, fuel cells, and solar

[8] ILT 2013.

[9] Custers et al. 2015.

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cells.[10] Airplane fuel (kerosene) is mainly used in large fixed-wing drones. An example of such a drone is the military Predator drone. This drone is used a lot by the US army and can be equipped with a number of different sensors, but also with rockets and other types of ammunition.[11]

Battery cells are mainly used in smaller multirotor drones. These drones are short range and require less operating time than drones using kerosene. These drones are often for recreational use, making it more practical for the drone to run on a rechargeable battery cell. An example of such a drone is the above-mentioned Phantom drone.[12]

A fuel cell is an electrochemical device that converts chemical energy from fuel directly into electrical energy. Because of the lack of conversions in thermic and mechanical energy, this conversion is efficient and environment friendly. Fuel cells are currently rarely used in drones. Only fixed-wing drones can be equipped with such a cell because of the cell's relatively high weight. A major advantage of using a fuel cell is the fact that drones can fly longer distances without recharging. For example, the Stalker drone which uses a fuel cell has a flight time of 8 h instead of 2 h.[13]

Drones using solar cells are rare in the current drone industry. Drones using solar cells are mainly fixed-wing drones. Because of the low efficiency of current solar cells, these cells are usually suitable for many multirotor drones. However, solar cells are suitable for small ornithopters. Solar cell drones attracted a lot of media attention when both Google and Facebook struck deals with manufacturers of these drones.[14] Their goal was to let solar-powered drones fly in the atmosphere permanently in order to enable people to connect to the Internet more easily and massively.

2.2.5 Widely Used Drone Models

To further illustrate the drone characteristics described above, some specific drone models are described in this section. Currently, drone models are developing fast and numerous drone models already exist. Due to the increasing popularity of drone technology, new models are developed at a fast pace. Therefore, it is

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[10] See Custers et al. 2015, for details about these interviews.

[11] http://science.howstuffworks.com/predator1.htm and http://www.deagel.com/Unmanned-Combat-Air-Vehicles.htm. Accessed April 1, 2016.

[12] http://www.techtimes.com/articles/5360/20140412/new-dji-phantom-drone-is-faster-and-boasts-longer-battery-life.htm. Accessed April 1, 2016.

[13] http://www.popularmechanics.com/military/a8956/longer-lasting-drones-powered-by-fuel-cells-15425554/. Accessed April 1, 2016.

[14] http://www.theguardian.com/technology/2014/mar/28/facebook-buys-uk-maker-solar-powered-drones-internet and http://www.bbc.com/news/business-27029443. Accessed April 1, 2016.

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impossible to describe here every drone model currently existing. Hence, only some models which have been in the media to some degree and models which are widely available for governments, industry, and citizens are described here. These are the widely used, well-known, and available drone models. The order in which these models are discussed is from small to large.

Delfly Explorer

The Delfly Explorer is an ornithopter drone that flies like a dragonfly and is being developed by Delft University of Technology in the Netherlands. The drone can take-off and fly fully autonomous within a closed environment. It can avoid obstacles by using two cameras. The drone has a weight of 20 g and can currently operate for only nine minutes because of the size and weight constraints of the battery. In the future, these models could be used for reconnaissance and air photography, but also for applications like greenhouse inspections to check if fruit is mature.[15] The Delfly Explorer is an interesting example of current developments in the drone industry. Drones tend to get smaller and lighter. Later in this chapter, future developments in drone technology are discussed in more detail.

Hubsan x4 Drone

The Hubsan x4 is a small multirotor drone developed by the Chinese company Hubsan. This mini drone is fairly simple in design and operation. It has four rotors and can be operated with a controller. Some models of the x4 drone come with a built-in camera for making pictures and recording video. The drone is currently a popular and relatively cheap alternative for the more advanced drones. The drone has a weight of 30 g, a radius of around 100 m and can operate for 7 min with a fully charged battery. Unlike most of the other models discussed, this drone does not have advanced features and is mainly built for recreational purposes.[16]

Parrot AR Drone

The Parrot is a drone mainly built for recreational purposes. It has a multirotor system that can be controlled by a smartphone or tablet. The drone can operate for 12–18 min and weighs about 400 g. Its speed is about 18 km/h and it has a range of about 50 m. The drone has two cameras, Bluetooth and WiFi technology and uses GPS-waypoints to fly a preprogrammed route. The Parrot is similar to the below-mentioned Phantom, both in applications and functions. Besides film and photography software, the drone is also equipped with gaming software, making its emphasis on recreation more clear. The gaming aspect includes a racing game and augmented reality driven shooter games in which a real-world environment is augmented by computer-generated graphics and/or sound.[17] The user can preprogram the drone with a task and settings like maintaining a particular altitude, after which it carries out the given task by itself.[18] The Parrot is one of

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[15] http://www.delfly.nl/explorer.html. Accessed 1 April 2016.

