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Spotlight

Consumer and Commercial Drones

How a technological revolution is impacting Irish society

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Abstract

This *Spotlight* examines the emerging technology of drones and their rapid proliferation into the consumer and commercial sectors. At the time of writing, drones are being adopted by a variety of organisations and industries worldwide, with wide-ranging consequences. This paper provides an overview of drone technology, including its future trends. It also explores examples of the real-world impact of drone use and the evolving legislation governing drones in Ireland.

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Glossary

This section sets out a number of definitions for the purpose of this L&RS *Spotlight*.

5G: is a family of mobile phone network technologies and standards which are currently being adopted by network operators worldwide.

ATC (Air Traffic Control): is the authority that monitors aircraft while in flight and ensures their safety by providing flight guidance and instructions.

AI (Artificial Intelligence): is the software on a drone that allows it to operate automatically or autonomously.

Automatic flight: is a type of drone flight where the AI is piloting the drone, with the pilot supervising and taking manual control if necessary.

Autonomous flight: is a type of drone flight where the AI is piloting the drone, and the pilot is not able to intervene and take manual control.

Beyond Visual Line-of-Sight (BVLOS): refers to drone flight where the device flies beyond the point where the drone pilot can see it with the naked eye.

Controlled airspace: refers to airspace that can only be accessed by aircraft with prior approval from ATC.

Drone: refers to a flying machine that does not have a pilot on-board.

Drone operator: refers to the legal owner of a drone.

Drone pilot: refers to the person responsible for the safe and successful flight of a drone. The pilot sends flight instructions to a drone during its operation and receives flight information back from the drone.

EASA (European Union Aviation Safety Agency): is the European Union (EU) agency responsible for civilian aviation safety.

Fixed-wing drone: refers to a type of drone that resembles an aeroplane (i.e. with two wings).

Geofencing: refers to a safety function that prevents a drone from entering a certain area, based on Global Positioning System (GPS) coordinates.

GDPR (General Data Protection Regulation): is a set of EU regulations on the gathering, processing, and use of personal data.

GPS (Global Positioning System): is a technology that allows a device to identify its exact location using signals sent from satellites.

IAA (Irish Aviation Authority): is the state-owned company responsible for regulating the use of Irish airspace, and the lawful operation of drones in the country.

IMU (Inertial Measurement Unit): are a group of sensors that measure how a drone is moving and how it is positioned while in flight.

Interference: refers to a loss of radio signal quality which arises when multiple devices are transmitting on the same frequency band, causing a “collision” of signals.

LOS (Line-of-Sight): is when a radio signal transmitter and receiver can “see” one another, because there are no obstacles directly between them.

Manned aviation: refers to flights carried out by aircraft which have human pilots (and possibly human passengers) on-board, such as commercial jet airliners.

Meteorology: refers to the study of the atmosphere, including weather forecasting. In the context of aviation, it refers specifically to the topic of how weather affects flight performance.

Model aircraft: refers to a type of remote-controlled toy aircraft that is modelled after real-world vehicles. These are typically flown by hobbyists in dedicated model aircraft clubs.

Multi-rotor drone: refers to a type of drone that has several rotors (propellers) that push air downwards and allow the drone to fly. These types of drones usually have four rotors, in which case they are also called “quadcopters”.

No-fly zone: refers to a protected area such as an airport or prison where a drone is not allowed to fly.

NLOS (Non-Line-of-Sight): is when an obstacle is between a radio signal transmitter and receiver, which prevents the two devices from “seeing” each other.

Off-the-shelf drone: refers to a drone which is fully assembled by the manufacturer and sold with all of the required components. This drone can be flown by the pilot out of the box, with no additional assembly or other DIY work required.

Radar: refers to a system that uses radio waves to track the location of aircraft.

Remote-controller: refers to a (typically handheld) device with buttons, switches, and joysticks that a pilot uses to wirelessly send flight commands to a drone.

Rotor: is a broader term for a propeller, which rapidly spins and pushes air in a certain direction and allows the drone to fly.

RPAS (Remotely Piloted Aircraft System): is another name for a drone.

RTH (Return-to-Home): is a drone failsafe where the AI will autonomously fly the drone back to where it originally started its flight should it lose the wireless connection with its pilot.

Shadowing: refers to a loss in signal quality where there is an obstacle between a transmitter and a receiver that blocks LOS, similar to how an obstacle in front of a light source blocks the light and creates a shadow.

Telemetry: refers to important information about the flight status of a drone, such as its height above ground, its speed, its GPS coordinates, and its battery power levels.

UAV (Unmanned Aerial Vehicle): is another name for a drone.

Uncontrolled airspace: refers to airspace that can be used by aircraft without prior approval from ATC.

VTOL (Vertical Take-Off and Landing): is the ability of an aircraft to move directly up or down when it is taking off or landing. An aeroplane cannot VTOL and so requires a runway, whereas a helicopter can VTOL and can land in a confined space.

Executive Summary

Drones are an emerging technology in the consumer and commercial sectors of the economy. This paper describes how they work, how the technology will develop, how it is currently used, and how it is regulated.

What are drones? In the broadest definition of the term, a drone is any flying machine that does not carry a pilot on-board. Due to their wide range of applications, drones come in a variety of shapes and sizes. Today, civilian drones can be as small as a smartphone or as large as a conventional manned aircraft. Certain drone models resemble miniature aeroplanes, with wings and rotors. Others resemble helicopters (with multiple spinning rotors pushing air downwards) or balloons. Each type of design has its own strengths and weaknesses, which correspond to the task that the drone is meant to fulfil.

As drones do not have a pilot on-board to fly them, they rely on a pilot on the ground to send them flight instructions remotely. Drones today resemble remote-controlled toys in that a typical drone is controlled via remote-controller. This control is achieved using wireless radio signals, similar to the type of radio signals used by WiFi or the mobile phone network. These radio signals are affected by the distance they have to travel between the remote-controller and the drone, by obstacles in the environment (such as trees or buildings) which can block the signal, and by other devices nearby which can cause radio interference. These issues limit the effective range at which a pilot can send commands to the drone, and so limit the distance that the drone can fly away from a pilot.

Drones are increasingly using Artificial Intelligence (AI) to help the pilot with their flying. This AI uses sensors on-board the drone to ensure safe and reliable flight. Some types of drones even include the option of letting the AI fly the drone by itself, with the human pilot supervising.

Most consumer drones on the market today include cameras which send a live video feed back to the pilot. This helps the pilot safely fly the drone and allows the pilot to take photos and videos from the drone’s aerial point of view.

How do the law enforcement agencies stop illegally used drones? The rise in drones has been accompanied by a rise in anti-drone technology. Drones are difficult to identify, track, and stop using conventional systems such as aircraft radar. Dedicated anti-drone measures are being developed which can allow authorities to protect sensitive areas from trespassing drones. This includes sensors to track drones based on their unique features (such as the sounds created by their rotors), as well as tools to stop or destroy these drones.

How is the technology developing? Drone technology is rapidly developing, with drones becoming increasingly more efficient and powerful. The remote-control link between the pilot and the drone will soon be extended by allowing both the pilot and the drone to connect into the 5G mobile phone network. This will allow drones to communicate with their pilots wherever there is phone service. The batteries used by drones are being improved to allow them to fly for longer periods of time and recharge more efficiently. The AI used by drones is becoming more advanced, allowing drones to be more independent of their pilot and to fly in a way that a human pilot would not be capable of.

How are drones being used? At the time of writing, drones are being used for a variety of tasks by hobbyists and professionals. Photographers and filmmakers have widely embraced drones for their ability to easily, safely, and affordably capture aerial photographs and videos. Thanks to drones, it is now easier than ever to create cinematic footage. Emergency services such as the Dublin Fire Brigade (DFB), Civil Defence, and the Irish Coast Guard now use drones in emergency scenarios, such as search and rescue work. Organisations such as ESB Networks use drones to inspect wind-turbines, as this allows pilots to perform infrastructure inspections without putting their safety at risk. Drones have established themselves as valuable tools in agriculture and environmental monitoring. Their ability to rapidly move and have a 'bird's eye view' of the environment allows pilots to use them for monitoring plant health, precision-spraying crops, and herding livestock. As drones can lift packages, they are used in parts of the world to carry out rapid deliveries. In parts of Africa, drones are currently used for delivering vital medical supplies. In China, drones are starting to be used in cities for package deliveries. As of 2020, commercial drone deliveries have been on trial in parts of Ireland. Drones are also capable of lifting radio communication equipment, which has allowed them to be used to provide mobile phone service. High-altitude balloon drones were used in Puerto Rico in 2017 to provide emergency phone service after Hurricane Maria. Currently, they are being used to deliver phone service in parts of Africa. Outside of the professional applications, drones are being increasingly used by hobbyists for racing.

The spread of drones has also resulted in an increase in crimes being committed by drone pilots. Over the past decade, drones have been involved in numerous air traffic incidents, including near collisions with commercial aircraft and airport shutdowns. Criminals have begun to use drones as spy tools to stalk and harass targets, as well as for scoping out isolated properties to identify valuables. In addition to this, drones have been used for smuggling contraband across national borders and into prisons, with numerous incidents occurring in Irish prisons. Drones have also been weaponised by criminals: organisations such as the Islamic State of Iraq and Syria (ISIS) have used modified drones in their conflict.

What are the regulations? Since the year 2000, drone use in Ireland has been regulated by the Irish Aviation Authority (IAA). The regulations have been updated on several occasions to keep up with the rapidly developing technology. On 31 December 2020, new EU-wide regulations governing drone use came into effect. These regulations impose requirements for drone pilot training and drone operator registration, as well as strict limits on how drones may be used, depending on their size and weight. In the coming years, the EU will adopt an air traffic management system for drones, to allow them to be safely used over densely populated areas and alongside manned aircraft. This air traffic management system is expected to be rolled out in phases up to the mid-2030s. As drones carry cameras, they are also subject to GDPR regulations, which may create legal challenges for drone operators intending to fly drones near or above private properties.

Conclusion. Drone technology is increasingly playing a bigger part in civil society. Drones can offer many valuable services to the public. However, to do so, they must be regulated in a way that accounts for both public welfare and the interests of drone operators. The growth of this technology in Ireland will rely on the policies adopted by Members of the Oireachtas with regards to its use.

Introduction

This L&RS *Spotlight* provides an overview of the emerging technology of drones, and the associated economic, social and ethical implications for Irish society. The term "drone" (often used interchangeably with the term Unmanned Aerial Vehicle (UAV) or Remotely Piloted Aircraft System (RPAS))[1] refers to an aircraft that does not have a pilot on-board and is instead controlled remotely from a distance. While drones have been in use by some military organisations for decades, recent developments in battery technology, portable electronics, and cheap electric motors have allowed drone technology to enter the civilian domain. Over the past decade, worldwide drone use in consumer and commercial markets has grown exponentially from year to year. In 2016, the global 'addressable market value'[2] for drones was estimated to be over US$127 billion.[3] Future forecasts for the United Kingdom suggest that drone technology may add £42 billion to its national GDP by 2030.[4] As of 2020, there are approximately 22,000 registered drones in Ireland, with even more drones that are unregistered.[5] The European Union Aviation Safety Agency (EASA) forecasts that by the mid-2030s, the typical European city may see in the region of 30,000 drone flights per hour.[6]

This rapid development may present a challenge for legislators and policymakers worldwide to regulate this technology in a manner that balances public welfare with innovative use by business and civil sectors. To be effective and enforceable, drone regulations must be written with an understanding of the technology and its limits. Given that the technology is developing at such a rapid pace, policymakers may need to look beyond what drones are capable of today, to ensure that drone regulations account for the trends and developments that are on the horizon.

This document is structured as follows. The first chapter introduces and discusses the main technical principles behind today's commercially available drones. The second chapter provides an overview of the main technological developments in the drone domain. The third chapter gives examples of how drones are currently being used in Ireland, as well as other parts of the world. The fourth chapter considers the legislation surrounding drone use in Ireland.

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[1] In this paper, for the sake of clarity the term "drone" will be used.

[2] "Addressable market value" refers to the current value of labour and businesses that could be replaced by drone-based solutions.

[3] PwC, *Clarity from above: PwC global report on the commercial applications of drone technology*, May 2016 (Last accessed 6 January 2021).

[4] PwC, *The impact of drones on the UK economy*, 2018 (Last accessed 6 January 2021).

[5] Anton McNulty, 'No privacy legislation on drones flying over homes', *Mayo News*, 3 March 2020 (Last accessed 6 January 2021).

[6] EASA, *Opinion No. 01/2020*, 13 March 2020, p. 28 (Last accessed 6 January 2021).

1. Principles of Drone Operation

The following chapter provides an overview of the various aspects of drone operation. This will help the reader appreciate the strengths and weaknesses of existing drone technology.

1.1 Drone Types

Drones can resemble small helicopters with multiple rotors, miniature aeroplanes, or balloons. Drones today can be as small as smartphones or as big as manned aircraft. Most drones are electric vehicles that are powered by on-board batteries.

Drones on the consumer and commercial markets come in a variety of designs, each with their own technical strengths and weaknesses (see Table 1 below). As most drones are electric vehicles, they rely on a limited battery supply to power their electronics and motors, which means that the design of the drone will directly affect the length of time a drone can fly. This also impacts on the types of jobs for which drones can be used.

Table 1: Drone Types

Drone Type	Description	Advantages	Disadvantages
Multi-rotor	Drones that fly using several rotors (propellers) which push air downwards and lift the drone up.	Most manoeuvrable drone type as capable of Vertical Take-Off and Landing (VTOL),[7] can hover in place, and can operate in narrow areas.	Consume a lot of battery power compared to other drone types, and so cannot stay in the air for very long.
Fixed-wing	Drones that resemble aeroplanes, with two wings.	Require less battery power to fly compared to multi-rotor drones and can fly for longer periods.	Cannot VTOL or hover, require a lot of open space to fly.
Balloon	Drones that resemble large balloons or blimps. May either have rotors or rely on wind to move around.	Most energy-efficient drone type. May be able to operate for days or even weeks in the sky.	Worst manoeuvrability of the three types. Vulnerable to wind when in the air.

Hybrid drone designs are also possible. For example, a fixed-wing drone can have multiple rotors that push air downward and enable VTOL functionality, exactly like a multi-rotor drone. These rotors would only be used during take-off and landing. When the drone is in the air, it would fly like a fixed-wing drone to benefit from reduced battery power use.

[7] VTOL is when a drone can move directly up or down during take-off and landing. The drone therefore does not require an open area for take-off. An analogy can be drawn to aeroplanes and helicopters. Aeroplanes require very large runways for take-off and landing, whereas helicopters can take-off and land in relatively small areas.

Consumer and commercial drones also come in an extensive range of sizes and weights. For instance, certain consumer drones designed for portability may be the size of a smartphone,[8] whereas commercial drones designed for heavy-duty operation can have sizes comparable to manned aircraft. Facebook's cancelled internet delivery drone, for example, had the wingspan of a commercial jet.[9]

While their shapes and sizes may significantly differ, all drones have the same key technologies in common. These are discussed in the following sections.

1.2 Drone-Pilot Communication Link

Pilots control drones using remote-controllers. These remote-controllers communicate with drones using radio signals similar to WiFi. The radio signals are affected by the distance between the controller and the drone, obstacles between the two, and other nearby devices which can cause interference. As a result, there is a limit to how far away the pilot can safely fly the drone.

To safely operate, a drone and its pilot need to maintain a reliable channel of communication. This section describes how this communication is achieved, and what its limitations are.

As an unmanned vehicle, the drone does not carry its pilot on-board. Instead, the pilot remains on the ground and sends flight commands to the drone using a remote-controller. These flight commands typically take the form of instructions to change the drone speed, travel direction or height above ground. The drone, in turn, sends telemetry information[10] about its flight back to the pilot. For most types of drones, it is not feasible to use a cable to connect the drone back to its pilot.[11] Instead, the drone and the pilot's remote controller communicate wirelessly, using radio communication technology similar to WiFi.[12] The radio signal for communication means that the connection link can degrade in quality and even fail. The three factors that cause signal degradation are discussed below.

[8] For example, the *Mavic Mini drone* from manufacturer DJI which weighs only 249 grams (Last accessed 6 January 2021).

[9] Adam Satariano, 'Facebook Halts Aquila, Its Internet Drone Project', *New York Times*, 27 June 2018 (Last accessed 6 January 2021).

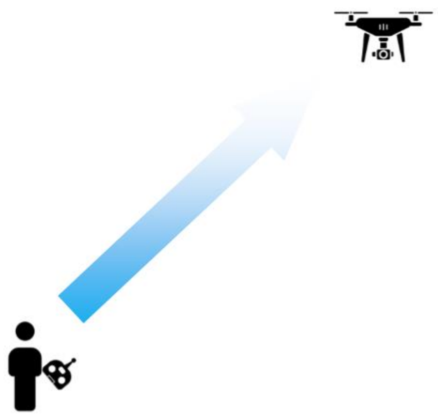
[10] Telemetry information refers to important information about the flight status of a drone, such as its height above ground, its speed, its GPS coordinates, and its battery power levels.

[11] For an example of a drone that uses a wired cable refer to *the AT&T COW drone* (last accessed 6 January 2021).

[12] Cheaper drone models tend to use WiFi for the connection; whereas more expensive models adopt proprietary radio technology.

1.2.A Signal Degradation over Distance

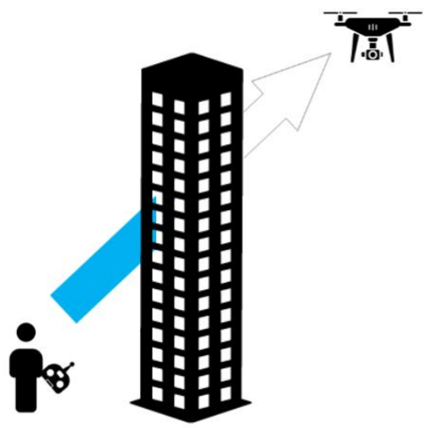
All radio signals lose power as they travel away from their transmitter.[13] When a signal arrives at a radio receiver, the device attempts to decode the information carried by the signal. If the signal is weak, then there is a chance that the data will be decoded with errors. Modern radio equipment is designed to correct these errors. However, the required process of error correction introduces a lag to the signal.



High-end commercial drones on the market today are marketed by manufacturers as capable of flying 5-10 kilometres away from their pilot before signal degradation becomes severe enough to disrupt communications between the two.[14] These numbers tend to be based on tests carried out in ideal conditions and do not account for other causes of signal degradation (as discussed below).

1.2.B Signal Shadowing

When a solid object is placed in front of a light source, it creates a shadow behind it due to the inability of the light to pass directly through the object. Radio signals experience a similar shadowing effect when a solid object is placed between a radio transmitter and a radio receiver.[15] Radio engineers commonly approximate the behaviour of radio signals to that of visible light when considering the shadowing effect. A signal between a transmitter and a receiver is said to be Line-of-Sight (LOS) if there are no obstacles between the two devices so that the two can "see" each other. Otherwise, this is considered Non-Line-of-Sight (NLOS).



A drone, therefore, benefits from a strong LOS signal to its pilot (when the pilot's remote-controller can see the drone). If the pilot flies the drone behind an obstacle, in what is referred to as Beyond Visual Line-of-Sight (BVLOS) flight, then the signal will very quickly degrade. A drone capable of flying kilometres away from the pilot under LOS conditions may suddenly lose connection at a distance of only a couple of hundred metres if it enters BVLOS flight.

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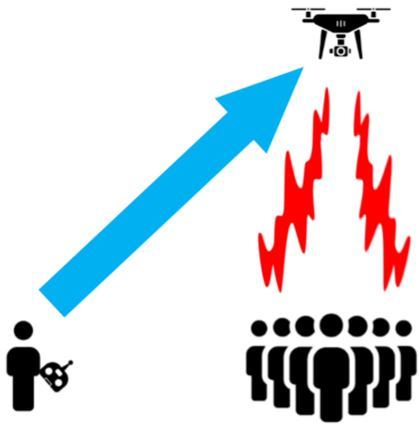
[13] A. Goldsmith, *Wireless Communications*. Cambridge: Cambridge University Press, 2005, p.32.

[14] For example, the [Autel Evo](#) drone is marketed as being capable of communicating up to 9 kilometres away from its pilot (last accessed 6 January 2021).

[15] A. Goldsmith, *Wireless Communications*. Cambridge: Cambridge University Press, 2005, p. 48.

1.2.C Signal Interference

Every radio signal is transmitted on a specific radio frequency. The spectrum of available radio frequencies is limited. For this reason, in each country, the spectrum is regulated by a communications regulator.[16] The communications regulator issues exclusive licences to stakeholders such as mobile phone operators to use specific spectrum bands. Certain spectrum bands, such as the Industrial, Scientific and Medical (ISM) bands, are intentionally kept licence-free to allow for free use by the public. This lack of a licence requirement is why the ISM bands are currently used by devices such as microwave ovens, WiFi routers, and the current generation of consumer drones.



When several devices transmit a signal on the same frequency, all the signals may be received simultaneously by a radio receiver. This causes the signals to interfere with one another and make it difficult for a receiver to decode the desired signal.[17] What this means is that a drone which is using the ISM bands for communicating with a pilot is vulnerable to any other nearby communications occurring on the same frequencies (e.g. from devices such as WiFi routers). Newer drone models are designed to account for this and can automatically choose specific ISM frequencies which do not appear to be in use. However, this helps only when there are unused ISM frequencies still available. For this reason, a drone which is capable of flying kilometres away from its pilot in an unpopulated rural environment may simply not be capable of maintaining a radio connection over the same distance when in a populated urban area.

1.3 Drone Artificial Intelligence

Drones have on-board sensors for tracking the surrounding environment. Drone Artificial Intelligence (AI) uses these sensors to assist the pilot with safely flying the drone. This assistance includes obstacle avoidance and safety features which are triggered in the event that the radio signal with the pilot is lost. Some drone models can fly entirely by themselves using just their AI, with no pilot control.

Drones are capable of a degree of independent navigation and flying. Using a variety of on-board sensors, drones can make decisions independently of their pilot input. This section provides an overview of how drones use AI to make decisions.

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[16] In Ireland, the communications regulator is the *Commission for Communication Regulation (ComReg)* (Last accessed 6 January 2021).

[17] A. Goldsmith, *Wireless Communications*. Cambridge: Cambridge University Press, 2005, p. 507.

The modern generation of commercially available drones come equipped with a variety of sensors which allow them to be aware of their surrounding environment during flight, and relay that information to the pilot (see Table 2 below).

Table 2: Drone Sensor Types

Sensors	Measurement Purpose	Description
Global Positioning System (GPS) receivers	Drone location in three-dimensional space	GPS receivers pick up signals from dedicated GPS satellites, which are used to determine the exact coordinates of a drone.
Infrared and optical proximity sensors	Distance to nearby obstacles	Cameras which are positioned around the drone that can detect nearby objects and calculate how far away they are from a drone, similar to the parking sensors in certain models of cars.
Inertial Measurement Unit (IMU)	Drone tilt, rotation and acceleration	Sensors that tell the drone if it is tilted, rotating, or moving in a certain direction, similar to an electronic spirit level.
Compass	Drone orientation relative to magnetic north	Sensors that detect the earth's magnetic field.
Barometer	Drone height changes	Sensors that measure air pressure, which changes as a drone moves up or down.
Thermometer	Temperature of drone components	Sensors that monitor the temperature of drone components such as the electronics, motors, and batteries, to warn the pilot if overheating occurs.

The exact combinations and configurations of sensors vary among drone models. Cheaper drones which are designed as toys for children may not have any sensors, whereas industrial drones intended for high-precision work may have all of the sensors listed, including backup sensors to minimise the chance of errors. A drone that uses multiple down-facing proximity sensors to detect the ground is shown in Figure 1 overleaf.

1.3.A Pilot Assistance

The drone AI uses the information from its sensors to keep the pilot informed about the state of the flight, as well as performing certain flight operations independently of pilot input. For example, if a drone detects an obstacle directly in its path, it will warn the pilot and may also choose to stop or fly around the obstacle, even if the pilot does not issue a ‘stop command’. Newer drone models can override a pilot’s flight instructions if the sensors suggest that the instruction is unsafe. Another important example of this capability is the use of geofencing. Geofencing refers to areas which a drone is not permitted to enter by its AI. Typically, these areas would be built into the drone by its manufacturer and would be based on the locations of no-fly zones (as determined by aviation organisations such as national aviation authorities).[18] If the AI detects from its GPS information that it is inside a no-fly zone, it will issue a warning to the pilot and either stop or attempt to land.

The AI on certain drone models also assists the pilot with flight. For example, a drone can automatically compensate for wind gusts, so that the drone is not blown off-course or flipped-over. The AI detects these wind gusts via its sensors, compensates against the wind to keep the drone steady and level, and warns the pilot about the presence of wind. This allows the pilot to focus on other aspects of the flight, instead of compensating for the wind. This acts as both a safety feature which protects the drone, as well as a navigational aid for the pilot.

Figure 1. Ground proximity sensors on the underside of a drone

1.3.B Automatic & Autonomous Flight

In addition to offering pilot assistance during flight, certain models of drones can fly by themselves using AI. This is referred to as automatic flight, whereby the human pilot oversees the flight and can assume manual control at any moment. Autonomous flight is also possible; this is when a drone is being piloted by AI with no direct communication to the pilot, such that the pilot is not able to take manual control of the drone.

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[18] DJI, '[DJI Improves Geofencing To Enhance Protection of European Airports and Facilities](#)', *Press Release*, 12 February 2019 (Last Accessed 6 January 2021).

The main types of AI-driven drone flights are given in Table 3 below.

Table 3: Types of AI-driven Drone Flights

Type	Description
Return-to-Home (RTH) flight	An important safety feature that has become widespread among newer drone models. If a drone loses the radio connection to its pilot (due to factors such as signal shadowing) it will attempt to autonomously return back to where it began its flight (based on GPS information), while searching for the pilot's radio signal and attempting to reconnect. This failsafe ensures that a loss of radio signal while a drone is mid-air will not result in a crash.
Following a designated flight path	Using the drone software, the pilot draws a flight path that the drone should fly along, specifying its speed, height, and other flight behaviours. The drone then follows this flight path automatically, reacting to any obstacles but otherwise keeping to the instructions specified by the pilot.
Flying over a designated area	The pilot can choose to designate a certain area that they wish the drone to fly in, and the drone AI will automatically calculate its own flight path within the bounds of this area. This type of automatic flight is typically used for surveying or photography work where a drone needs to fly over every part of a certain area to take recordings or measurements.
Object tracking	Certain drone models have AI which is capable of image recognition. Using this, a drone can be instructed to identify a moving object which it locates/identifies with its camera (i.e. 'sees'). The drone then follows the object, keeping it in-frame. This type of flight is popular for video-recording, as it allows the pilot to easily record a moving object using the drone.

In the flight examples in Table 3, the drone communicates with the pilot whenever the radio connection is available. The pilot can choose to override or cancel the AI at any time. As the AI is flying the drone by itself, the pilot can also choose to allow the drone to disconnect from the pilot's remote-controller without triggering the RTH functionality, and thus fly autonomously. This allows the drone to fly a large distance away from the pilot in BVLOS flight. However, the clear challenge with this is that the pilot may not receive information from the drone about the flight, and therefore cannot intervene if there is an emergency. At the time of writing, autonomous flight is illegal in Ireland due to the safety concerns of allowing drones to fly with no pilot oversight.[19]

[19] The current regulations governing drone use in Ireland are the Commission Implementing Regulation (EU) 2019/947 (Last accessed 6 January 2021), see Section 4.3.

1.4 Drone Cameras

Most drone models have on-board cameras which send a live video feed back to the pilot. This camera feed helps the pilot fly the drone and allows the pilot to take photos and videos from the sky.

In addition to the optical sensors described in the previous section, most drone models are equipped with a camera, which enables many of the current drone applications.[20] The potential for drones to be used to spy on people and violate their privacy is one of the bigger concerns with the spread of drone technology; this concern has been raised in Dáil Éireann on several occasions.[21] This section considers the camera capabilities of the typical consumer drone model.

Figure 2. Drone remote-controller displaying drone camera view and flight information

Typical commercial drone cameras attempt to strike a balance between being pilot-friendly and offering good surveillance opportunities. While the drone camera may also be used by the drone AI for flight purposes, the main function of the camera is to provide the pilot with a live view from the drone.

[20] See Chapter 3.

[21] Minister for Transport, Tourism and Sport, Shane Ross T.D., Response to Parliamentary Question No. 557 (Aviation Industry Regulations), *Dáil Éireann Debate,* 16 May 2017 (Last accessed 6 January 2021); Minister for Justice and Equality, Charles Flanagan T.D., Response to Parliamentary Question No. 355 (Legislative Measures), *Dáil Éireann Debate,* 5 November 2019 (Last accessed 6 January 2021).

This has two important functions:

- The drone camera assists the pilot with flying the drone, by letting the pilot see nearby obstacles and other important landmarks.
- The drone camera gives the pilot an aerial view of the surroundings, letting them take photos and videos from the sky and engage in aerial surveillance.

These two functions impose very different requirements on the design of the drone camera: the former requires the camera to be able to see obstacles around it, while the latter requires a camera which can see things clearly from a distance. To give the pilot a clear picture of the drone surroundings for flight, the camera needs to have good peripheral vision (which is referred to as a “wide field-of-view”). Such a camera would allow the pilot to see everything in front of the drone in a wide area. The fundamental trade-off with a wide field-of-view camera is that it sacrifices a detailed view of distant objects to achieve this peripheral vision. This means that such a camera does not provide the pilot with good surveillance images.

When a pilot takes a photo or records a video, a copy of the material is stored on the pilot’s mobile device (such as a smartphone).[22] Certain models of drones can also store the material via internal memory, allowing them to record photos and videos, even when a connection to the pilot is unavailable (such as during autonomous flight).

1.5 Anti-Drone Measures

Authorities have access to a variety of tools and technologies to stop trespassing drones. These include special sensors which detect and track drones, devices which can hack a drone and force it to land, as well as devices which can knock a drone out of the sky or otherwise destroy it.

Drones flying into sensitive areas without permission are becoming a growing problem. In response, a variety of technological solutions have been created to give authorities (such as law enforcement authorities) the ability to track, deter, capture, or destroy trespassing drones, while also tracking down their pilots.[23]

Anti-drone measures can be grouped under three categories:

- detecting drones,
- disrupting drone communications, and
- physically disabling the drone in flight.

[22] By connecting drones to smartphones members of the public can quickly and easily share their drone footage over the internet.

[23] J. Wang, Y. Liu, and H. Song, ‘Counter-Unmanned Aircraft System(s) (C-UAS): State of the Art, Challenges and Future Trends’ *Arxiv e-prints*, August 2020.

1.5.A Detecting Drones

The first steps to stopping a drone involve detecting its presence and determining its location. Drones can vary in size and their rotors can be quite loud (particularly for multi-rotor drones that have several rotors). Therefore, detecting a drone can be as straightforward as simply seeing it and hearing it. While straightforward, this type of visual detection can be susceptible to errors. In December 2018, Gatwick airport had to shut down its flights for almost two days due to sightings of trespassing drones on airport grounds. Numerous drone sightings were reported by members of the public. However, in the aftermath of the intrusion, the accuracy of these reports was questioned.[24]

More accurate drone detection can be achieved using the following technical means:

Radar. Manned aircraft such as aeroplanes and helicopters are tracked by authorities using radar waves, which are a type of radio signal. A transmitter sends out radio signals into the sky and these signals are reflected off the aircraft back down to earth. A radar dish picks up these signals and determines the location of the aircraft in the sky based on how the signal was reflected. Radar detection can accurately detect aircraft across extremely large distances in this manner. However, radar designed to detect manned aircraft has difficulty detecting drones (due to their size).[25] For this reason, new types of radar designed to detect small drones are required. These anti-drone radar systems are designed to detect and identify the unique features of drones, such as their spinning rotors. The disadvantage of these systems, though, is that they work over much shorter distances than radar for manned aircraft.

Detecting the drone-pilot wireless link. As discussed in Section 1.2, drones use radio signals to wirelessly communicate with their pilot. This radio communication can be detected by anti-drone equipment and used to locate and track the drone.[26] The effectiveness of this method depends on two factors. First, if the drone is flying autonomously, it may not be communicating with a pilot at all. Therefore, there may not be any radio signal to detect. Second, if the drone radio signal is using the WiFi frequency band, then it may be difficult for the anti-drone equipment to distinguish the drone signal from other types of WiFi signals. As a result, the anti-drone equipment may not identify the drone, or it may detect another WiFi signal and mistake it for a drone.

Drone visual detection. Drones can have very distinct colours and shapes compared to other flying objects such as birds. For this reason, they can be detected using cameras that have image-recognition AI.[27] These types of cameras may not be suitable during night or in other low-light conditions. However, thermal cameras can be used instead as drones generate heat from their

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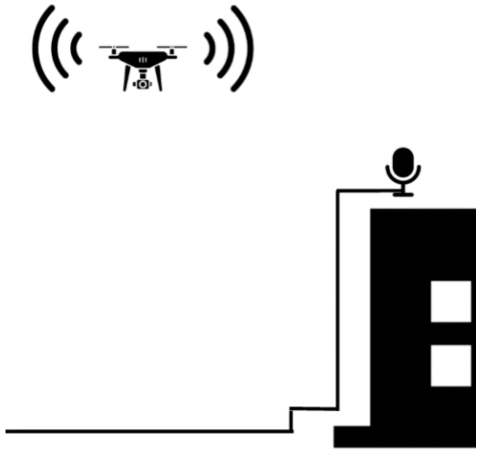
[24] 'Some Gatwick drone sightings 'may have been police devices'', *RTÉ News*, 29 December 2018 (Last accessed 6 January 2021); Samira Shackle, 'The mystery of the Gatwick drone', *The Guardian*, 1 December 2020 (Last accessed 6 January 2021).

[25] I. Guvenc, F. Koohifar, S. Singh, M. L. Sichitiu, and D. Matolak, 'Detection, Tracking, and Interdiction for Amateur Drones' *IEEE Communications Magazine*, vol. 56(4), April 2018, pp. 75-81.

[26] *Ibid*.

[27] C. Briese, A. Seel, and F. Andert, 'Vision-based detection of non-cooperative UAVs using frame differencing and temporal filter' *International Conference on Unmanned Aircraft Systems (ICUAS)*, June 2018, pp. 606-613.

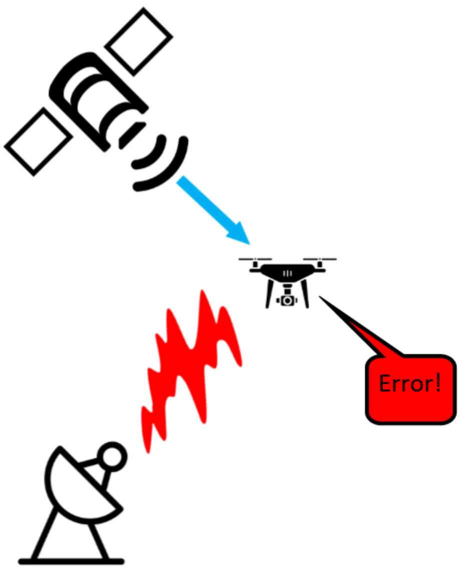
batteries, electrical circuits, and motors during operation. This makes them visible to thermal cameras irrespective of the time of day.