[16] http://www.hubsan.com/productinfo_16.html. Accessed April 1, 2016.

[17] For detailed information about augmented reality see for example Carmigniani et al. 2011.

[18] http://ardrone2.parrot.com/. Accessed April 1, 2016.

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the most widely used and popular models for recreational activities at the moment.[19] Surveillance and privacy issues regarding this drone have caused a lot of discussion in for example Germany.[20]

DJI Phantom

The Phantom drone is a multirotor drone with four rotors and is mainly built for recreational purposes. The drone comes with a camera and can be controlled using a smartphone or a WiFi controller. The smartphone can also control the camera to move and make pictures or record video. The Phantom can fly at around 54 km/h and it can operate for about 25 min. Just by programming the flight altitude and certain waypoints the drone can take-off, land, make recordings, and return automatically.[21]

Raven

The Raven is a fixed-wing drone developed in 2002. The drone was originally developed for the US Army but is frequently used by many other countries as well, making it one of the most widely used drones in the world at this moment.[22] The main purpose of the Raven is surveillance and it can be controlled remotely or preprogrammed for autonomous operation. The Raven has a width of 1.4 m, weighs about 2 kg, and can stay operational for 60–90 min within a range of 10 km. It is equipped with an optic and an infrared camera. Like regular model airplanes, the Raven can be launched by throwing it in the air. It lands by gliding toward a preprogrammed landing site and can compensate for the impact when hitting the ground by falling apart.[23]

ScanEagle

The ScanEagle is a fixed-wing drone dating from 2004 and is mainly used as a surveillance tool. It is equipped with an optic and/or infrared camera and can operate for over 20 h. It is 3.1 m in width, 1.2 m in length, weighs 18 kg and has a cruising velocity of 89 km/h. The drone can be launched by pneumatic pressure and it can land with a skyhook system, plucking it out of the air. Therefore, a landing strip is not necessary. Contrary to most fixed-wing drones, the ScanEagle needs little space to take-off or land.[24]

In this section, a number of core characteristics of drones were described to determine the main differences between drones and their technical properties. These characteristics are displayed schematically in Fig. 2.1.

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[19] Laxague et al. 2013.

[20] Mortimer and Parrot 2011.

[21] http://www.dji.com/product/phantom-2. Accessed April 1, 2016.

[22] Alex 2015.

[23] http://www.avinc.com/uas/small_uas/raven/. Accessed April 1, 2016.

[24] http://www.boeing.com/history/products/scaneagle-unmanned-aerial-vehicle.page and http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104532/scan-eagle.aspx. Accessed April 1, 2016.

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Characteristics	Delfly Explorer	Hubsan x4 Drone	Parrot A.R. Drone	DJI Phantom	Raven	ScanEagle
Type of drone						
Fixed-wing	-	-	-	-	X	X
Multirotor	-	X	X	X	-	-
Other	X	-	-	-	-	-
Autonomy						
Human operated system	-	X	X	X	X	X
Human delegated system	-	-	X	X	X	X
Human supervised system	X	-	-	-	-	-
Fully autonomous system	-	-	-	-	-	-
Size/weight						
Large drone (25-150 kg)	-	-	-	-	-	-
Small drone (2-25 kg)	-	-	-	-	X	X
Mini drone (up to 2 kg)	X	X	X	X	-	-
Energy source						
Airplane fuel	-	-	-	-	-	X
Battery cells	X	X	X	X	X	-
Fuel cells	-	-	-	-	-	-
Solar cells	-	-	-	-	X	-

Fig. 2.1 Overview characteristics

2.3 Types of Payloads and Their Applications

This section will discuss the types of payloads that can be attached to drones. Virtually all kinds of payloads can be attached to drones, the only restrictions are usually the weight and size of payloads. Most drones are equipped with cameras by its manufacturer. Other payloads can be ordered at drone manufacturers, but drone users also can attach payloads to their drone themselves. In this section, we will distinguish between sensors and other types of payloads. We will describe some applications for these payloads as well.

2.3.1 Sensors

The weight, model, and energy source of a drone are major factors influencing its maximum altitude, flight duration, flight range, and maximum payload. An important category of payloads are sensors. Most drones are nowadays equipped with cameras. Cameras and microphones are the most often used payloads for drones and often come standard when buying a drone. Cameras can be regular cameras but also infrared. Such cameras may enable night vision and heat sensing. Other sensors include biological sensors that can trace microorganisms, chemical sensors (‘sniffers’) that can measure chemical compositions and traces of particular chemical substances including radioactive particles and meteorological sensors that can measure wind, temperature, humidity, etc.

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Cameras can be useful payloads for the prevention, criminal investigation, criminal prosecution, and sentencing of criminal behavior. Most applications assume drones to be flying camera surveillance. The preventive function of camera surveillance shows mixed results.[25] Citizens expect more crime prevention from police presence than from camera surveillance.[26] The preventive function of camera surveillance, including drones, will probably be very limited when there are not at least a substantial number of drones in the sky. However, even with a large number of drones in the sky, the preventive function may be limited as with regular camera surveillance.[27] It is often assumed that live monitoring images or reviewing camera footage after a crime, may be useful to reconstruct incidents or to trace, arrest and prosecute perpetrators.[28] In practice, reviewing images indeed may yield useful information for solving crime, for instance, for tracing and arresting suspects, for excluding potential suspects, identifying witnesses, finding missing persons, reconstructing incidents, and finding stolen objects and vehicles. Satisfaction about camera surveillance among law enforcement agencies is limited however.[29] Camera images can be useful as steering information for the police during criminal investigations. Drones may also be useful for forensics, since drones can be used to investigate crime scenes without stepping on valuable traces. Due to the high angle under which drones record images, it is not always likely that faces can be recognized. The use of image processing software, such as image recognition and license plate recognition may be limited for the footage collected with drones. Footage collected with drones may also be used in court as evidence. In the US there are examples of this.[30]

Law enforcement applications for drones are not limited to the use of cameras. Other sensors may also provide opportunities. For instance, heat sensors are very useful for detecting hemp that people are growing in their attics. Chemical sensors may be useful for detecting traces of illegal drugs. Drones equipped with WiFi hotspots may provide clues about someone's position and can be used for tapping phone and Internet use.

In the security domain drones are useful as observation and surveillance instruments. Webster distinguishes three mechanisms[31]: non-active systems, in which cameras act as a visual deterrent by using fake cameras to create the illusion of surveillance without actual monitoring or storage, reactive systems, which have recording, storage and playback facilities for footage of incidents after an event has occurred, and proactive systems with live surveillance from a dedicated control room with recording, storage and playback facilities, allowing for an

[25] Taylor 2011.

[26] Sparks et al. 2001; Brands and Schwanen 2013.

[27] Welsh and Farrington 2008.

[28] Ditton 2000; Koskela 2003.

[29] Custers 2012; Custers and Vergouw 2015.

[30] Sherwell 2014.

[31] Webster 2009.

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immediate response to incidents as they occur. Drones can be used for all three types of surveillance. However, it is unlikely that citizens will feel safer, as research has shown for live monitoring.[32] In fact, people usually do not know whether camera systems are proactive, reactive, or non-active.

Drones equipped with sensors may also provide useful intelligence about particular situations, such as the presence of people or buildings in a particular areas or reconnaissance surveys of areas. In case of disasters or crises, information collected with drones may contribute to improved situational awareness. Remote areas or places that are difficult to reach (e.g., because of traffic jams), may be easily accessible for drones. The higher altitude position of a drone may provide better overviews and provide images for reconstructions, evidence, and insurance claims. In the area of security, drones are also useful for purposes of crowd management, for instance, at large demonstrations, music festivals, sports games, and other events. Drones with cameras are useful for tracking people and assessing potential escalations. For instance, drones may provide information of a group of protesters heading in a particular direction or information about two groups of football fans moving toward each other. Drones may be useful for protecting VIPs, vulnerable buildings (nuclear power plants, harbors, airports), and infrastructure (water supply, internet, etc.). In case of large fires, drones may provide information about the size and development of the fire, the release of toxic particles and the direction of local winds. In case of accidents with nuclear power plants drones can trace the presence and dissemination of radioactivity. Most of these applications focus on movements; identifying individuals is much more difficult with drones.

For inspections and maintenance of infrastructure, such as highways, railroads, windmills, bridges, pipelines and dams, drones may be a useful tool. Weak spots, erosion, or wear and tear may be detected with cameras. The use of infrastructure, such as the movement of vehicles, aircraft, and ships can easily be monitored. In case of traffic jams, the traffic can be rerouted and the data collected can be used for traffic analyses. Pipelines leaking gas or water may be detected. High objects like roofs, chimneys, windmills, and electricity network cables can be inspected from close distance when using drones.