Drone sound detection. As drone rotors create noise, they can be detected using microphones specially designed for the purpose. Researchers have designed microphones that have AI which allows them to identify the specific sound of drone rotors.[28] By placing several microphones in a location and connecting those microphones together, a microphone system can not only detect a drone but also determine its location, by comparing the sound levels at the different microphones.[29] The disadvantage of this detection approach is that it works over a relatively short distance and is vulnerable to ambient noise from the environment.

Each of the detection methods described above has its own strengths and weaknesses. A reliable drone detection system would therefore need to combine several detection methods to ensure its accuracy.

1.5.B Disrupting Drone Communications



Once a trespassing drone is identified and located, lawful authorities can use a variety of methods to stop the drone.[30] One approach is to disrupt the drone's communication systems, which can involve the following:

Signal jamming. The drone-pilot radio link is vulnerable to other radio transmissions on the same frequency. By intentionally transmitting a high-power radio signal on the frequency that the drone is using it is possible to stop communication with the pilot. If a drone is not flying autonomously, then jamming the communication signal will result in a number of potential outcomes. Depending on the drone model, these include either the drone triggering its RTH failsafe and flying back to the pilot, the drone stopping

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[28] S. Jeon, J. Shin, Y. Lee, W. Kim, Y. Kwon, and H. Yang, 'Empirical study of drone sound detection in real-life environment with deep neural networks' *25th European Signal Processing Conference (EUSIPCO)*, September 2017, pp. 1858-1862.

[29] X. Chang, C. Yang, J. Wu, X. Shi, and Z. Shi, 'A Surveillance System for Drone Localization and Tracking Using Acoustic Arrays' *IEEE 10th Sensor Array and Multichannel Signal Processing Workshop (SAM)*, July 2018, pp. 573-577.

[30] Note that in Ireland drones are legally treated as aircraft, and therefore it is unlawful for members of the public to interfere with their flight or attempt to destroy them.

in mid-air, or falling out of the sky. As many drone models rely on GPS transmissions from satellites for their navigation, these signals can also be jammed. Note that losing the GPS signal by itself may not be sufficient to stop a drone flight, particularly if it is being flown manually by a pilot. While effective, the disadvantage of signal-jamming is that it can negatively impact bystanders. Transmitting jamming signals on WiFi frequencies will disrupt WiFi communication for all nearby devices, not just the drone. Similarly, a GPS jammer can disable GPS for everyone in its vicinity, which can be dangerous if used in an airport environment with aircraft in the air.

Signal spoofing. Signal spoofing refers to the practice of sending false signals to a receiving device, to fool it into doing something the authorities want. For example, the authorities may transmit false GPS signals which are designed to fool the drone into leaving the area or landing.[31] If the authorities know what kind of radio signal the pilot uses to talk to the drone, then they can spoof the pilot's signal. This will fool the drone into treating the authorities as its pilot, and so it will obey their flight commands. While successfully spoofing a signal and fooling the drone is more technically complicated than simply jamming those signals, signal spoofing is far less likely to do harm to others in the area.

1.5.C Physically Disabling the Drone

When disrupting the drone's communications systems is ineffective or unsuitable, a variety of solutions exist to stop the drone more directly. These involve the following:

Shooting the drone down. The most straightforward way to permanently disable a drone is to shoot it down. During the Gatwick airport incident of December 2018, British Armed Forces snipers were deployed around the airport area with the intention of firing on the drone.[32] However, a moving drone may pose a very challenging target, even for a trained sharpshooter. Military-grade anti-missile systems such as the American Close-in Weapon System (CIWS)[33] can offer far more reliable protection. The obvious drawback of this approach is that gunfire may simply be too dangerous due to the risk of stray bullets. Depending on the location and the risk posed by the drone, the option of shooting the drone down may create a bigger problem than it will solve.

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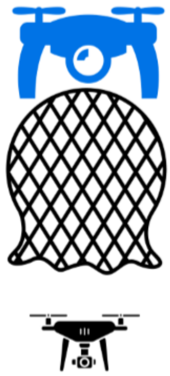
[31] A.J. Kerns, D.P. Shepard, J.A. Bhatti, and T.E. Humphreys, 'Unmanned Aircraft Capture and Control Via GPS Spoofing' *Journal of Field Robotics*, vol. 31(4), June 2014, pp. 617-636.

[32] 'Gatwick chaos: Police 'could shoot down drone'', *BBC News*, 21 December 2018 (Last accessed 6 January 2021).

[33] John Keller, 'Raytheon to upgrade and overhaul computer-controlled radar-guided shipboard weapons in $109.6 million order', *Military & Aerospace Electronics*, 12 March 2020 (Last accessed 6 January 2021).

Directed-energy weapons. This category of weapon involves using focused energy in the form of lasers[34] or microwaves[35] to damage the drone. A drone is vulnerable to laser beams due to its reliance on its camera and other optical sensors; a laser beam can temporarily or permanently blind these sensors. A sufficiently powerful laser beam can also cause the drone to heat up to the point where its electronics and battery break, causing the drone to crash. A directed microwave beam, meanwhile, can disable a drone's electronics, thereby causing it to malfunction and likely crash. The advantage of these directed-energy weapons is that they are less dangerous to bystanders than the gunfire-based alternatives. These weapons still pose a risk of causing unintended damage to nearby equipment, however. Laser beams can cause damage over large distances; firing a laser into the sky can accidentally strike distant aeroplanes or satellites in orbit.



Nets. As a drone requires rapidly spinning rotors to move, catching it in a net and trapping the rotors is a reliable way to stop it. The difficulty of achieving this lies in bringing the net to the drone's location in the air. One solution is to fire the net at the drone from a portable cannon using compressed air.[36] In Japan, authorities are using their own drones to carry these nets and "sweep up" the intruding drones.[37] While the difficulty of trapping the drone in a net is a disadvantage, the big benefit of this anti-drone solution is that it is much safer for bystanders and nearby equipment (as compared to the options discussed above).

Trained attack birds. A novel solution that has been explored[38] (and subsequently abandoned[39]) by Dutch authorities is the use of trained birds to attack and bring down drones. Certain birds of prey such as falcons have a long history of being trained for hunting. This type of animal husbandry can be adapted for dealing with drones. The effectiveness of this approach relies entirely on how well the animal is trained, as it may have problems responding to commands from its handlers or identifying the correct drone to attack, especially if there are other drones operating lawfully in the area. Another drawback of this approach is the relative cost. Trained birds can be prohibitively expensive; the Dutch authorities abandoned their anti-drone attack bird program due to its lack of cost-effectiveness.[40]

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[34] Ben Wolfgang, 'Air Force tests new anti-drone laser weapon', *Washington Times*, 15 September 2020 (Last accessed 6 January 2021).

[35] Evan Ackerman, 'Raytheon Sets Phasers to Drone Destruction with Directed Energy Weapon Test', *IEEE Spectrum Tech Talk*, 28 November 2016 (Last accessed 6 January 2021).

[36] Matt Reynolds, 'Anti-drone net launcher can down quadcopters from 100 metres', *Wired Magazine UK*, 4 March 2016 (Last accessed 6 January 2021).

[37] Keith Wagstaff, 'Tokyo Police to Deploy Net-Carrying Drone to Catch Rogue Drones', *NBC News*, 11 December 2015 (Last accessed 6 January 2021).

[38] 'Dutch police fight drones with eagles', *BBC News*, 12 September 2016 (Last accessed 6 January 2021).

[39] 'Dutch police drops drone-hunting eagles project', *NL Times*, 7 December 2017 (Last accessed 6 January 2021).

[40] *Ibid.*

1.5.D Assistance from Drone Manufacturers

Drone manufacturers can play a big part in preventing drone misuse. As previously mentioned in Section 1.3, certain drone manufacturers include geofencing restrictions into a drone to prevent it from flying into restricted areas. Drone manufacturers can provide authorities with tools to easily detect and track their specific drones.[41] With the cooperation of drone manufacturers, authorities can respond to drone threats more quickly and with less risks to members of the public.

[41] An example of this is the *DJI Aeroscope*, (Last accessed 6 January 2021).

2. Technological Developments

The usefulness and safety of drones is determined by a number of underlying technologies, which continue to develop at a rapid pace. This is such that every year drones are used in new applications that were not possible before. In this chapter several major technological trends, which will impact how drones will be able to perform in the near future, are discussed. This will give the reader a better understanding of how drone technology will evolve in the years ahead and how this will impact on its applications.

2.1 Communication Link Improvements

The effective range of the radio link between the pilot and the drone restricts how far drones can fly. By connecting the pilot and drone through a communications network (instead of having them talk directly via a radio link) this range limitation can be removed. The mobile phone network is the best candidate to use, although other network types such as dedicated satellite networks may be used for some drone applications.

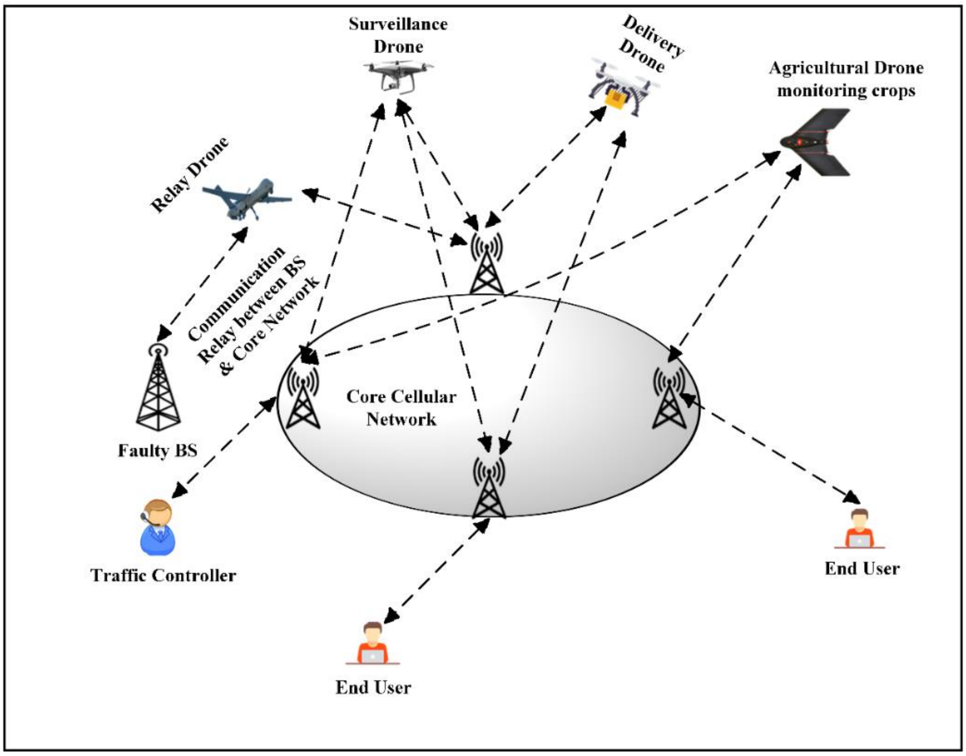
The drone flight range is limited by its ability to maintain a wireless connection to its pilot. Allowing drones to fly further, while still communicating with the pilot, is one of the biggest hurdles to cross for drone technology to thrive. The drone communication range has improved in recent years, as manufacturers have designed better communication systems used by their drones and remote-controllers. There is, however, a practical limit to how far the drone-pilot link can extend when the two are directly connected.

To truly solve the communication challenge, the drone and pilot would need to talk “indirectly” through a communication network. The most well-known example of such a communication network is the mobile phone network, which allows customers to talk to one another using their phones across large distances. The phones themselves are not directly talking to one another via wireless link; each phone is wirelessly connected to a nearby mobile phone tower, which sends the phone data through the network to its destination (in this example, the other person’s phone). Enabling the drone and pilot to communicate in this manner would allow them to be a large distance apart and thereby solve the range issue.

2.1.A Using the Mobile Phone Network

While creating a new communication network for drones may be necessary in some specific cases, for most drone users the mobile phone network is the most suitable solution. The big benefit of the mobile phone network is that it already exists. Consequently, there is no need to invest in new infrastructure such as new radio towers for drones. The telecommunications industry has recognised the importance of the phone network for providing this type of wireless connectivity, and is designing the next generation of phone networks with this in mind.[42] While 4G (and the mobile network generations before it) were designed to serve mobile phones, the new family of communications technologies and standards (referred to as 5G)[43] is designed to also provide connectivity to new types of devices. These include Internet of Things (IoT) gadgets,[44] connected and autonomous vehicles, as well as drones (as depicted in Figure 3 below).[45]

Figure 3. Drones connected to the mobile phone network, where Base Station (BS) refers to the phone towers



Source: H. Ullah, N. Gopalakrishnan Nair, A. Moore, C. Nugent, P. Muschamp, and M. Cuevas, '5G Communication: An Overview of Vehicle-to-Everything, Drones, and Healthcare Use-Cases' *IEEE Access*, vol. 7, March 2019, pp. 37251-37268.

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[42] A. Ghosh, A. Maeder, M. Baker, and D. Chandramouli, '5G Evolution: A View on 5G Cellular Technology Beyond 3GPP Release 15' *IEEE Access*, vol. 7, September 2019, pp. 127639-127651.

[43] ComReg, [About 5G](#) (Last accessed 6 January 2021).

[44] Internet of Things refers to the principle of attaching computers and sensors to everyday objects and connecting them together through the internet, to allow them to perform useful functions. As an example, consider an internet-enabled smartwatch which keeps track of your physical exercise using various sensors.

[45] H. Ullah, N. Gopalakrishnan Nair, A. Moore, C. Nugent, P. Muschamp, and M. Cuevas, '5G Communication: An Overview of Vehicle-to-Everything, Drones, and Healthcare Use-Cases' *IEEE Access*, vol. 7, March 2019, pp. 37251-37268.

Research is still underway into providing this drone connectivity, as drones create several unique problems for the mobile phone network.[46] As they have to meet a certain standard of safety, the communications link provided by the phone network needs to meet a high quality standard.[47] For example, to allow a pilot to effectively control a drone, the video signal from a drone's camera has to be able to reach the pilot's remote controller within a very short length of time.[48] Furthermore, as drones are airborne they experience very different radio conditions to what people on the ground experience.[49] Designing the phone network to allow a drone to always have a high-quality wireless connection to its pilot wherever it may fly is a complicated task.[50] A number of academic and commercial research groups around the world are working on this problem.[51]

2.1.B Using Other Networks

In addition to using the phone network, other options are possible for the drone-pilot link. Long range military drones, such as those used by the US Air Force, rely on satellite links, where satellites in orbit relay the data between the drone and the pilot.[52] This solution has also been proposed for civilian drones in applications where the drones may have to fly in regions with no mobile phone coverage.[53] Another option that is possible for drones is what is known as an "ad-hoc network".[54] If a fleet of drones are flying in a certain area, then the drones can set up a temporary network amongst each other. A pilot communicating with a distant drone would send data to a nearby drone instead, and that data would be relayed through the ad-hoc network to its destination drone. The advantage of this ad-hoc network is that it does not rely on any additional infrastructure, as the drones themselves perform all the network routing operations.

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[46] Y. Zeng, Q. Wu, and R. Zhang, 'Accessing From the Sky: A Tutorial on UAV Communications for 5G and Beyond' *Proceedings of the IEEE*, vol. 107(12), December 2019, pp. 2327-2375.

[47] *Ibid.*

[48] The technical term for this is "low latency".

[49] For example, typical phone towers have antennas which are pointed down towards the ground to send radio signals to people using their phones at ground-level; as a result, the drones which are high above ground receive a weak signal from those antennas.

[50] Y. Zeng, J. Lyu, and R. Zhang, 'Cellular-Connected UAV: Potential, Challenges, and Promising Technologies' *IEEE Wireless Communications*, vol. 26(1), February 2019, pp. 120-127.

[51] In Ireland, this research is carried out by groups such as the Science Foundation Ireland research centre *CONNECT* and the *Hamilton Institute* in NUI Maynooth. (Last accessed 6 January 2021).

[52] Alberto Cuadra and Craig Whitlock, 'How drones are controlled', *Washington Post*, 20 June 2014 (Last accessed 6 January 2021).

[53] M. Vondra, M. Ozger, D. Schupke, and C. Cavdar, 'Integration of Satellite and Aerial Communications for Heterogeneous Flying Vehicles' *IEEE Network*, vol. 32(5), September 2018, pp. 62-69.

[54] W. Zafar and B. Muhammad Khan, 'Flying Ad-Hoc Networks: Technological and Social Implications' *IEEE Technology and Society Magazine*, vol. 35(2), June 2016, pp. 67-74.

2.2 Flight Time Improvements

The length of time a drone can stay in the air depends on its battery power. New battery technologies are emerging which will extend this time. New battery recharging mechanisms are being developed which will allow drones to recharge their batteries automatically without human involvement. Solar power and laser power are also being developed for drones, to allow them to recharge by landing in sunlight or even in mid-air.

Most consumer drones on the market are battery powered. They have a rechargeable battery on-board which provides power to the drone components, including the electric motors which spin the rotors. As an electric battery can store a limited amount of energy, a battery-powered drone has a limited amount of time it can fly in the air. This also means that there is a limited distance it can fly from its starting point. As electric batteries are the key to enabling the electric car market, there is a significant amount of commercial and academic interest in developing new types of batteries.[55] These new batteries will be more cost-effective to manufacture, easier to recharge, and they will be able to store more energy, leading to longer device usage on a single battery charge.[56] Naturally, other consumer devices will also benefit from these developments. At the time of writing, a typical commercial multi-rotor drone may have a flight time of between 30-60 minutes on a full battery charge; this flight time may increase four-fold by 2030 due to new battery types which can store more energy.[57]

In addition to the improvements to battery energy storage, there is ongoing research into improving how drone batteries recharge. Currently, drone batteries are recharged in the same manner as other consumer electronics. The drone pilot removes the battery from the drone and connects it to a power supply such as an electrical outlet. This means that if a drone is running out of battery power, it must return to its pilot and land to have its battery replaced and the old battery recharged. This battery recharging and replacement takes up valuable time and forces the drone to always remain close to its pilot. An alternative has been proposed by researchers who have developed a robotic battery-switching station.[58] In this scenario, the drone lands at the station, and a robotic arm replaces its battery with a new one. The entire process is automated so that the human pilot does not need to take part, and therefore the pilot does not need to be close to the docking station. Another option is to recharge the drone wirelessly.[59] In this case, the drone lands (or hovers

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[55] E. Chemali, M. Preindl, P. Malysz, and A. Emadi, 'Electrochemical and Electrostatic Energy Storage and Management Systems for Electric Drive Vehicles: State-of-the-Art Review and Future Trends' *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4(3), September 2016, pp. 1117-1134.

[56] *Ibid.*

[57] B. Galkin, J. Kibilda, and L. A. DaSilva, 'UAVs as Mobile Infrastructure: Addressing Battery Lifetime' *IEEE Communications Magazine*, vol. 57(6), June 2019, pp. 132-137.

[58] D. Lee, J. Zhou, and W. T. Lin, 'Autonomous battery swapping system for quadcopter' *International Conference on Unmanned Aircraft Systems (ICUAS),* June 2015, pp. 118-124.

[59] M. Lu, M. Bagheri, A. P. James, and T. Phung, 'Wireless Charging Techniques for UAVs: A Review, Reconceptualization, and Extension' *IEEE Access*, vol. 6, May 2018, pp. 29865-29884.

overhead) next to a wireless power supply which recharges its battery, again without the need for the human pilot.

Solar power is viewed as a promising technology for drones.[60] When equipped with solar panels, a multi-rotor drone would have the ability to land anywhere in direct sunlight to recharge, instead of being limited to dedicated recharging stations.[61] Such a drone could be released “into the wild” to carry out its mission, land somewhere to recharge its batteries, and then continue. Combined with the communication link improvements described in Section 2.1, this could also allow the drone to travel great distances away from the pilot.

For situations where a drone must stay in the air for a very long time, laser power is an option. One company have demonstrated a laser-powered prototype drone which uses a modified solar panel that is hit by a laser on the ground.[62] The laser energy is harvested by the solar panel and used to power the drone. The energy delivered by the laser is enough to keep the drone in the air, which means it can keep flying for as long as the laser is powering it. The drawback of this power technique is that a laser powerful enough to keep the drone in the air is powerful enough to cause damage if it hits something other than the drone.

2.3 Drone Artificial Intelligence Improvements

Drone Artificial Intelligence (AI) is being developed to allow drones to make more complicated decisions independently of pilot commands, such as choosing their own flight paths to safely and efficiently perform their tasks. AI is also being improved to allow drones to closely cooperate with other drones and fly as coordinated “swarms”.

With the help of an array of on-board sensors, drones can make low-level decisions about their flight (using AI). As previously noted in Section 1.3, these decisions currently involve reacting to obstacles to avoid collisions or following flight instructions previously issued by the pilot. Drone AI is a significant research topic among the academic and commercial sectors.[63] The purpose of this research is to develop more advanced types of AI which would allow drones to perform more functions independently of the pilot.

2.3.A Drones Choosing Their Own Flight Paths

Chen and Rho consider a disaster response example for their drone AI application.[64] In the case of an emergency (such as an earthquake), drones would be used by first responders to quickly

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[60] *Ibid*.

[61] N. Kingry *et al*., ‘Design, Modeling and Control of a Solar-Powered Quadcopter’ *IEEE International Conference on Robotics and Automation (ICRA)*, May 2018, pp. 1251-1258.

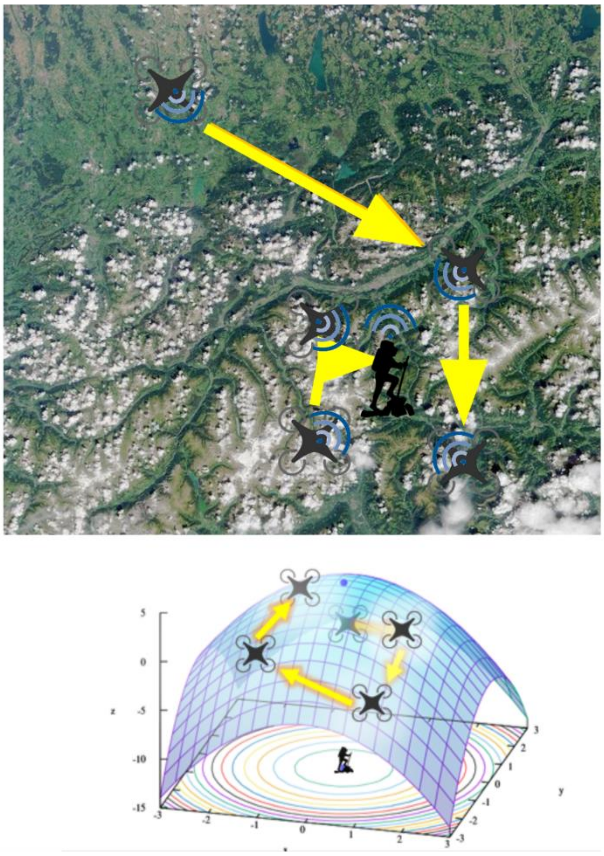
[62] Bill Read, ‘Fly By Light’, *Royal Aeronautical Society*, 14 February 2017 (Last accessed 6 January 2021).

[63] Y. Zhou, B. Rao, and W. Wang, ‘UAV Swarm Intelligence: Recent Advances and Future Trends’ *IEEE Access*, vol. 8, October 2020, pp. 183856-183878.

[64] B. Chen and S. Rho, ‘Autonomous Tactical Deployment of the UAV Array Using Self-Organizing Swarm Intelligence’ *IEEE Consumer Electronics Magazine*, vol. 9(2), March 2020, pp. 52-56.

assess damage and help in search and rescue efforts.[65] Using today's technology, a fleet of these drones would need to be operated by a team of pilots, with each pilot manually flying their drone and using the drone on-board camera to identify areas of interest. Chen and Rho propose applying AI to automate part of this operation. A drone pilot would designate an area of interest to a fleet of drones, and the drones would then decide amongst themselves how to carry out the mission in the most efficient manner. This would allow a single human pilot to simultaneously control several drones effectively, as the drones would focus on the small-scale decision-making, leaving the pilot to focus on the big picture. Murphy, Sreenan, and Brown of University College Cork (UCC) have created a prototype search and rescue drone that can automatically find a missing person in the wilderness by listening for their mobile phone signal and travelling to its source, without the pilot having to control the flight path of the drone (see Figure 4).[66]

Figure 4. Automatic drone search & rescue



Source: Seán Óg Murphy, UCC

Another example presented by Esrafilian, Gangula, and Gesbert considers drones performing a transportation task, such as a delivery job.[67] Given a destination to fly to and a map of the surrounding environment, a drone can use AI to decide its own route to the destination based on a number of factors, such as the availability of mobile phone coverage for its pilot link. The drone pilot would simply have to tell the drone its destination, and the drone AI would decide the rest.

2.3.B Drone Swarm Behaviour

In addition to automating parts of the drone pilot's tasks, AI can allow drones to be used in new applications. AI can potentially react to changing conditions faster than a human pilot, and therefore it can allow a drone to fly in a way that would be too risky or too difficult for a pilot.[68] An example of this is the Intel drone fleet that was flown for the opening ceremony of the 2018 PyeongChang Winter Olympics.[69] Over 1,200

[65] See Section 3.2.

[66] S. O. Murphy, C. Sreenan, and K. N. Brown, 'Autonomous Unmanned Aerial Vehicle for Search and Rescue Using Software Defined Radio' *IEEE Vehicular Technology Conference,* April 2019

[67] O. Esrafilian, R. Gangula and D. Gesbert, '3D-Map Assisted UAV Trajectory Design Under Cellular Connectivity Constraints' *IEEE International Conference on Communications (ICC)*, June 2020.

[68] Jeremy Hsu, 'To Fly Solo, Racing Drones Have a Need for AI Speed Training', *IEEE Spectrum Tech Talk*, 4 June 2019 (Last accessed 6 January 2021).

[69] Intel, 'Intel Drone Light Show Breaks Guinness World Records Title at Olympic Winter Games PyeongChang 2018', *Press Release*, 9 February 2018 (Last accessed 6 January 2021).

drones carrying colourful lights moved in perfect synchronicity to create three-dimensional shapes and figures. This was achieved using AI which allowed the drones to work together and fly in unison. Given the large number of drones, their intricate movement, and the close distances between them, such a performance would be impossible to achieve using human pilots. This type of "swarm" behaviour can be used outside of entertainment purposes to allow drones to perform new types of operations in areas such as search and rescue.[70]

2.3.C Machine Learning

The field of AI is currently experiencing a revolution due to the development of Machine Learning (ML).[71] Prior types of AI rely on a human to design its behaviour. By contrast in ML, the AI teaches itself how to act, based on trial-and-error experimentation. This can allow AI to be used to solve problems that were previously unsolvable by AI. This revolution has impacted a variety of technical fields, and drones are no exception.[72] While ML will not only make drone AI more capable than before, it will also affect how the AI is trained. For example, if ML is used to teach a drone AI how to fly in a certain environment, the AI would need to practice flying through the environment, trying different paths and different strategies. After some experimentation, the AI would determine how it should fly and would remember this behaviour for future flights. This new type of AI would therefore impact how drone pilots would use their drones and create new regulatory challenges.

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[70] X. Zhu, C. Bian, Y. Chen and S. Chen, 'A Low Latency Clustering Method for Large-Scale Drone Swarms' *IEEE Access*, vol. 7, December 2019, pp. 186260-186267.

[71] A. Ghafourifar and M. Evans, 'The Machine Learning Revolution: How Artificial Intelligence Could Transform Your Business', *Forbes Magazine*, 20 October 2018 (Last accessed 6 January 2021).

[72] Z. Ullah, F. Al-Turjman and L. Mostarda, 'Cognition in UAV-Aided 5G and Beyond Communications: A Survey' *IEEE Transactions on Cognitive Communications and Networking*, vol. 6(3), September 2020, pp. 872-891.

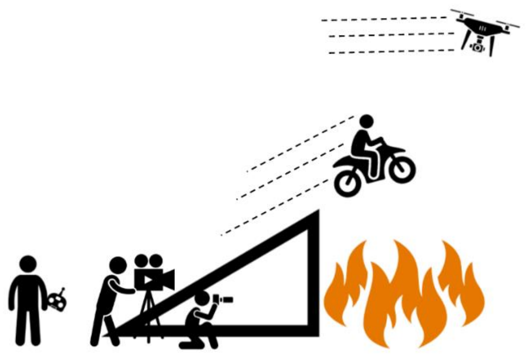
3. Real Life Applications of Drone Technology

At its core, a drone is a flying computer with one or more cameras. As such, any application that requires an "eye in the sky" or the lifting of relatively light packages can be fulfilled by drone technology. Certain jobs that were previously carried out by helicopters can now be done using drones, with the benefits of reduced costs,[73] faster deployment times, and a possible reduction of greenhouse gas emissions.[74] This chapter provides an overview of several areas of society where drone technology has already had an impact, whether in Ireland or abroad.

3.1 Photography and Filmmaking

Drones allow photographers and filmmakers to easily and affordably create panoramic aerial shots, without the costs and risks associated with using helicopters.

Photographers and filmmakers were among the first to begin using drones as tools for professional work.[75] Aerial shots have long been popular among filmmakers for capturing panoramic views. In the past these types of shots were made using helicopters. The use of helicopters has several natural limitations for filmmakers. A helicopter cannot be safely flown very close to the ground or close to densely populated areas, which limits the type of aerial shots that can be achieved. When civilian drone technology reached a point that drones could be used to carry professional cameras, it opened up entirely new opportunities for photographers and filmmakers.[76] For the fraction of the price of a helicopter, a filmmaker can now get the exact aerial shot they are looking for. Due to the significantly smaller size and weight of a drone (compared to a helicopter), the photographer or filmmaker can also fly the device in entirely new ways, creating cinematic shots that would have been impossible in the past.[77]



[73] A single helicopter may cost hundreds of thousands of euro to operate and maintain, whereas a single professional drone may cost only a few thousand euro, with much cheaper service costs. In addition to the up-front cost of purchasing a helicopter, there are other operating costs associated with helicopters, such facility fees, fuel purchases, and maintenance fees. British Helicopter Association, *Introduction to the world of helicopters* (Last accessed 7 January 2021); Miriam McNabb, 'How Much Should I Spend on a Professional Drone?', *Drone Life*, 4 April 2017 (Last accessed 7 January 2021).

[74] Due to drones being electric vehicles, unlike existing models of civilian helicopters.

[75] The 2012 film *Skyfall* was one of the first films to use drones for shooting an action sequence. Brian Fung, 'It's a bird!, It's a plane! It's a drone that makes movies!', *Washington Post*, 15 August 2013 (Last accessed 7 January 2021).

[76] Angela Watercutter, 'Drones Are About to Change How Directors Make Movies', *Wired Magazine*, 6 March 2015 (Last accessed 15 December 2020); Stephanie Zacharek, 'How Drones Are Revolutionizing the Way Film and Television Is Made', *Time Magazine*, 31 May 2018 (Last accessed 15 December 2020).

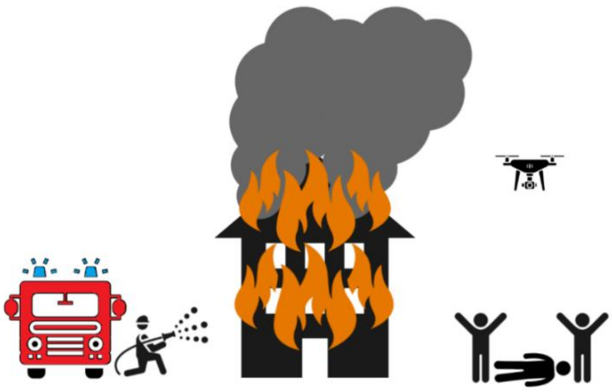
[77] Examples of such shots include up-close photographs of wildlife and shots taken in densely populated urban areas. 'The Drone Awards 2020 showcase astonishing images of the world', *RTÉ News*, 26 September 2020 (Last accessed 7 January 2021).

3.2 Emergency Services and Law Enforcement

Emergency services use drones as an “eye in the sky” to coordinate emergency crews and look for survivors. Presently, the Dublin Fire Brigade (DFB), Civil Defence and the Irish Coast Guard are using drones in their emergency work, with An Garda Síochána considering adopting the technology.

As cheap, easy-to-use flying cameras, drones are a natural fit for emergency services. The DFB has been using drones as part of their emergency response since 2016.[78] In an emergency, such as a fire, a DFB pilot travels to the site of the incident (while keeping a safe distance away), launches the drone, and flies it over the site while using the live feed from the drone camera to coordinate the emergency response. This is a function that previously would have been performed by service helicopters, as in the filmmaking sector. The key innovation introduced by drone technology is its deployment speed. A drone can be carried by the operator in a backpack to the incident site and launched within minutes, whereas a manned helicopter would need to be launched from a dedicated heliport and travel to the incident site, resulting in a potentially slower response.

The advantages that drones offer over manned helicopters have prompted the Civil Defence to invest in their own drone fleet, to be used for search and rescue operations alongside An Garda Síochána and the Irish Coast Guard.[79] Drones allow a pilot to very quickly inspect a large area for signs of life. In an emergency scenario, where time is limited, this rapid response can have life-saving results. As drones fly in the air, they are not affected by difficult or inaccessible ground, which means that search and rescue teams are able to check areas for signs of life that would otherwise be very difficult or unsafe to reach, such as steep mountains or shorelines. The drones used by Civil Defence also carry thermal cameras, which further simplify the process of locating people in wide open areas.[80] As of 2020, the Irish Coast Guard have their own search and rescue drone teams operating on the west coast of the country.[81]



An Garda Síochána is currently exploring the possibility of using drones as part of their law

[78] Mark Hilliard, ‘Dublin Fire Brigade likely to begin using drones before end of year’, *Irish Times*, 9 November 2015 (Last accessed 7 January 2021).

[79] Claire Murphy, ‘Civil Defence drone pilots to help in cases of missing persons’, *Irish Independent*, 26 November 2018 (Last accessed 7 January 2021).

[80] Civil Defence, *Search & Rescue*, (Last accessed 7 January 2021).

[81] Pat Flynn, ‘Doolin Coast Guard unit drone team goes live’, *Clare Herald*, 20 December 2019 (Last accessed 7 January 2021).

enforcement operations.[82] the Gardaí are considering using drones for operations such as road traffic surveillance, mapping out crime scenes, and ensuring public order at crowded events.[83] Due to the COVID-19 crisis, law enforcement agencies abroad have begun using drones to enforce public compliance such as social distancing.[84] Concerns have been raised about the civil rights issues that may arise from the Gardaí using drones, with the Irish Council of Civil Liberties issuing a statement that the use of drones in this manner may negatively impact on the privacy and freedom of assembly rights of Irish citizens.[85] The police in the UK have faced similar criticism from privacy campaigners for their use of drones in policing COVID-19 restrictions.[86] Wexford County Council have used drones to monitor COVID-19 compliance in public areas such as caravan parks, which was found by the Data Protection Commission (DPC) to have been a potential breach of data protection regulations. The DPC also highlighted that no data protection impact assessment (DPIA) was carried out, although Wexford County Council had included a requirement for a DPIA in its drone policy by the time of the DPC decision.[87]

3.3 Infrastructure Inspection and Surveying

Drones can be used to safely carry out up-close inspections of infrastructure such as wind turbines and power lines. ESB Networks has begun using drones for this purpose. Drones can also be used by civil engineers to make 3D scans of an area, for analysis purposes.