Drones with sensors may be useful to supervise and enforce permits, for instance, permits for building a structure, parking permits, and permits for removing trees. Drones may also be useful for purposes of cartography and geomapping. These are promising applications of drone use in the near future.[33] Drones are cheaper than aerial photography from manned aircraft and also cheaper than satellite imaging. Since drones can get closer to the surface, they can also

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[32]Brands et al. 2013.

[33]COM (2014) 207, *A new era for aviation, opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner*. Communication from the commission to the European Parliament and the Council, European Commission, April 8, 2014.

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reach different angles and perform other measurements like 3D terrain modeling, research on vegetation, and geomorphology (erosion, seismographic activity, volcanic activity, etc.).

When equipped with particle sensors, drones are useful for detecting the emission of particulates. Concentrations and emission rates of sulfur oxides, nitrogen oxides, and ammonia can be measured. Other sensors can measure light, sound, and radiation. These applications of drones may contribute to the environment and are also less polluting than manned aircraft.[34] Drones may also help monitoring illegal waste dump and transport of toxic waste. When particular animals are provided with RFID tags, drones can track migrations, biodiversity, poaching, and habitats. Images created by drones may also be useful for estimating animal populations and tracking their behavior.[35] Drones with sensors are currently used in agriculture, for instance, for monitoring crop growth, estimating biomass, checking for weeds and plant diseases, and evaluating the quality and level of water.

The use of drones in border surveillance is particularly useful in vast areas and areas that are difficult to reach or access. Border surveillance may prevent trafficking illegal drugs and illegal migration. The US government uses drones on the Mexican border.[36] The Australian government has announced the use of drones for border surveillance, particularly for finding boat refugees. Frontex, the EU agency for border security explicitly mentions the use of drones in establishing the border surveillance system EUROSUR.[37]

In the field of cinematography, television, and entertainment there are wide possibilities for drones. Drones provide the opportunity to take high camera shots.[38] During the 2014 Winter Olympics in Sochi, Russia drones were used to film sportsmen. Also, drones are particularly useful for providing overviews of landscapes, cities, and buildings. In movies, pursuit scenes can be recorded from an aerial perspective.[39] Drones can fill the 'gap' between hoisting cranes (with limited height) and helicopters (with high costs). In what is called drone journalism, drones enable journalists to cover news, large events, and police pursuits.

Citizens can easily order small drones via the internet and such drones are usually equipped with cameras. People use these cameras to record or take pictures of their homes and their neighborhood, sometimes just for fun, sometimes for other purposes, like neighborhood crime prevention. Other recreational purposes in which drones are used are bird watching, sportsmen recording

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[34]RPAS Steering Group 2013, p. 29.

[35]Klonoski 2013.

[36]Carroll 2014; Preston 2014.

[37]http://www.dw.com/en/european-parliament-approves-eurosur-border-surveillance/a-17149625. Accessed April 1, 2016.

[38]Fung 2014.

[39]CBS News 2014.

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themselves[40] and making selfies (self-portraits featuring the photographer).[41] A typical example of a drone specifically designed for making selfies is the Nixie, a bracelet that can unfold as a drone.[42] This drone is still in development, however.

The use of drones in science is also a growing domain. Drones may be useful to collect all kinds of research data. For instance, in meteorology drones can collect data on humidity, pressure, temperature, wind force, radiation, etc. Apart from hurricanes, some drones can withstand severe storms.[43] In case of nearing tornados or hurricanes, people can be timely evacuated. Drones can gather relevant data in places that were hitherto difficult or costly to reach—data that may provide new scientific insights,[44] increasing knowledge about the environment, the atmosphere, and the climate. Such knowledge may improve existing models and provide more accurate predictions.

Drones are also becoming more common in archeology.[45] Drones can survey landscapes cheaper and more detailed than satellites. From the air, patterns in landscapes can be observed, for instance, vegetation that indicates an old road or settlement. Images collected by drones can also be used to reconstruct sites and excavations. In geography, drones can be useful for estimating populations, for instance, in slums. Even in developed countries actual populations may differ from what is officially registered, as there may be significant numbers of illegal immigrants. New tribes in remote areas, like in the Amazon rainforests, may still be discovered with the use of drones. Drones may be useful in mapping and monitoring urbanization and traffic flows. Geological surveys with drones are already used in finding new sources of gas and oil.[46]

2.3.2 Other Payloads

Apart from the sensors described in the previous subsection, all kinds of other payloads can be attached to drones. Most payloads that are not sensors involves cargo that needs to be delivered, i.e., mail like letters and parcels, medicines, meals, supplies, and fire extinguishers. Cargo can also be illegal, such as narcotics

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[40] Beckham 2014.

[41] Drones, even without any payload, are popular among citizens for recreational use. In this context, drones are often referred to as remote controlled airplanes/helicopters. Some people like to participate in air racing or pylon racing, a competition in which a drone has to fly a series of prescribed figures or has to fly a route the fastest. In pylon racing the drone has to fly 10 laps around three pylons in a triangular position as fast as possible. In combat games, paper ribbons are attached to each drone and then drones have to cut off each other's paper ribbons in their flight.

[42] http://www.flynixie.com. Accessed April 1, 2016.

[43] Kelly 2013.

[44] Richardson 2014.

[45] Euronews 2013.

[46] Parker 2014; Dillow 2013.

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and firearms. In some cases, the cargo is not intended for delivery; examples of such payloads are ads and WiFi hotspots.

From a commercial perspective, drones are considered interesting for delivering mail, parcels, and other cargo. A typical example would be supplying oil drilling platforms or remote islands. In the US there are speculations about delivering pizzas using drones[47] and in Russia pizzas are already delivered using drones.[48] In China drones deliver pies.[49] However, it is likely that these experiments are mainly interesting for publicity reasons, in order to draw attention to a specific company or product, rather than from an efficiency in logistics perspective, as there are obvious limits to the size and weight of the cargo that small drones currently can carry. In the US, Amazon intends to deliver its orders using drones, but the authorities have prohibited the use of drones.[50]

Another commercial application of drones is that of flying advertisements. Objects, banners, ticker tapes, and speakers can be attached to drones to disseminate marketing messages. Examples may be to attach a large beer can or a large shoe with a logo to a drone and fly it around. However, such applications are still in development.

As mentioned above, drones in the security domain often use cameras and other sensors. Other useful payloads include, for instance, fire extinguishing materials[51] and speakers and light signals for crowd control purposes.[52] More controversial is the use of drones equipped with weapons, teargas, etc.[53] For search and rescue operations, drones may be used to supply water, food, medicine, and AEDs to stranded mountaineers, people in the desert or people who were shipwrecked. Infrared cameras may be useful to find lost people and save them from hypothermia, dehydration, etc. After disasters like earthquakes or tsunamis, complete infrastructures may be disables, but drones may be equipped with WiFi to restore communication networks. Highly controversial is the use of drones for targeted killing.[54]

Drones in agriculture do not only focus on monitoring. In Japan, currently already 30 % of the rice fields are sprayed with drones.[55] Pesticides and fertilizers can be used in minimum quantities by means of so-called precision farming. Drones are faster, safer, and less damaging than tractors. They may also scare

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[47] Pepitone 2013.

[48] Daily Mail 2014.

[49] Atherton 2013.

[50] McNeal 2014.

[51] Wells 2014.

[52] Finn and Wright 2012.

[53] Whitehead 2012.

[54] Statman 2004; Kretzmer 2005; Gross 2006.

[55] Koebler 2013.

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away birds, plant seeds, and impregnate fruit trees,[56] although these applications require much more precision than is currently possible from a technological perspective.

Some people use drones to make a personal statement, for instance to demonstrate or use their freedom of expression. A typical example is an incident during a soccer game between Serbia and Albania in 2014. During the game, a drone with the flag of 'Greater Albania,' flew in the stadium. Serbian players took the flag but were attacked by Albanian players. The audience became angry and ran on the field, attacking the Albanian players, who had to run for their lives.

Other freedom of speech or more recreational uses may include drones equipped with projectors to spread news or images,[57] for instance, by projecting live images on buildings or walls. A creative form of using drones are spaxels (pixels in space). In this application drones equipped with LED lighting fly in the night sky and draw 3D drawings, something similar to fireworks.[58]

2.4 Frequency Spectrum Issues

In order to perform a flight, most drones have a need for a certain amount of wireless communications with a pilot on the ground. In addition, in most cases there is a need for radio communication for the payload, like a camera or some kind of sensor. To allow radio communication to take place frequency spectrum is required. The requirements for frequency spectrum depend a on the type of drone, the flight characteristics and the payload. Since frequency spectrum does not end at national borders and manufacturers have a need for (semi) global markets, international coordination on the use of frequency spectrum is required. Within the CEPT,[59] EU,[60] ITU,[61] and ICAO[62] a number of working groups are dealing with this issue.

This section will first address the legal issues on frequency spectrum usage and electronic equipment. Secondly the surveillance and compliance (enforcement of the usage of frequency spectrum and equipment requirements) will be addressed. Finally, some attention will be given to special government usage.

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[56]Wozniacka 2013.