Drones are very well-suited for industrial sectors that require overseeing large projects spanning large territories or working in unsafe environments.[88] Drones are commonly used today for performing inspections of critical infrastructure such as wind turbines. Given their size and moving parts, wind turbines pose a challenge for workers investigating damage or signs of disrepair. With a drone, a worker can safely remain on the ground while getting an up-close view of the wind turbine from an angle that cannot be seen from the ground.[89] Additional sensors (e.g. thermal cameras or Light Detection and Ranging (LiDAR)[90] sensors) can be carried by the drone to detect

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[82] Aiden Corkery, '[Gardaí to look into using drones for first time](#)', *Business Post*, 17 May 2020 (Last accessed 7 January 2021).

[83] *Ibid.*

[84] Courtney Linder, '[Police Are Using Drones to Yell at People for Being Outside](#)', *Popular Mechanics*, 17 March 2020 (Last accessed 7 January 2021).

[85] '[Irish Council of Civil Liberties raises privacy concerns about potential drone use by Gardaí](#)', *Irish Examiner*, 18 May 2020 (Last Accessed 7 January 2021).

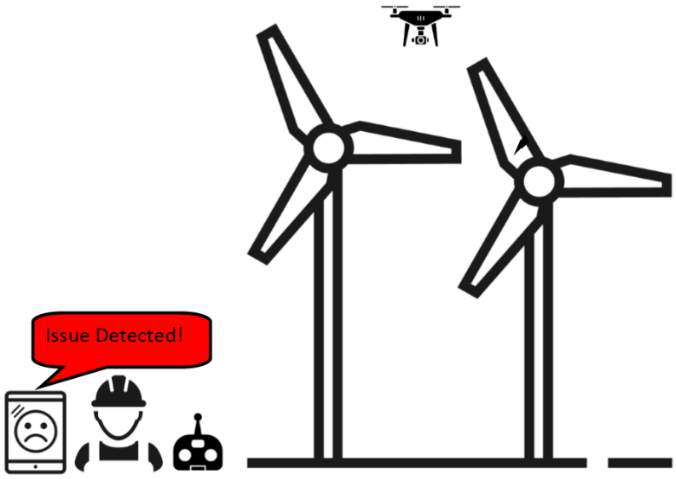
[86] '[Coronavirus: Peak District drone police criticised for 'lockdown shaming''](#), *BBC News*, 27 March 2020 (Last accessed 7 January 2021).

[87] Cianan Brennan, '[Covid-19: Council broke the law by using drones to monitor public movement](#)', *Irish Examiner*, 4 October 2020 (Last accessed 7 January 2021).

[88] Accenture Consulting, *A business approach for the use of drones in the Engineering & Construction industries*, 2016, p. 5 (Last accessed 7 January 2021).

[89] Jennifer Runyon, '[How Drones Will Transform Wind Turbine Inspections](#)', *Renewable Energy World*, vol. 20(6), 2017 (Last accessed 7 January 2021).

[90] LiDAR is a system that uses laser pulses to create 3D scans of an object.



issues not visible to the naked eye.[91] With the inclusion of AI, the inspection process can also be largely automated by the drone, reducing the time and effort involved in the inspection. All of this results in a corresponding reduction of costs, with current estimates suggesting that drones can reduce wind turbine survey expenses by up to 80%.[92] Drones are used in a similar manner to inspect other types of infrastructure such as railway lines, power lines, and gas pipelines.[93] At the time of writing, ESB Networks has completed a pilot project to apply drone inspections to their power lines,[94] and has begun the use of automatic drones for wind turbine inspections.[95]

In addition to allowing workers to safely and efficiently inspect infrastructure, drones can provide for a deeper level of analysis when surveying an area. Drones can be used to "scan" an area and create a 3D model, using a technique known as "photogrammetry".[96] Users can then extract important information from this 3D model that would otherwise be difficult to obtain. For example, drones have been used by researchers to generate a 3D topology map of a quarry, from which they were then able to accurately calculate the remaining volume of deposits left in the quarry.[97] This type of 3D surveying can be applied to a wide range of applications and scenarios. Possibly, the most well-known example of photogrammetry is Google Earth, which offers users high resolution 3D scans of major world cities. Due to the technical and regulatory restrictions on drone use, these scans are currently made using low-flying manned aeroplanes with cameras.[98]

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[91] M. Car, L. Markovic, A. Ivanovic, M. Orsag and S. Bogdan, 'Autonomous Wind-Turbine Blade Inspection Using LiDAR-Equipped Unmanned Aerial Vehicle' *IEEE Access*, vol. 8, July 2020, pp. 131380-131387.

[92] Charles Choi, 'The Future of Drones and Wind Power', *Inside Unmanned Systems*, 28 October 2020 (Last accessed 7 January 2021).

[93] Peter Gutierrez, 'Infrastructure Inspection – UAS Are All Over It', *Inside Unmanned Systems,* 1 May 2019 (Last accessed 7 January 2021).

[94] ESB Networks, *Innovation for the Network of the Future*, 2020, p. 40 (Last accessed 7 January 2021).

[95] ESB Networks, 'Sterblue helps deliver ESB's ambition for a cleaner future', *Press Release*, 4 May 2020 (Last accessed 7 January 2021).

[96] In photogrammetry, a large number of photographs of an area are taken from different angles. These photographs are then entered into an AI algorithm along with the exact GPS coordinates where they were taken. The AI algorithm recreates the 3D shape of the area using these photographs and GPS coordinates.

[97] Á. Török, G. Bögöly, Á Somogyi, T Lovas, 'Application of UAV in Topographic Modelling and Structural Geological Mapping of Quarries and Their Surroundings-Delineation of Fault-Bordered Raw Material Reserves' *Sensors (Basel)*, vol. 20(2), January 2020 (Last accessed 7 January 2021).

[98] Natalie Dennis, Google, 'Google Earth's incredible 3D imagery, explained', *Press Release*, 18 April 2017 (Last accessed 7 January 2021).

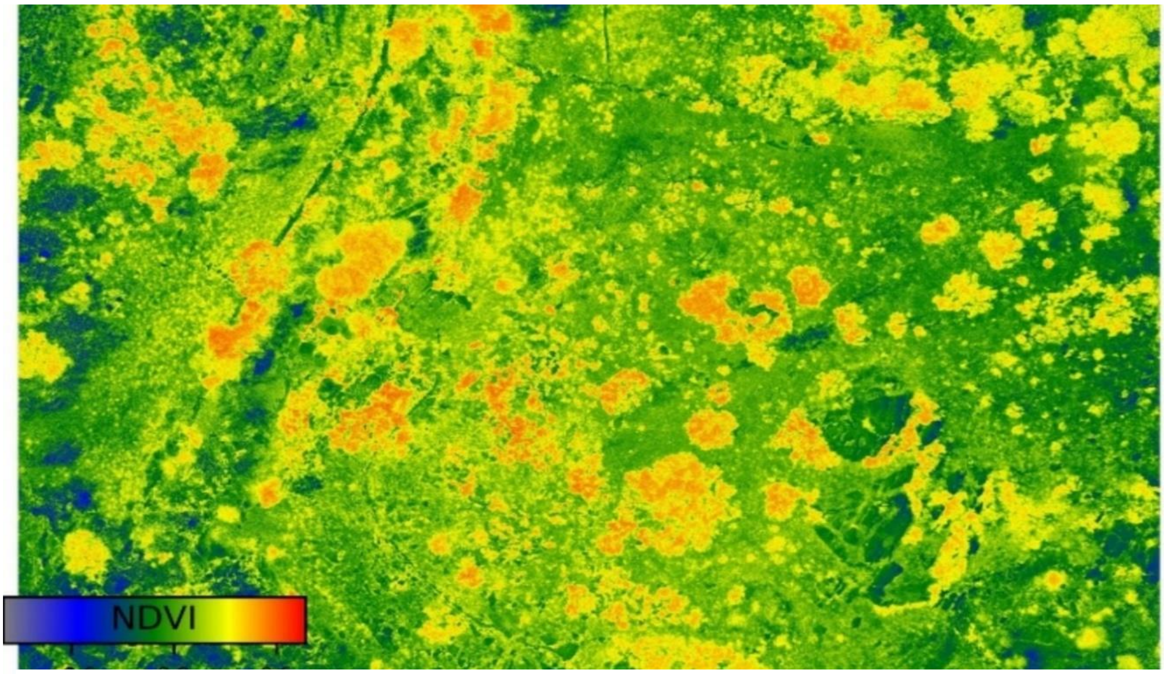
3.4 Smart Agriculture and Environmental Monitoring

Farmers and environmental workers can use drones for monitoring plant health, gathering environmental measurements, crop spraying, and herding livestock.

The agricultural and environmental sectors are also beginning to benefit from drone technology, for similar reasons as the infrastructure inspection markets described above. Drones can allow a pilot to quickly and safely inspect a large area such as a field or a patch of forest from the sky. Not only does this result in more efficient inspection work, but the use of drones in this manner allows for entirely new types of environmental monitoring.[99]

Plants absorb sunlight, while reflecting some of that sunlight as near-infrared (NIR) light. NIR light is not visible to the human eye but can be seen by cameras. Depending on whether a plant is healthy or not, it will reflect a different amount of NIR light. A camera in the sky looking at a patch of trees, for example, can look at the NIR light from all of the trees and identify which trees are sick by seeing which ones stand out. This is a measurement technique known as Normalised Difference Vegetation Index (NDVI) (shown in Figure 5). Organisations such as the National Aeronautics and Space Administration (NASA) have used satellites for taking NDVI measurements of the Earth.[100] With drones, this type of analysis is now available to private citizens such as

Figure 5. Drone photo showing NDVI values of plants, where warmer colours show healthier plant life



Source: John Campbell, MuonRay Enterprises

[99] Benjamin Pinguet, 'The Role of Drone Technology in Sustainable Agriculture', *PrecisionAg*, 22 April 2020 (Last accessed 7 January 2021).

[100] National Aeronautics and Space Administration (NASA), *Earth Observation Data* (Last accessed 7 January 2021).

independent farmers. Using a drone, a typical farmer can take NDVI measurements of a crop, identify the exact areas where there are crop health issues, and react accordingly.[101]

Drones can also be used to physically take measurements from the environment. An example of this is an Environmental Protection Agency (EPA) trial which investigated whether drones could be used to collect water samples from lakes.[102] The EPA is responsible for monitoring the quality of water in Ireland's lakes, which normally involves travelling by boat to various parts of a lake and collecting water samples by hand. The speed and mobility of a drone can allow a pilot to gather water samples from certain points on a lake's surface more quickly than if the pilot has to travel there by boat. The report suggested that the use of a drone for sample gathering could make the process more than three times faster, with the additional benefits of allowing the pilot to gather samples in areas inaccessible by boat, while also being less invasive to wildlife. The report highlighted the disadvantages of using a drone, which included the up-front costs of the hardware compared to the cost of using a boat, the restriction on the sample weight that the drone can carry, as well as the legal permissions that are required for operating the drone.[103]

Another emerging application for drones in agriculture is crop spraying. As drones can carry a certain amount of weight, it is possible to fly them close to crops and spray them with liquids such as pesticides. By precisely controlling the height and speed of a drone, the pilot can ensure a precise amount of fluid is delivered to a crop, which can offer more efficient crop-spraying than conventional ground-based methods.[104]

In smart agriculture, sensors are becoming more commonplace. For example, health sensors similar to smartwatches are available to enable farmers to monitor the health of their livestock in real-time.[105] These sensors wirelessly transmit information to the farmer; however, the effective distance across which these sensors can transmit data is not very long.[106] This is an issue for large farms, as it means the sensors may be spread out in such a way that they cannot directly communicate with the farmer unless the farmer travels to them. Drones offer a possible solution to this, as they can quickly travel around a farm, flying close to relevant sensors of interest, gathering the data from them and then passing it on to the pilot.

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[101] Kevin O'Sullivan, 'Drones set to help Irish farmers practise 'precision agriculture'', *Irish Times*, 21 October 2019 (Last accessed 7 January 2021).

[102] EPA Research, *Assessing the Potential of Drones to Take Water Samples and Physico-chemical Data from Open Lakes*, prepared by H. Lally, I. O'Connor, L. Broderick, M. Broderick, O. Jensen, and C. Graham, Galway-Mayo Institute of Technology, 2020 (Last accessed 7 January 2021).

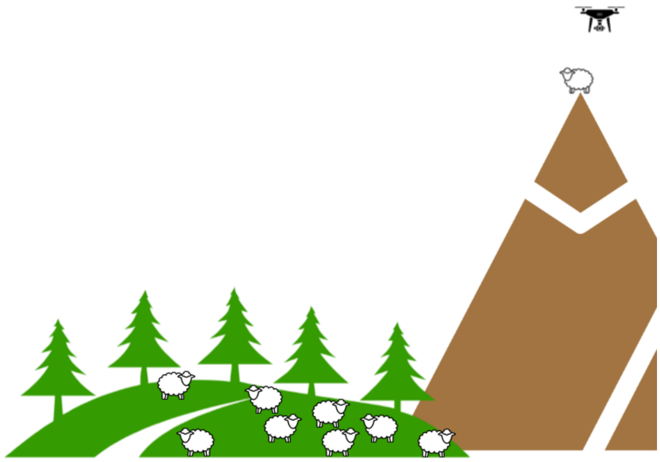
[103] *Ibid*, pp 18-19.

[104] Stephen Cadogan, 'First large drone adapted for agricultural use', *Irish Examiner*, 2 December 2019 (Last accessed 7 January 2021).

[105] Enterprise Ireland, *Fitbits for cows: how wearables are driving the 'Internet of Animals' in agriculture*, prepared by Alan Horan (Last accessed 7 January 2021).

[106] The wireless communication of these sensors is affected by the same issues that affect the drone-pilot communication link, discussed in Section 1.2.

One of the challenges posed by drones on farms is that the noise from their rotors may disturb animals. This, however, also creates an interesting opportunity for using drones to herd livestock. Farmers in parts of the world such as New Zealand have begun using drones for precision herding, where the drone is flown in such a way as to direct the herd and control stragglers.[107] The Irish Natura And Hill Farmers Association (INHFA) has called for government grants to support the purchase of drones to enable this type of herding.[108]



The agricultural drone market continues to develop worldwide, with some forecasts suggesting that it may become a billion US dollar market by 2024.[109]

3.5 Delivery and Transportation

Drones have been used to make emergency medical deliveries in situations where deliveries by road are not feasible. In parts of the world, drones are beginning to be used to deliver packages and other products (e.g. food). Drone medical and shopping delivery trials were carried out in Ireland in 2020. There is a growing interest in using bigger drones as flying taxis in the future.

While drones cannot carry heavy weights (as compared to ground vehicles), their ability to quickly fly through the sky has made them an attractive option for delivery scenarios where quick delivery times are critical, such as with medical deliveries. In 2016, one company began using drones for delivering blood packs to hospitals in Rwanda.[110] As it is a developing country, the quality of Rwandan road infrastructure creates difficulties for emergency response, including blood delivery

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[107] Peter Holley, '[New Zealand farmers have a new tool for herding sheep: drones that bark like dogs](#)', *Washington Post*, 7 March 2019 (Last accessed 7 January 2021).

[108] Declan O'Brien, '[Calls for government funding of drones to herd hill sheep](#)', *Irish Independent*, 22 September 2020 (Last accessed 7 January 2021).

[109] Andrew Meola, '[Exploring agricultural drones: The future of farming is precision agriculture, mapping, and spraying](#)', *Business Insider*, 8 January 2020 (Last accessed 7 January 2021).

[110] Martin Giles, '[Zipline launches the world's fastest commercial delivery drone](#)', *MIT Technology Review*, 3 April 2018 (Last accessed 7 January 2021).

services. As drones are unaffected by road conditions, they offer a suitable solution when ground-based delivery is not feasible. These drones are capable of autonomously[111] flying a round trip of up to 160 kilometres at a speed of up to 120 Km/h, which allows them to perform 15-minute deliveries that would take over three hours by road.[112] As of 2020, these delivery services have been expanded into Ghana, as well as the US.[113] The quick delivery times have even allowed drones to be used for transporting live organs. In 2019, a drone was used to deliver a kidney for transplantation from one US hospital to another; the 4 ½ kilometre distance between the two was covered by the drone in 10 minutes, setting a new medical milestone.[114]

Drones are also becoming increasingly used for deliveries outside of the medical context. In China, a delivery company operates drones on one of its delivery routes in order to avoid traffic congestion.[115] These autonomous drones deliver parcels from a storage facility to a collection locker, where the drones automatically land and unload their cargo, before returning. According to the company, using drones instead of ground vehicles allowed them to reduce a 40-minute trip to only eight minutes, while reducing delivery costs by almost 80%.[116] Other companies offer drone food delivery services in parts of China.[117]

[111] As the drones have to perform long-distance BVLOS flight, allowing a pilot to remotely control them is not feasible due to wireless connectivity challenges.

[112] Aryn Baker, '[Zipline's Drones Are Saving Lives]', *Time Magazine*, 31 May 2018 (Last accessed 7 January 2021).

[113] Noah Lewis, '[A tech company engineered drones to deliver vital COVID-19 medical supplies to rural Ghana and Rwanda in minutes]', *Business Insider*, 12 May 2020 (Last accessed 7 January 2021); '[Zipline drones deliver supplies and PPE to US hospitals]', *BBC News*, 27 May 2020 (Last accessed 7 January 2021).

[114] David Freeman, '[A Drone Just Flew a Kidney to a Transplant Patient for the First Time Ever. It Won't Be the Last]', *NBC News*, 3 May 2019 (Last accessed 7 January 2021).

[115] '[DHL Express and EHang Partner to Bring Last-Mile Drone Delivery to China]', *Inside Unmanned Systems*, 24 May 2019 (Last accessed 7 January 2021).

[116] *Ibid.*

[117] '[China Is on the Fast Track to Drone Deliveries]', *Bloomberg*, 3 July 2018 (Last accessed 7 January 2021).