[57]Hamlet 2014.

[58]Dronelife 2014.

[59]Conférence Européenne des Administrations des Postes et des Télécommunications; http://www.cept.org. Accessed April 1, 2016.

[60]European Union; http://ec.europa.eu/transport/modes/air/uas. Accessed April 1, 2016.

[61]International Telecommunication Union: a specialist body of the United Nations; http://www.itu.int. Accessed April 1, 2016.

[62]International Civil Aviation Organisation; http://www.icao.int. Accessed April 1, 2016.

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2.4.1 Legal Issues on the Use of Frequency Spectrum and Electronic Equipment

2.4.1.1 The Use of Frequencies

The international regulation of the use of frequency spectrum is laid down in the so-called Radio Regulations (RR).[63] The RR contains the complete texts as adopted by the World Radiocommunication Conferences (WRC). These conferences are organized every four years by the International Telecommunication Union (ITU), a body of the United Nations. The RR contains, besides regulations, a table which lists all the frequency allocations. All regional and national tables of frequency allocations are derived from this table. An allocation may have a primary or secondary status, meaning that a primary user may cause harmful interference to a secondary user of the frequency spectrum but not vice versa. Several countries also have the notion of a tertiary allocation which often deviates from the ITU table. Tertiary users may not cause any interference to primary and secondary users and must accept all interference from all other users. Cases of interference to those users are most often not acted upon by the national regulator. Applications that make use of license exempt bands often have a secondary or tertiary allocation.

Within Europe the CEPT is tasked with the detailed allocation of frequencies and the required frequency spectrum engineering in order to investigate the compatibility between radio systems. The CEPT also drafts a European position on frequency matters for the coming World Radio Conference (WRC).

A number of frequency bands are allocated to the aeronautical services. Traditionally these bands were reserved for manned aircraft operations. In the WRC-12 frequency band 5030–5091 MHz was allocated on a primary basis to be used by remotely piloted aircraft systems (RPAS), drones, but only for control and non-payload communications (CNPC). This frequency band has been allocated for commercial unmanned aircraft systems which are able to fly over large distances and may fly in controlled airspace, used by manned aircraft. ICAO has been tasked to set up a band plan to facilitate the international use of this band, however, there is no clear coordination on this work. Investigations are ongoing to indicate which are the relevant criteria to be taken into account. At this moment, June 2015, no band plan has been made.

Furthermore, international discussions are ongoing about the use of the regular satellite services to used for Command and Control of RPAS. These fixed satellite services (FSS) are not initially meant to be used for aeronautical safety services.[64] Therefore, criteria need to be set to validate the possible use of FSS for safety services.

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[63] https://www.itu.int/pub/R-REG-RR. Accessed April 1, 2016.

[64] Resolution 153 (WRC-12); http://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000A0007PDFE.pdf. Accessed April 1, 2016.

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For small drones no specific frequency allocations have been made on an international level for command and control or payload. Given the major developments in this area in the past few years, the demand for frequency spectrum is ever increasing. The lack of reserved frequency spectrum means that drones can, in most countries, only make use of generally available (license-free) frequency spectrum. Within Europe a large number of license-free frequency bands have been allocated. Several European Recommendations and decisions like ERC Rec 70-03 give a list of all these bands together with technical limitations and requirements. Since these bands are license-free the frequency band is shared with other unlicensed users on a secondary or tertiary basis. Two popular license-free bands used for drones for command and control and payload communications, the 2.4000–2.4835 MHz and 5.470–5.725 MHz bands, have to comply with the regulations that apply to broadband data transmission systems like WIFI. In Europe the band 5.725–5.875 MHz is available for non-specific short-range communication with a maximum transmission power of 25 mW effective isotropic radiated power.[65] Because of the popularity of WIFI, especially in the 2.4000–2.4835 MHz, there is a reasonable chance of interference between drones and other usage in populated areas, which may lead to the loss of control over the drone. The receiver of the drone may pick up a high level of interference because of the height of its flight. Therefore, together with the low transmission power requirements, only drone flights within line of sight of the pilot and with low safety requirements can use these frequencies.

For drone flights that require large flying distances, for instance for the observations of dikes, woodlands and borders, it is not realistic to make use of the license exempt bands mentioned. Special arrangements have to be made to make these flights possible. In most cases a license for the use of dedicated frequencies is required, which is the competence of the national regulating authority (NRA). The frequencies which may be used for command and control and payload communications, if required, will in most cases not be in the low frequency ranges. For instance in the Netherlands it is expected that a part of the 7 GHz band, which is also in use for ENG/OB,[66] may be used for these purposes. Using these high frequencies requires a line of sight connection between the ground transmitter/receiver and the drone. Together with often low flying altitudes of the drone it requires careful preflight planning to preserve line of sight conditions throughout the whole flight. In future the internationally reserved frequency range between 5030 and 5091 MHz for CNPC may be used for flights beyond line of sight. If during a flight payload communication is required, for instance, in cases of fire or border control, other additional frequencies are needed.