In 2020, a drone delivery company began delivery trials in Moneygall, Co. Offaly and Oranmore, Co. Galway.[118] In Moneygall, they worked with local pharmacies to deliver prescription medication to residents self-isolating due to COVID-19. In Oranmore, they partnered with several takeaways and shops, including Tesco, to deliver online purchases to nearby customers. To comply with regulations, these automatic drone deliveries were carried out across short two-kilometre distances and were monitored at all times by human operators who were ready to take manual control of the drones in case of any issues.[119]

As delivery drone technology continues to mature, there is a growing interest in using bigger, more powerful drones as flying taxis to carry human passengers. Unlike conventional passenger helicopters, these drones would not have pilots on-board and would instead rely on a degree of automatic flight. This would potentially reduce the operating expenses and the costs for the passengers while still offering the benefits of air travel such as the avoidance of road congestion. At present, there are dozens of companies developing taxi drone technology.[120] The technology is currently in the prototype stages, with the rate of commercialisation slowed by safety and legislative concerns. As taxi drones carry human passengers, the safety standards that must be met are more stringent than with smaller and lighter package delivery drones. While drone taxi services are still years away, forecasts for the worldwide drone transportation market suggest that it may be worth US$1.5 trillion by 2040.[121]

The adoption of drone technology for delivery and transportation services is part of a larger technological trend of automating the transport and logistics sectors. There are significant concerns about the impact of automation on job security in the sector.[122] A report from PwC estimates that as much as 50% of jobs in the transport sector are at risk of being automated by the mid-2030s,[123] resulting in large labour migrations as workers switch to new jobs. While automation will also create new jobs in new markets,[124] it is not clear if the amount of new employment opportunities will be enough to cover the jobs that have been replaced, and if those replaced by transport automation, will have access to the new job markets.

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[118] 'From takeaways to medication, Irish drone company changes course over coronavirus pandemic', *RTÉ News*, 18 May 2020 (Last accessed 7 January 2021); Ciara O'Brien, 'Tesco and Manna to offer drone deliveries in Galway', *Irish Times*, 9 September 2020 (Last accessed 7 January 2021).

[119] Manna Aero, *Manna Aero FAQ*, (Last accessed 7 January 2021).

[120] Adrienne Bernhard, 'The flying car is here – and it could change the world', *BBC Future*, 12 November 2020 (Last accessed 7 January 2021); Bernard Marr, '6 Amazing Passenger Drone Projects Everyone Should Know About', *Forbes*, 26 March 2018 (Last accessed 7 January 2021).

[121] Morgan Stanley Research, *Are flying cars preparing for takeoff?*, 23 January 2019 (Last accessed 7 January 2021).

[122] Eva Short, 'How worried are you about job automation?', *Silicon Republic*, 17 September 2018 (Last accessed 7 January 2021).

[123] PwC, *Will robots really steal our jobs? An international analysis of the potential long term impact of automation*, February 2018 (Last accessed 7 January 2021).

[124] The McKinsey Global Institute suggests that 8 to 9% of labour demand in 2030 may be for new types of jobs that currently do not exist. McKinsey Global Institute, *Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages*, 28 November 2017 (Last accessed 7 January 2021).

3.6 Telecommunications

Drones are being used as flying mobile phone networks to provide people on the ground with phone connectivity in areas with limited phone service.

One of the big issues faced by mobile network operators is dealing with service demand fluctuations. A mobile phone network is typically built in a certain area based on predictions of local average service demand; if the area experiences an increase in users who are trying to use the mobile phone network, the network may become overwhelmed and the users will experience a drop in service quality. If these "service demand hotspots" are predictable in advance, the network operators can plan ahead and put up additional infrastructure to deal with the demand spikes.[125] Otherwise, if the service demand hotspots occur with little warning,[126] the network in the area can become overwhelmed. Issues may also occur if a piece of infrastructure breaks or otherwise stops functioning properly. For example, if a mobile phone tower above a busy street breaks, then this will result in a loss of phone service for everyone there.

Drones can carry phone communications equipment and, as such, they have attracted the attention of the telecommunications sector as tools for dealing with these network issues.[127] If a service demand hotspot appears in an area that cannot be accommodated by the existing mobile phone infrastructure, then a fleet of drones can be deployed to fly over the area. This fleet provides temporary phone service to people on the ground, either until the demand hotspot disappears, or until the network operators can apply a more permanent solution. This type of drone use is still in the early stages of adoption. However, the concept has been successfully proven in real-world conditions as part of disaster relief efforts.[128]

In 2017, Puerto Rico was devastated by Hurricane Maria.[129] For weeks, most of the region was left without electricity, which also resulted in the loss of mobile phone service. Google's parent company, Alphabet, responded with Project Loon. This involved launching 30 solar-powered balloon drones carrying phone communications equipment

[125] For example, network operators are aware than sports stadiums will become service demand hotspots whenever a sport event occurs, and so plan their network to have extra capacity for these events.

[126] For example, a public gathering in an area that does not normally see large crowds.

[127] M. Mozaffari, W. Saad, M. Bennis, Y. Nam, and M. Debbah, 'A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems' *IEEE Communications Surveys & Tutorials*, vol. 21(3), March 2019, pp. 2334-2360.

[128] Mary-Ann Russon, 'Drones to the rescue!', *BBC News*, 30 April 2018 (Last accessed 7 January 2021).

[129] 'Puerto Rico's death toll rises to 34 following Hurricane Maria', *Irish Times*, 4 October 2017 (Last accessed 7 January 2021).

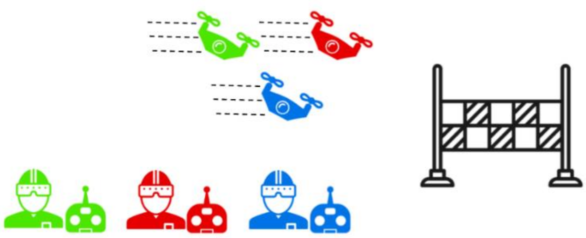
over Puerto Rico.[130] These drones hovered 20 kilometres above ground,[131] travelling on air currents while providing basic phone service to those affected by the hurricane. It is estimated that approximately 100,000 people were provided phone service using these drones until the phone network was brought back online.[132] In 2020 these drones provided mobile phone service to parts of Mozambique and Kenya.[133] In January 2021, Alphabet announced the cancellation of Project Loon due to financial difficulties.[134]

3.7 Recreational Use

Drone racing is an international sport that has brought in millions of television and online viewers from across the world in 2020. There are drone racing clubs in Ireland which organise their own events.

Remote-controlled model aircraft have a long history among hobbyists, spanning most of the 20th century.[135] Today, the drone technological revolution has made recreational flight more accessible to the public than ever before. Safety features such as GPS, AI assistance, and on-board cameras have made it easier to safely and enjoyably fly a remote-controlled aircraft.

In addition to the consumer off-the-shelf drone market, this technological trend has also created a new market for DIY racing drones. Members of the public can buy individual drone components such as motors, cameras, and drone electronics and assemble them at home. These types of drones are often designed for speed or acrobatic performance, with certain high-performance models capable of reaching speeds of up to 260 Km/h.[136] To allow for precise control of the drone, the drone pilots wear virtual reality (VR) headsets which receive the video feed from the drone camera.



[130] Ryan Nakashima, '[Google's parent company has made internet balloons available in Puerto Rico, the first time it's offered Project Loon in the US]', *Business Insider*, 21 October 2017 (Last accessed 7 January 2021).

[131] At this height, the drones were safely above the controlled airspace used by manned aircraft, see Section 4.1.

[132] Jessica Guynn, '[Google parent's Project Loon delivers Internet to 100,000 in Puerto Rico]', *USA Today*, 9 November 2017 (Last accessed 7 January 2021).

[133] Tom Bowker, '[High-flying balloons to boost northern Mozambique's internet]', *Associated Press*, 13 May 2020 (Last accessed 7 January 2021); Duncan Miriri, '[Alphabet's Loon launches balloon internet service in Kenya]', *Reuters*, 8 July 2020 (Last accessed 7 January 2021).

[134] Jennifer Elias, '[Alphabet cancels Loon, project to beam internet to earth from balloons]', *CNBC*, 21 January 2021 (Last accessed 9 February 2021).

[135] British Model Flying Association, *[History of Model Flying]* (Last accessed 7 January 2021).

[136] '[DRL Racer sets new world speed record!]', *Rotor Drone Pro Magazine*, 11 April 2019 (Last accessed 7 January 2021).

Professional global sports organisations such as the Drone Racing League (DRL) have emerged to organise international drone racing competitions. In 2020, drone races organised by the DRL were broadcast on TV channels and online platforms where they received millions of viewers.[137] Ireland has drone racing clubs which organise their own competitions.[138]

3.8 Illegal Uses

Drones are being used by criminals worldwide for smuggling contraband and spying on citizens. Modified civilian drones have also been used as weapons, both in assassination attempts and on battlefields.

The spread of drone technology among members of the public has unfortunately resulted in drones being used in illegal activities. As drones have such a wide range of uses, these illegal activities also vary significantly in scope and severity.

As consumer drones can be purchased by members of the public, without proof of training or certification,[139] this has allowed individuals to fly drones without knowledge of the legal restrictions or the safety risks involved. This unregulated use of drones has resulted in drones being flown in an illegal manner, for example, by flying near airports and creating hazards for manned aircraft. EASA reports that there were 12 collisions or near-collisions in the EU which involved drones and manned aircraft in 2018.[140] Due to the danger that drones pose for aircraft, if a drone is detected inside airport airspace, the typical procedure is to halt flights until the risk has passed. This can result in significant delays and flight cancellations, with the corresponding economic impact.[141] Other examples of illegal, high-risk flights include drones being flown over stadiums during sporting events[142] and over gorse fires, with the latter disrupting the fire-fighting efforts of emergency services.[143]

As drones allow a pilot to oversee an area from the sky, they have become popular spy tools for criminals. In the UK, drones have been used by criminals for stalking, voyeurism and

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137 Alan Baldwin, '[Drone racing-League viewing figures flying high amid virus shutdown]', *Reuters*, 24 March 2020 (Last accessed 7 January 2021).

138 '[Enthusiasts seek safe place for 160km/h drone races]', *RTÉ News*, 10 March 2017 (Last accessed 7 January 2021).

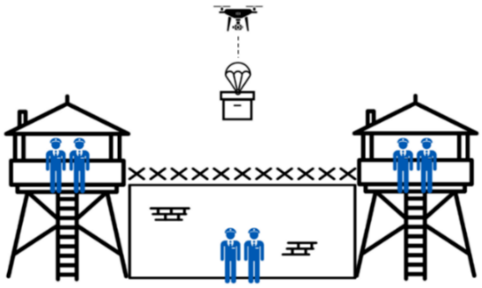
139 For more information on the current pilot training and certification requirements, see Section 4.3.

140 EASA, *Annual Safety Review 2020*, 30 July 2020, p. 145 (Last accessed 7 January 2021).

141 The incident in Gatwick airport in 2018 caused more than 1,000 flight cancellations. Samira Shackle, '[The mystery of the Gatwick drone]', *The Guardian*, 1 December 2020 (Last accessed 6 January 2021).

142 '[Man fined for illegally flying drones over football stadiums]', *BBC News*, 15 September 2015 (Last accessed 7 January 2021).

143 Alan O'Keeffe and Philip Ryan, '[Flying drones near gorse fires 'putting lives at risk']', *Sunday Independent*, 15 July 2018 (Last accessed 7 January 2021).



harassment.[144] In rural Ireland, isolated houses are vulnerable to thieves, who often target farming equipment or vehicles left outdoors. Drones have been used to survey rural properties to identify the locations of valuables from a safe distance.[145]

The ability of drones to transport cargo quickly, affordably, and in a manner that makes it difficult for authorities to detect, has also made them an attractive option for smuggling contraband. So-called "narco-drones" have become widespread for smuggling drugs over the US-Mexico border, with authorities struggling to combat these devices.[146] Drones have been used to smuggle contraband into prisons on numerous occasions in countries around the world.[147] In Ireland, cases of drone smuggling have been reported at Wheatfield, Limerick, Castlerea and Mountjoy prisons,[148] with the Prison Service beginning to deploy anti-drone systems in response.[149]

While drone technology originated in military applications before moving into the civilian domain, the evolution of civilian drones has allowed this technology to come full-circle and be used as a weapon by non-state actors. In the US, civilians have attached firearms to drones to use them as remote-controlled weapons.[150] In 2018, two drones carrying explosives were used in an assassination attempt on the president of Venezuela, Nicolás Maduro.[151] The Islamic State of Iraq and Syria (ISIS) have extensively used modified consumer drones in combat.[152] Off-the-shelf consumer drones were modified to carry explosives such as hand grenades which were then dropped from a safe height. As conventional anti-aircraft systems have difficulties stopping drones,[153] it is reported that in the period of 2016-2017, the coalition forces fighting ISIS had difficulties countering this new drone threat. This prompted the deployment of dedicated anti-drone defence systems.

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[144] David Mercer, 'Revealed: Drones used for stalking and filming cash machines in the UK', *Sky News*, 23 February 2019 (Last accessed 7 January 2021).

[145] Conor Lally, 'Drones being used by criminals to spy on farms and rural properties', *Irish Times*, 3 October 2018 (Last accessed 7 January 2021).

[146] Tim Wright, 'How Many Drones Are Smuggling Drugs Across the U.S. Southern Border?', *Air & Space Magazine*, June 2020 (Last accessed 7 January 2021).

[147] 'Charges over drone drug smuggling into prisons', *BBC News*, 15 March 2018 (Last accessed 7 January 2021).

[148] Sorcha Pollak and Jack Horgan-Jones, 'Drone used in attempted drug drop at Dublin's Mountjoy Prison', *Irish Times*, 18 March 2019 (Last accessed 7 January 2021); Marese McDonagh, 'Minister promises new tech to counter drone smuggling into prisons', *Irish Times*, 2 May 2019 (Last accessed 7 January 2021).

[149] Minister for Justice, Helen McEntee T.D., Response to Parliamentary Question No. 364 (Prison Security), *Dáil Éireann Debate,* 10 December 2020 (Last accessed 7 January 2021).

[150] Alex Lockie, 'An 18-year-old mounted a gun to a drone and fired shots in the middle of the woods', *Business Insider*, 22 July 2015 (Last accessed 7 January 2021).

[151] 'Venezuela President Maduro survives 'drone assassination attempt'', *BBC News*, 5 August 2018 (Last accessed 7 January 2021).

[152] Don Rassler, Combatting Terrorism Center at West Point, *The Islamic State and Drones: Supply, Scale, and Future Threats*, July 2018 (Last accessed 7 January 2021).

[153] Refer to Section 1.5.

4. Regulations on Drone Use

This Chapter provides an overview of the regulatory landscape surrounding the use of drones in Ireland. For specific questions on the laws for drone use by members of the public, the reader is encouraged to refer to the IAA webpage on drones, as well as EASA's Frequently Asked Questions page.

To ensure the safe operation of drones in Ireland, the technology is regulated at national level by the IAA,[154] and at EU level by EASA.[155] At the time of writing, the existing Irish Aviation Authority (Small Unmanned Aircraft (Drones) and Rockets) Order 2015 ('The 2015 Order'),[156] governing drone use is being substituted by Commission Implementing Regulation (EU) 2019/947 ('The Regulation'). This Regulation came into effect on 31 December 2020. The purpose of this section is to provide an overview of this transition, along with an overview of other legislation that is relevant to drone operations. It is the responsibility of anyone who intends to fly a drone in Ireland to be familiar with this legislation, and to follow the restrictions that are put in place by the relevant authorities.

4.1 Controlled and Uncontrolled Airspace

The skies above Ireland are monitored by Air Traffic Control (ATC) and are regulated by the IAA. Parts of the sky can only be accessed by aircraft if the flights have been approved in advance by ATC.

Airspace is separated into different categories. The two main categories of airspace are controlled and uncontrolled.

- **Controlled airspace** is actively monitored by ATC, which uses radio communication and radar technology to track and manage aircraft. In Ireland, the IAA further divides this controlled airspace into Class A and Class C,[157] depending on the type of monitoring the ATC provides. For an aircraft to lawfully enter controlled airspace, the pilot needs to provide a flight plan to the ATC in advance of the flight and must receive clearance to enter.
- **Uncontrolled airspace** (referred to as Class G by the IAA) is any airspace where aircraft can enter and operate without prior authorisation from the ATC (such as filing a flight plan).

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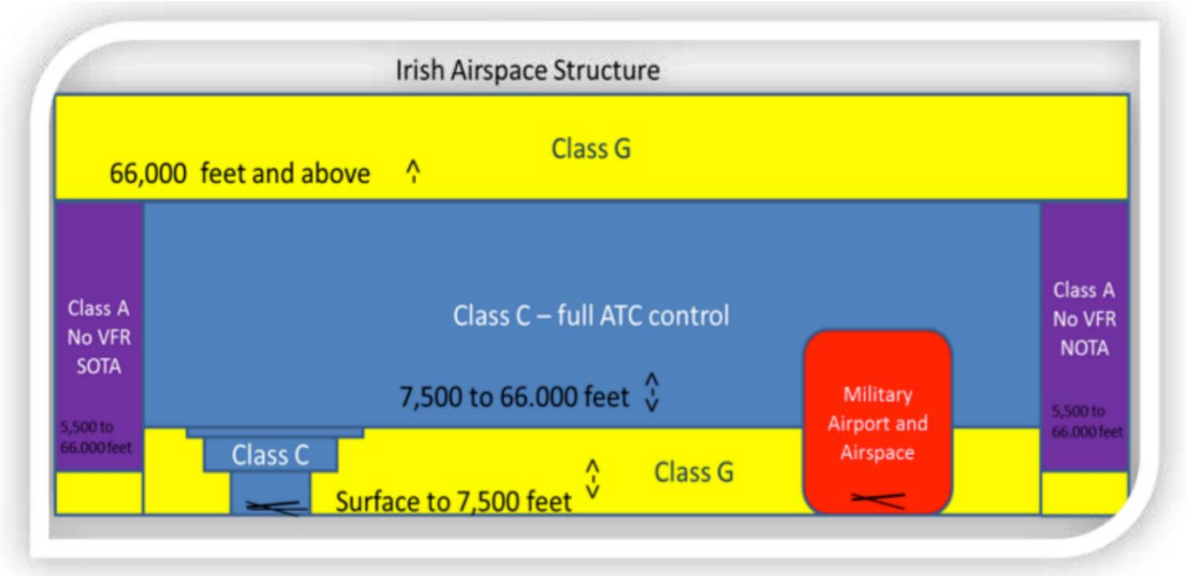
[154] *Irish Aviation Authority* (Last accessed 7 January 2021).

[155] *European Union Aviation Safety Agency* (Last accessed 7 January 2021).

[156] S.I. No. 563 of 2015.

[157] IAA, *Guide to IAA Air Traffic Management Operations*, at p. 8 (Last accessed 7 January 2021).

Figure 6. IAA Airspace Classes



Source: IAA, *Guide to IAA Air Traffic Management Operations*, at p. 9

In addition to the above categories, the IAA designates certain airspaces as being restricted, due to additional safety or security concerns. For example, the airspace around Casement Aerodrome is restricted, and any aircraft flying in the area must follow additional guidelines from ATC.[158]

4.2 Prior Regulations on Drone Use

Since 2000, Ireland has seen several regulations governing drone use. These regulations have introduced restrictions on drone flights around airports and urban areas, restrictions on the permitted weights of drones, as well as requirements for drone registration and pilot training.

This section provides a brief overview of the history of drone regulation in Ireland, before the adoption of the current regulations. The first set of regulations that governed drone use in Ireland were brought into effect in 2000, with the Irish Aviation Authority (Rockets and Small Aircraft) Order 2000 ('the 2000 Order').[159] The 2000 Order laid out the main flight restrictions for unmanned aircraft having a weight below 20 kilograms.[160] These restrictions included:

- A ban on flying within 5 kilometres of an airport without prior permission from airport operators;
- A ban on flying higher than 120 metres above ground;[161] and
- A ban on flying inside controlled airspace.

[158] *Ibid*.

[159] S.I. No. 25 of 2000.

[160] S.I. No. 25 of 2000, section 1(1) and section 5.

[161] Manned aircraft are prohibited from flying below 150 metres outside of take-off and landing. IAA, *Guide to IAA Air Traffic Management Operations*, p. 7 (Last accessed 7 January 2021).

It is important to note that when the order came into effect in 2000, civilian drones in their current form did not exist. Unmanned aircraft available to civilians at the time were either remote-controlled toys or model aircraft used by hobbyists. These devices did not have technology such as GPS or collision-avoidance sensors. Perhaps more importantly, these devices also did not have on-board cameras that could allow a pilot to perform remote surveillance. The 2000 Order therefore imposed unmanned aircraft restrictions purely from the perspective of avoiding issues for manned aircraft, with no regard for issues of privacy. Another important factor regarding the 2000 Order concerned the imposed weight categories of unmanned aircraft. According to the 2000 Order, unmanned aircraft weighing below seven kilograms were only required to adhere to the minimum airport distance requirement, with the remaining restrictions being imposed on heavier aircraft.[162] This was in line with the technological capabilities of unmanned aircraft at the time; an aircraft weighing less than seven kilograms would be unlikely to fly far enough to pose a serious threat to aircraft in controlled airspace, and so was of little regulatory concern to the IAA.

The release of the first camera-equipped, off-the-shelf consumer drone (the Parrot AR drone) in 2010 created new issues for the regulatory framework. This new class of drone was easier to fly than previous unmanned aircraft, significantly lighter[163] and included an on-board camera. Due to their weight, these new drones were exempt from the 2000 Order. In response, the IAA published the Operations Advisory Memorandum 02/12 ('the Memorandum')[164] and IAA Aeronautical Notice O.63.[165] In addition to removing the drone weight exemption, these new regulations brought in new restrictions on drone use to ensure safety for pedestrians. Under the new regulations, drone pilots were forbidden to:

- Fly the drone more than 500 metres away from their location or fly the drone in BVLOS mode;
- Fly within 150 metres of a person, vehicle, or building that is not under the control of the pilot;
- Fly in a congested area without prior IAA approval;
- Fly within 150 metres of a crowd of people without prior IAA approval; and
- Fly without valid liability insurance.

In addition to the previous restrictions, it should be noted that the IAA recognised the issue of drone radio connectivity for long-distance or BVLOS flight, and so specifically prohibited it with the Memorandum. The Memorandum also introduced a distinction between commercial and hobbyist flight. Following this distinction, any drone flight performed for commercial purposes would need to be approved by the IAA in advance.

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[162] S.I. No. 25 of 2000, section 5(3).

[163] The Parrot AR drone weighed less than a kilogram.

[164] An Advisory Memorandum is an explanatory document of law that is in effect, whereas an Aeronautical Notice is a legal extension of a Statutory Instrument or Regulation.

[165] IAA, 'Remote Piloted Aircraft Systems Use Grows in Ireland', *Press Release*, 20 November 2014 (Last accessed 7 January 2021); K. O'Sullivan, 'Low-flying Drones and Ownership of Airspace in Ireland' *Conveyancing and Property Law Journal*, vol. 21(1), 2016, pp. 7-11.

The 2015 Order introduced two important requirements for drone use: drone registration and drone competency training. It also removed the differentiation between hobby and commercial pilots. Under the 2015 Order, drones were separated into several weight classes, as set out below.

- All drones weighing more than one kilogram (or intended to be flown higher than 15 metres above ground) were required to be registered online with the IAA, with a unique registration number displayed on the drone exterior.[166]
- All drones weighing more than four kilograms required the pilot to take a course of drone safety training from an IAA-approved authority.[167]
- All drones weighing more than 25 kilograms were not permitted to fly without prior permission from the IAA.[168]

The introduction of a drone registration database and pilot competency training allowed the IAA to introduce additional safety mechanisms to drone flight, while at the same time streamlining the regulatory process for using drones commercially. Under the 2015 Order, pilots intending to use a drone for commercial purposes were no longer required to seek IAA approval before each individual flight, assuming the flight met the standard regulations.[169] The requirement for mandatory liability insurance was also removed, with liability insurance only recommended to pilots seeking IAA permission to fly drones beyond the standard limits. While previously introduced restrictions on drone use were kept, some specific safety thresholds were adjusted in line with the evolving drone technology.[170]

With the 2015 Order, the IAA set the foundation for drone pilot schools and their IAA-approved training programmes. A typical course for a drone pilot would consist of two full days of classes followed by a day of practical flight training. Courses typically covered:

- Existing legislation on drone use;
- The principles of drone operation;
- Meteorology and working with weather forecasts; and
- Dealing with emergencies

In addition to allowing the drone pilot to fly drones above four kilograms, the pilot certificate of competence (PCC) allowed the drone pilot to apply for Specific Operating Permission (SOP) from the IAA. The SOP was a mechanism by which the IAA could issue specific exemptions to drone pilots, to allow them to fly beyond the normal operational limits. As part of the application, the pilot would present a flight plan giving information about the flight, including potential safety risks and how they were to be mitigated by the pilot. The IAA would then, subject to any IAA instructions or restrictions, issue written permission to proceed with the flight. To fly in controlled airspace, an

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[166] S.I. No. 563 of 2015, section 7(1).

[167] S.I. No. 563 of 2015, section 7(7).

[168] S.I. No. 563 of 2015, section 7(8).

[169] Unlike the 2000 Order, the 2015 Order did not distinguish between hobbyist and commercial flight, which removed the additional requirements for commercial pilots.

[170] For example, section 7(5) of the 2015 Order reduced the minimum permitted flying distance to pedestrians from 150 metres to 30 metres.

additional application was required by the IAA, outside of the SOP. This required the drone pilot to detail the exact time, duration, location of the flight, details of the pilot and the drone, as well as mobile phone numbers to allow ATC to contact the pilot during flight.

4.3 Current EU Regulations on Drone Use

At the time of publication, drone use in Ireland is subject to EU regulations. These regulations introduce new drone categories that civilian drones must operate under. The regulations also introduce additional training and registration requirements for drone pilots and operators.

As of 31 December 2020, civilian drone use in Ireland is subject to the newly adopted Commission Implementing Regulation (EU) 2019/947 ('The Regulation'), which has replaced the 2015 Order.[171] The Regulation has introduced a number of notable changes to how drones are to be operated in Ireland. In summary, these changes include:

- **Drone categories:** The Regulation defines three categories for civilian drones, based on risk profile. In increasing order of risk, these are the 'Open', 'Specific' and 'Certified' categories.
- **Mandated safety features:** The Regulation mandates that consumer drones sold in the EU market must conform to one of several defined operating classes, with safety features such as geofencing and remote operator identification to be included by the manufacturers.
- **Risk-based approach to regulation:** The Regulation imposes restrictions on drone use based on the level of risk associated with the flight, with no regard given to the purpose of the flight (whether hobbyist, commercial, or government service).[172]
- **Mandatory drone operator registration:** Drone operators are required to register with their national aviation authority, regardless of their drone category.
- **Mandatory pilot competency training**. All pilots are to receive a basic level of drone pilot training from their national aviation authority or an approved training organisation.
- **Cross-border sharing of registration data**: The operator registration data is to be shared between the national aviation authorities of all the EU Member States, to allow all drone operators the ability to operate in any Member State once registered with their own authority.[173]
- **Automatic flight permissions:** The Regulation recognises the ability of some drone models to fly using on-board Artificial Intelligence (AI), without direct pilot control. Allowances are made for certain types of automatic flight under specific conditions.

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171 'Know the drone safety rules before you fly – IAA', *RTÉ News*, 17 December 2020 (Last accessed 7 January 2021). Note that certain IAA Aeronautical Notices such as U.04 (which governs maximum drone heights near airports) will remain in effect and be updated to work with the new Regulation.

172 Under Article 3 of the Chicago Convention on International Civil Aviation (of which Ireland is a signatory), state-operated aircraft are not subject to civil aviation regulations. As such, it is currently unclear to what extent organisations such as the Dublin Fire Brigade (DFB) must adhere to the Regulation when operating its drones in an emergency. (Last accessed 7 January 2021).

173 Note that the UK is implementing this EU regulation *at national level* (Last accessed 7 January 2021) but, due to Brexit, UK regulations may diverge in the future. At the time of writing, registration data sharing is not due to be implemented between Ireland and the UK.

- **Privacy risk mitigation**: The Regulation recognises the potential for drones to violate the privacy of individuals. As such, all drones that are equipped with a camera require operator registration, irrespective of drone weight or other factors.
- **Noise pollution mitigation**: The Regulation recognises the issue of noise pollution created by drones during flight. As such, drones operating in the open category must meet set noise requirements, while pilots looking to fly drones in the specific category must account for noise in their flight plans.
- **Standard scenarios:** The process of applying for flight permission from national aviation authorities has been streamlined with the introduction of "standard scenarios", which serve as templates for pilots to refer to in their applications.

These points are discussed in more detail in the following subsections.

4.3.A Open, Specific, and Certified Categories

To address the diversity of drone shapes, sizes, and designs on the civilian and commercial markets, the Regulation introduces three main categories for drones, based on the anticipated risks involved with their flight.

The **Open category** includes drones that pose the least risk to public safety or privacy, such as small drones used by hobbyists.[174] A pilot intending to fly an Open category drone does not require prior permission from their national aviation authority. The Open category includes drones with a weight of up to 25 kilograms, and is further subdivided into three subcategories A1, A2, and A3, as outlined in Table 4.

Table 4: Open Category Subcategories

Subcategory	Flying in urban areas	Flights over pedestrians	Flights over crowds
A1	Permitted	Permitted, but should be avoided	Prohibited
A2	Permitted	Prohibited, must keep 30 metres away from pedestrians (or 5 metres if operating in low-speed setting)	Prohibited
A3	Prohibited, must keep 150 metres away from urban areas	Prohibited	Prohibited

Drones in all three subcategories must fly below 120 metres above ground, and BVLOS flight is prohibited. The limit on the maximum distance a drone can fly from the pilot is removed, provided the pilot can see the drone without the use of binoculars or other equipment. The subcategories also permit some types of automatic flight; provided a drone stays within 50 metres of a pilot and the latter can take control of the drone in an emergency the drone is allowed to fly by itself.

[174] Commission Implementing Regulation (EU) 2019/947, Article 4.

A key element of the Regulation is that any drone sold for use in the EU must adhere to a set of product standards, which are similar to the CE marking scheme. New drones sold in the EU for use in the Open category are required to conform to one of five specified classes based on their weight, maximum speed, maximum noise output, and included safety features, in accordance with the [Commission Delegated Regulation (EU) 2019/945](#) ('the Delegated Regulation'). These classes are denoted as C0, C1, C2, C3, and C4, as outlined in Table 5.

Table 5: Open Category Drone Classes

Class	Weight	Permitted subcategories	Notes
C0	<250 grams	A1, A2, A3	-19 m/s max speed -120 metre max distance to pilot
C1	<900 grams	A1, A2, A3	-19 m/s max speed
C2	<4 kilograms	A2, A3	-must have 3 m/s low-speed setting
C3	<25 kilograms	A3	-includes AI flight modes
C4	<25 kilograms	A3	-does not include AI flight modes

All new drones sold in the EU market must be visibly labelled and marketed as belonging to one of these five classes by the manufacturers. A transition period until June 2022 is in place, during which, existing drones that are not labelled may operate under the three categories and depending on their weight class. Post-June 2022, any drones below 250 grams can operate under the A1 category, otherwise they are restricted to A3.

The **Specific category** refers to drones below 25 kilograms that are flown in a way that is not covered by the Open category.[175] For example, flying a one-kilogram drone above a crowd of people would be covered by the Specific category. For this type of flight, the drone pilot is required to receive permission from the national aviation authority prior to take-off. The drone pilot presents a flight plan to the IAA with an assessment of potential risks, and the steps taken to mitigate them. The Regulation streamlines the application process by introducing what are called "standard scenarios". These are example scenarios that describe a drone flight, define the risks involved, and indicate what steps are to be taken to ensure safety. Under previous regulations, the pilot needed to carry out this risk assessment by themselves for each individual application. Now, the pilot can simply indicate which standard scenario their intended flight aligns with and follow the relevant safety requirements. The standard scenarios for the Specific category will be published by EASA in 2021. Under the Regulation, certain organisations that operate drones may also apply for a Light UAS Operator Certificate (LUC) from their national aviation authority, which gives them additional privileges.[176] These privileges include the possibility of authorising their own flights under the Specific category, by carrying out their own risk assessments. This LUC mechanism can streamline drone operations for organisations such as the DFB.

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175 Commission Implementing Regulation (EU) 2019/947, Article 5.

176 The full requirements for a LUC, and the responsibilities and privileges of a LUC holder are included in Part C of the Annex to Commission Implementing Regulation (EU) 2019/947.

The **Certified category** refers to drone operations with the highest risk.[177] This includes large drones flying in congested areas, drones carrying human passengers, and drones carrying dangerous goods. Given the high-risk nature of these drone flights, they will be subject to similar (if not the same) regulations as manned aircraft. This means that the drones will need to be registered with the national aviation authority. They will need to meet strict airworthiness requirements and their ground maintenance will also be regulated.[178] At the time of writing, the exact regulations to be imposed on the Certified category of drones have not been published by the IAA or EASA.

4.3.B Drone Operator Registration and Pilot Training

The Regulation introduces a distinction between "drone operators" and "drone pilots". The "drone operator" is the owner of a drone (whether an individual or a company), whereas a "drone pilot" is the person responsible for flying the drone safely. A hobbyist flying their own drone is therefore both an operator and a pilot. The Regulation mandates that all drone operators that own a drone, which either weighs more than 250 grams or has a camera, and does not meet the definition of a "toy" according to Directive 2009/48/EC of the European Parliament and of the Council on the safety of toys,[179] must register with their national aviation authority.

The Regulation also mandates that any pilot who intends to fly such a drone must receive a basic level of competency training from their national aviation authority.[180] The Regulation defines this as an online multiple-choice test issued by the national aviation authority comprising of 40 questions on the following topics:

- Air safety;
- Airspace restrictions;
- Aviation regulation;
- Human performance limitations;
- Operational procedures;
- Drone general knowledge;
- Privacy and data protection;
- Insurance; and
- Security

This level of training is considered sufficient to allow a pilot to fly in subcategories A1 and A3 of the Open category.

[177] Commission Implementing Regulation (EU) 2019/947, Article 6.

[178] For example, the maintenance will only be performed by authorised and trained maintenance crews, who will need to keep detailed and accurate records of a drone's maintenance history.

[179] To qualify as a toy under this Directive, the drone must be manufactured in a way that takes child safety into account and must be intended to be used by persons under 14.

[180] The full competency training requirements for all three subcategories in the Open category are included in Part A of the Annex to Commission Implementing Regulation (EU) 2019/947.

To be eligible for the A2 subcategory, as well as the Specific category, a Certificate of Remote Pilot Competency is required. To obtain this certificate, a drone pilot must undergo a second training course with their national aviation authority or authorised training organisation. This training consists of an additional online course that covers:

- Meteorology;
- Drone flight performance; and
- Technical and operational mitigations for ground risk.

This training also includes a test of the pilot's competency in flying the drone, administered by a registered training organisation. At the time of writing, pilot online training in Ireland is carried out via the IAA website.[181] The online training course consists of a short instructional video[182] and multiple-choice exam, after which the pilot receives a proof of completion of online training (shown in Figure 7). The website also allows certified pilots to complete further training via one of the approved pilot training centres.[183] While the approval of the pilot training centres is carried out by the IAA, the Regulation does not set out competency requirements or standards for these training centres.