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[65] https://en.wikipedia.org/wiki/Effective_radiated_power. Accessed April 1, 2016.

[66] Electronic News Gathering and Outside Broadcasting.

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2.4.1.2 European System of Standardization

Drones require radio systems to allow communication between the drone and the pilot. European Aviation Safety Agency (EASA) directive 216 is only applicable for drones with a weight above 150 kg[67] and only for control and non-payload communications. In the European Economic Area[68] the radio equipment on board drones up to 150 kg therefore need to comply with the essential requirements of the R&TTE[69] and EMC[70] directives for command and control communications. All pure payload communications in drones need to comply with these directives. The R&TTE directive will be replaced by the RED[71] directive by June 2016. Manufacturers and importers have the responsibility for compliance of their drones before placing them on the market. If the drone complies with the essential requirements a CE marking has to be affixed to the drone or eventually to the packaging or the accompanying documents. Furthermore, a declaration of conformity has to be published.

2.4.2 Surveillance and Compliance

2.4.2.1 Use of Frequencies

Drones use frequencies that may cause harmful interference for a number of reasons. These can be

- Drones bought outside the European Union and used in Europe might well use frequencies intended for other use in Europe and interfere with that other usage.
- The use of a particular frequency requires a license because other users also make use of those frequencies. If no license is issued no planning has taken place and interference can occur.
- The combination of emitting equipment might unintentionally cause interference.
- Radio equipment in a drone may malfunction.
- The use of high transmission power may not be in accordance with regulations.

In cases of reported interference the NRA may start a surveillance to resolve the issue. Due to the relative short flight time of drones interference may have ceased to exist when the reported interference case is investigated. In severe cases and reoccurrence of interference administrative fines may be issued.

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[67] This may change in the future.

[68] All EU countries, Lichtenstein, Norway and Iceland.

[69] Radio and Telecommunications Terminal Equipment.

[70] Electro Magnetic Compatibility.

[71] Radio Equipment Directive.

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2.4.2.2 Electronic Equipment

National regulating authorities have the responsibility to verify the compliance of radio equipment to the R&TTE[72] and the EMC directives. Within Europe, the national regulating authorities coordinate their efforts within ADCO.[73] Based on risk analysis the national regulating authorities take samples of radio equipment entering the European market. If severe noncompliance to the EMC or R&TTE/RED directives is established the radio equipment may be taken off the national and European market. Since drones require radio equipment this procedure also applies to them.

2.4.3 Government Usage

In most countries the frequencies for drones used by the government is regulated differently than commercial or private use. The government, or parts of it like the Ministry of Defense, can make use of dedicated frequency bands which they use for their entrusted tasks. Additionally a number of governmental organizations can make use of (military) satellites to command and control their drones even outside their own territories. This, however, does not mean that all ministries within a government have sufficient frequency spectrum available for drones. In most countries special legal arrangements exist to allow (parts of) the government to increase or release their rights on the use of frequencies. For instance, in the Netherlands the government has to substantiate its claim for frequencies in a dedicated plan in which they describe in detail their current and future frequency needs. In the UK the principal of frequency spectrum pricing is used, in which the price for spectrum is used as an important mechanism to ensure that those resources are used efficiently by the users.[74]

In Europe drones used by the government, if they are not commercially of the shelf, do not need to comply with the EMC and R&TTE/RED directives. As mentioned before this does not mean that they can use any frequency they like or may cause harmful interference to other users with the same ore higher status.

2.4.4 Conclusions on Frequency Spectrum Issues

No dedicated 'drone-only' spectrum is available. The current spectrum usage by drones can be facilitated by license-free spectrum or, on a national basis, licensed

[72] From June 2016 RED directive; http://ec.europa.eu/growth/sectors/electrical-engineering/rtte-directive/index_en.htm. Accessed April 1, 2016.

[73] Administrative Co-operation.

[74] http://www.ictregulationtoolkit.org/5.5. Accessed April 1, 2016.

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spectrum. To accommodate international usage and future needs, efforts have to be made to make spectrum available for the use of drones. The availability of spectrum is essential for the operation of RPAS. Several organizations are dealing with the spectrum requirements for the drone market. Distinctions within the drone market by weight classes, the application of safety services and the different types of payloads lead to complexity. Intentions of the regulating authorities are to enable safe operation of unmanned aircraft on a large scale in segregated and nonsegregated airspace, used for a broad range of services. Harmonization and the development of standards must contribute to a competitive worldwide market of radio equipment, which is not causing interference to other services or suffering interference from those services.

2.5 Future Developments

There are three major developments in drone technology: miniaturization, autonomy, and swarms. The first development, miniaturization, is the most incremental development. As in most areas of robotics, each new generation of drones is a bit smaller, lighter, and cheaper than the previous generation. For instance, new materials and lighter and more efficient batteries create better trade-offs between the drone and its flight range, maximum altitude, and maximum payload. The limits of miniaturization are unknown. The smallest commercially available drones are more or less the size of credit cards, but experts indicate that within a few years we can expect drones the size of insects.

Cheaper and smaller drones are also likely to result in the ubiquity of drones. Whereas drones may now still be a rare sight in the sky, it is expected that within a few years, there will be plenty of drones available among the general public. This expectation is based on the rate at which drones are manufactured and sold. Drones are popular birthday and Christmas presents for teenagers, they are popular among photographers and sportsmen and there is an increase in small companies that offer drones services.

A second major development is the further increasing autonomy of drones. Drones are often seen as remote control aircraft, but there are technologies that enable autonomous operations, in which the remote control by a human operator is partially of completely excluded.[75] Most drones that are commercially available are remotely controlled, but at the same time they already contain elements of autonomy, mostly software for flight stabilization. More professional drones offer the possibility to pre-program flights. In the near future, more autonomy is expected with regard to determining flight routes, sense and avoid systems[76] for

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[75] USDoD 2013.

[76] Finn and Wright 2012.

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performing evasive maneuvers (e.g., birds, airplanes), adapting to changing weather conditions and defensive reactions when drones are under attack.

A third major development is the use of drones in swarms.[77] The increasing autonomy of drones enables the cooperation between drones in so-called swarms. The use of swarms may widen the range, flight duration, and maximum payload for particular applications. For instance, using drones in swarms, one drone may take over a task from another drone with an exhausted battery. In this way, the flight range can be extended beyond the range of the first drone. Drones that fly beyond the reach of control signals or are damaged during their flight can be replaced by other drones. Heavy payloads may in some cases be distributed over several drones, exceeding the payload of only one drone. Swarms of drones may be used as sensor networks.[78] When drones are used to follow several persons, a problem may arise when they split up. When using swarms, each drone may follow an individual instead of having to choose whom to follow. A technological difficulty to overcome concerns the fact that drones in swarms have to communicate with each other besides communication with ground control, which requires many more communication channels.

2.6 Conclusions

This chapter provided an overview of the different technological aspects of drones. This overview includes the different types of drones currently used and their technical specifications, potential payloads and applications, frequency spectrum issues and the current and near-future technological development in drone technology.

The first important distinction made is that between the actual drone (the platform) and the attached equipment (the payload). The different types of drones can be differentiated by the type (whether it is fixed-wing, multirotor or something else), the degree of autonomy, the size, weight, and the power source. These technical specifications are determining factors for the drone's capabilities, for example it's range, flight duration, and loading capacity. The payload can consist of almost anything. Some examples include all sorts of sensors (like cameras, sniffers, and meteorological sensors) and different kinds of freight (like parcels, medicine, fire extinguishing powder, and flyers). In this chapter, we also described a number of applications for drones and their different payloads. These applications illustrate the potential of drones and of their payloads. More examples of drone use are discussed in Part II of this book.

In order to be able to control a drone, communication between the user and the drone and/or its payload is required. For this communication frequency spectrum

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[77] See also: https://www.youtube.com/watch?v=UQzuL60V9ng. Accessed April 1, 2016.

[78] Bürkle et al. 2011.

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is required. At this moment, there is no spectrum available dedicated to drones only. Currently, the spectrum usage by drones can be facilitated by license-free spectrum or licensed spectrum on a national basis. Efforts have to be made to make spectrum available specifically for drone usage in order to accommodate the international usage of drones. Since frequency spectrum does not end at national borders, international coordination of its use is required. This is an essential part in the operation of drones. Therefore, standards have to be developed in order to create a feasible worldwide market which is not causing interference to other services or suffers from interference from other services.

Future developments of drone technology include drones becoming smaller, lighter, more efficient, and cheaper. Therefore, drones will become increasingly widely available to the general public and they will be used for an increasing scope of applications. It is to be expected that drones will become more autonomous and more capable of operating in swarms in the near future.

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