Figure 7. IAA Proof of Completion of Online Training

The IAA website also allows for drone operator registration. The IAA issues the operator with a unique ID code upon completion of this registration, which must be displayed on the exterior of each drone belonging to the operator. Under the Regulation, drones in the Open category are not required to be insured, whereas insurance requirements for the Specific category are to be determined by the national aviation authority. The IAA requires proof of liability insurance for any drone operator registering under the Specific category.

Prior to the Regulation, the national aviation authority of each EU Member State had their own drone pilot/operator database. Data was not shared between Member States. As a result, pilots travelling from one Member State to another would be forced to register with that Member State's national authority, and possibly repeat their competency training. Harmonisation of drone operations between Member States is one of the stated objectives of the Regulation. Following these objectives, efforts are currently underway to allow for database sharing between the different authorities. In October 2020, EASA put in place a broker solution to allow database sharing between Member States, as EASA continues to develop a centralised EU-wide database. This will come into effect by the end of 2024.[184]

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[181] IAA, *IAA Drone Operator Registration* (Last accessed 7 January 2021).

[182] The video is publicly available on *Youtube* (Last accessed 7 January 2021).

[183] Examples of these training centres include *Avtrain* and *Flyryte* (last accessed 7 January 2021).

[184] EASA, 'EASA Delivers Broker Solution to Enable European-Wide Sharing of Drone Registration Data', *Press Release*, 22 October 2020 (Last accessed 7 January 2021).

4.3.C Mandatory Safety Features

The Delegated Regulation requires that all new drones sold on the EU market (except for the C0 class) be fitted with several safety mechanisms by the drone manufacturers.[185] This includes a **remote operator identification system**, the use of which allows a drone to transmit identification radio signals during its flight. These signals contain the operator's ID, the drone's serial number, and telemetry information about the drone flight. Pedestrians on the ground (both law enforcement personnel and members of the public) will be able to receive these signals on their mobile devices. This will give them information about the drone and its operator and allow them to respond to any issues arising from the drone.[186]

Other safety mechanisms mandated by the Regulation include **location geofencing**, **safety lights** for night-time visibility, and **RTH functionality** in case of a loss of the drone-pilot communication link. Some of these features are already present in certain drone models on the consumer market. However, the Regulation now makes them mandatory to be certified under the C1-C4 drone classes.

4.4 U-Space and Drone Air Traffic Management

In the coming years, the EU will adopt a new drone air traffic management system, to allow ATC to monitor and regulate drone flights in the sky. This roll-out will occur in four phases, with the final phase forecasted for the mid-2030's.

To allow long-distance BVLOS flights (such as those used for medical deliveries), and to ensure that drone fleets can operate in dense urban areas, national aviation authorities need to be able to oversee and manage drone air traffic in the same manner that they currently manage manned aircraft. Using the existing air traffic management system for managing drones is not feasible for both technical as well as regulatory reasons. From a technical perspective, drones cannot be successfully tracked using existing radar systems.[187] Current forecasts on drone use suggest that drone air traffic may soon be so dense that it will be impossible for the current human ATC to cope.[188] From a regulatory perspective, drones tend to fly in low-height uncontrolled airspace and, under the current EU Regulation, most drones and drone pilots are not subject to the same level of regulatory scrutiny as manned aircraft.

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[185] These requirements are included in the Annex to Commission Delegated Regulation (EU) 2019/945.

[186] This is similar to an existing system used by manned aircraft called Automatic Dependent Surveillance-Broadcast (ADS-B). With ADS-B, manned aircraft transmit information about their own flight to other aircraft, as well as to ATC on the ground. Not only does this create an additional layer of safety, but it also makes the air network more transparent for members of the public. ADS-B tracking websites such as *FlightRadar24* (last accessed 7 January 2021) allow members of the public to see real-time information about aircraft currently in flight, including their location and their destination. Bethany Whitfield, 'How It Works: ADS-B', *Flying Magazine*, 8 February 2017 (Last accessed 7 January 2021).

[187] See Section 1.5 on anti-drone measures.

[188] EASA, *Opinion No. 01/2020*, 13 March 2020, p. 28 (Last accessed 6 January 2021).

For these reasons, an entirely new type of air traffic management system may need to be created to cope with drone traffic.[189] Such a system must:

- Be compatible with the existing air traffic management system for manned aircraft;
- Be compatible with the different drone categories;
- Be compatible with national regulations; and
- Have the capacity to accommodate the rapidly growing number of drones in the EU.

In 2017, the Single European Sky ATM Research Joint Undertaking (SESAR JU)[190] published the blueprint for a regulatory framework to support these traffic management services, known as U-Space. The blueprint proposes that U-Space be adopted in four phases, with each phase introducing increasingly complicated management functionality.[191] These phases are outlined below.

U1: U-Space foundation services. In this phase, support for basic services such as online drone databases, remote drone identification and geofencing is introduced.

U2: U-Space initial services. In this phase, services such as drone flight planning, drone tracking, and integration with manned airspace traffic management are introduced.

U3: U-Space advanced services. In this phase, support for urban drone traffic management is introduced, with conflict detection and avoidance[192] automated using AI.

U4: U-Space full services. Full adoption of AI for automated drone management and safe integration of drones into controlled airspace alongside manned aircraft.

Each phase will rely on the increasing use of AI for automation, as well as wireless drone connectivity via infrastructure such as the mobile phone network.[193] According to its development roadmap, SESAR JU aims to see full deployment of U1 by 2022 and U2 by 2027, with U3 and U4 deployed in the mid-2030s.[194]

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[189] *Ibid*.

[190] SESAR JU is a public-private partnership set up as part of the Single European Sky initiative to reform air traffic management in the EU. *Discover SESAR* (Last accessed 7 January 2021).

[191] SESAR JU, *U-Space Blueprint*, 2017, p. 5 (Last accessed 7 January 2021).

[192] Conflict detection and avoidance here refers to decisions about who gets the right-of-way when moving in the air, similar to the function of a traffic light at an intersection.

[193] SESAR JU, *Consolidated Report on SESAR U-Space Research and Innovation Results*, 2020, p. 31 (Last accessed 7 January 2021). See Section 2.1 for more information on infrastructure connectivity.

[194] SESAR JU, *European ATM Master Plan: Roadmap for the Safe Integration of Drones Into All Classes of Airspace*, 2017, p. 17 (Last accessed 7 January 2021).

4.5 GDPR and Drone Camera Recordings

Drones that have cameras may be subject to GDPR if they gather video footage of members of the public. The nature of drone flights may raise new GDPR issues in the future.

To ensure the privacy of its citizens and protect their personal data, the EU has adopted the Regulation (EU) 2016/679, also known as the General Data Protection Regulation (GDPR). GDPR sets out clear definitions for what kind of data constitutes as "personal data" and imposes requirements on how personal data must be managed. As drones carry cameras that can transmit and record video footage, they can capture non-sensitive[195] personal data. As such, their operators are obliged to comply with the GDPR. The enforcement of GDPR in Ireland (including cases where data is gathered by drones) falls under the remit of the Irish Data Protection Commission (DPC).[196] At the time of writing, the DPC has not issued official guidance regarding drone use. As drone cameras can be compared to vehicle dash-cams (in that they are used to record footage for safety or liability purposes), the published guidelines on dash-cam use could potentially serve as a model.[197] Following these guidelines, a drone operator may be regarded as a data controller, and therefore subject to GDPR regulations, depending on the exact material captured by the drone camera. GDPR includes a "household exemption" to allow private individuals to freely process their own data. This exemption does not apply if the recorded data includes other individuals outside of the household, as established by the Court of Justice of the European Union in the case *Rynes vs Urad*.[198] In cases where the household exemption does not apply, the drone operator would be expected to comply with data protection requirements, even if the operator is a hobbyist flying a drone for recreational purposes. The operator must:

- Process the data in a transparent manner. This means that members of the public must be made aware that data is being processed and have means to contact the drone operator;
- Store only necessary data for only the necessary length of time. This means the operator must avoid recording footage of other people unless the drone flight requires it, and then must delete the data when they are finished with it;
- Store the data securely. This means that the drone operator must take steps to protect the data from unauthorised access; and
- Ensure that stored data is available to the persons recorded. Drone operators must be able to share any recordings they make with the people in the recordings on request.

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[195] Sensitive data refers to data about a person's health, political opinions, genetic data, or their intimate life, as defined in Article 9 of the GDPR.

[196] While the drone flight rules introduced by the EU Regulation will help prevent privacy violations caused by drones, data protection is outside the jurisdiction of aviation authorities such as EASA or the IAA. Anton McNulty, 'No privacy legislation on drones flying over homes', *Mayo News*, 3 March 2020 (Last accessed 6 January 2021).

[197] DPC, *Guidance for Drivers on the Use of Dash Cams*, June 2020 (Last accessed 7 January 2021).

[198] Judgment of 11 December 2014, *Rynes v Urad pro ochranu osobnich udaju* (Case C-212/13) EU:C:2014:2428 (Last accessed 7 January 2021).

As a new and rapidly evolving technology, drone use in the future may raise new issues and challenges for privacy and data protection. For example, consider the scenario of a drone flying to a house in a residential estate to perform some sort of task. The drone flies directly over houses and gardens at a safe height above ground. The drone has a camera which provides a live video feed to a pilot; this video feed is also recorded for safety and liability purposes. Flying the drone in this manner raises several possible issues which are discussed below.

4.5.A Consent to Record

Obtaining consent from those in a video recording is a common solution to ensure GDPR compliance.[199] Given the nature of drone flights, this may not always be feasible. If a drone operates over a long range, it may fly over dozens of private properties. Depending on the type of drone operation being carried out, it may not be feasible for the drone operator to seek prior consent from individuals before a drone flight (as the flight path may not be known in advance). Article 6 of the GDPR[200] allows for lawful video processing even without consent, provided at least one of the following conditions is met:

- The video processing is needed to comply with a legal obligation;
- The video processing is needed to protect the vital interests of a person;
- The video processing is being carried out in the public interest or as part of official authority granted to the drone operator; or
- The video processing is necessary to pursue the legitimate interests of the operator or a third party, as long as those interests are not overridden by the interests or fundamental rights and freedoms of the person being recorded.

"Vital interests" refers to a situation (often an emergency) where the data gathering is needed 'in order to protect someone's life, or mitigate against a serious threat to a person',[201] such as when a drone is being used as part of an ambulance response. "Legitimate interests" refers to a broad range of interests including 'commercial interests, individual interests, or broader societal benefits'.[202] The safety and liability concerns of a delivery drone carrying a valuable delivery to a client may qualify as "legitimate interests". Therefore, the lawfulness of allowing drones to record camera footage without the prior consent of the people on the ground may depend heavily on the exact purpose of the drone flight and whether the recorded footage is necessary for its operation.

4.5.B Data Anonymisation

One of the ways in which drone operators can avoid the restrictions of GDPR is to ensure that the data they collect is anonymised. Blurring individuals' faces and car registration numbers in video footage removes the ability to identify individuals from that footage alone. This may ensure that the

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[199] R. Kennedy and M.H. Murphy, *Information and Communications Technology Law in Ireland*, Dublin: Clarus, 2017, p. 107.

[200] Article 6, GDPR.

[201] DPC, *Guidance Note: Legal Bases for Processing Personal Data*, December 2019, p. 16 (Last accessed 7 January 2021).

[202] *Ibid*, p. 22.

footage is no longer counted as personal data, and therefore not subject to GDPR regulations.[203] However, legal challenges may arise in respect of other information stored by the drone. During flight, a drone stores telemetry data, including its precise GPS coordinates at any given moment. If the drone records video footage of somebody in their back garden and blurs their face, this does not anonymise the individual if the corresponding stored GPS coordinates point directly to their back garden. From the GDPR definition, this is referred to as “pseudonymisation” which is defined as:

> ‘the processing of personal data in such a manner that the personal data can no longer be attributed to a specific data subject without the use of additional information, provided that such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person.’[204]

As long as it is possible to identify someone from pseudonymous data then it is still regarded as personal data according to the GDPR.[205]

4.5.C Autonomous drone operations

The current trends suggest that certain types of drone flights in the future may be carried out using AI, with human pilots playing an indirect supervisory role. In addition to the safety concerns around autonomous drone flights, issues with data processing and GDPR may arise, depending on the purpose of a drone flight. Article 22 of the GDPR states that:

> ‘The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her.’[206]

If the drone is simply performing a delivery function and is recording video footage for safety purposes, then the autonomy should not create an issue under Article 22. However, if a drone is using video footage and image recognition of people to decide how to behave, then this may be a violation under Article 22, unless special precautions are taken by the drone operator to ensure automated profiling does not happen.

4.5.D Minimising Personal Data Processing

Minimising the amount of data gathered and the length of time that it is stored is one of the key objectives of GDPR legislation. It is one of the most reliable ways to ensure GDPR compliance. For drone operators, this means designing their operations to avoid recording footage whenever it is possible. For example, during its food delivery trials in Oranmore, Co. Galway, delivery company Manna Aero only used the cameras on-board their drones to provide their pilots with a live feed for

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[203] GDPR is specifically concerned with the processing of personal data. Article 1, GDPR.

[204] Article 4, GDPR.

[205] Recital 26, GDPR.

[206] Article 22, GDPR.

safety purposes, with none of this footage being recorded.[207] As drones rely on a variety of sensors for their flight (such as infrared proximity sensors) which are incapable of gathering personal data, it is entirely possible to operate drones without any conventional cameras at all. This creates a safety trade-off, but through developing technologies in the areas of AI and drone wireless communications, it is possible to safely operate drones for certain tasks in a manner that does not gather the personal data of people on the ground.

4.6 Drone Use in Sensitive Areas

Drones are banned from being flown in heritage sites and wildlife sanctuaries by the relevant authorities such as the Office of Public Works. Only the IAA has the remit to regulate airspace use, however, which means that drones can still be legally flown above these areas.

Ireland is home to a large number of nature reserves, wildlife sanctuaries, and heritage sites. Due to their aesthetic qualities, these sensitive areas often attract drone pilots for filming purposes. These drone flights pose a new safety risk for these areas (due to the potential for drone collisions).[208] They also can negatively impact the scenery and the public's enjoyment of same with their noise and appearance. For these reasons, relevant authorities either restrict or ban the use of drones around sensitive areas. The Office of Public Works (OPW), for example, bans drone flights around the heritage sites under its care,[209] while The National Park & Wildlife Service (NPWS) only permits drone use under special circumstances.[210]

The use of Irish airspace by aircraft is under the authority of the IAA, and this has created a degree of confusion regarding drone use in these sensitive areas. The OPW and NPWS have the authority to ban drone pilots from launching a drone or landing it on the territory of the sensitive areas, but they cannot enforce airspace restrictions above these areas, as that is the sole remit of the IAA. The IAA can declare no-fly zones around certain locations to protect them from drone flights. Currently there are no-fly zones in place around airports, prisons, and hospitals in Ireland. However, sensitive areas such as heritage sites or wildlife sanctuaries do not have no-fly zones in place. As such, flying a drone above a sensitive area is lawful, assuming all other drone restrictions are obeyed, and provided that neither the drone nor the pilot physically interact with anything in the site (such as landing on the premises).

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[207] Manna Aero, *Manna Aero FAQ*, (Last accessed 7 January 2021).

[208] For example, a drone crashing and getting stuck into the wall of Tintern Abbey, Co. Wexford. Noel Baker, 'Ancient monuments damaged by modern day life', *Irish Examiner*, 7 March 2017 (Last accessed 7 January 2021).

[209] Heritage Ireland, *Filming and Photography* (Last accessed 7 January 2021).

[210] Connemara National Park, *Photography & Drones* (Last accessed 7 January 2021).

4.7 Role of An Garda Síochána and the Irish Air Navigation Service

An Garda Síochána is responsible for enforcing lawful drone use, alongside the IAA. As such, the Gardaí will need to respond to the frequently changing regulations and the rising number of drones in the country. The creation of the Irish Air Navigation Service will also split the regulation of drone technology in the country between two state bodies. The impact this will have on drone regulation in Ireland will need to be carefully studied.

As discussed above, depending on how it is used, a drone flight can fall under the remit of several authorities such as the IAA, the DPC, the OPW, the NPWS as well as the relevant local authorities. This can create confusion as to which organisation is responsible for enforcing lawful drone use. The IAA has the sole remit of enforcing the safe use of Irish airspace by aircraft, including drones. The Gardaí have the authority to intervene if a drone is being used in a clearly anti-social and dangerous manner. However, the Gardaí do not currently have the authority to search pilots and seize drones if there is a suspicion of a flight violation, unless directed to do so by the IAA. This means that the IAA must work very closely with the Gardaí to ensure the enforcement of the regulations. Due to the rapidly evolving regulatory landscape surrounding drone use, there is a requirement that members of the Gardaí need to be adequately familiar with this landscape to rapidly and effectively respond to unlawful drone use. Furthermore, the growing number of drones in the country means that the Gardaí will be required to increase their policing of drone use to ensure public welfare.

The Air Navigation and Transport Bill 2020 ('The Bill') proposes to establish a new Irish Air Navigation Service (IANS), which would perform the air navigation functions in Ireland. The Bill would, in effect, split the safety regulation functions and the for-profit ATC functions between the IAA and the IANS respectively. The impact of this split would need to be carefully examined to ascertain its implications in respect of budget, governance, transfer of functions and the implementation of same. The effect of the split on the implementation and enforcement of the EU Regulations as well as the upcoming U-Space drone traffic management systems will also need to be studied. At the time of writing, the Bill has completed Second Stage, having been debated in the Dáil in early February[211], and has been referred to the Select Committee on Transport and Communications Networks for Committee Stage.[212]

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[211] Air Navigation and Transport Bill 2020: Second Stage, *Dáil Éireann Debate,* 4 February 2021 (Last accessed 9 February 2021).

[212] Air Navigation and Transport Bill 2020: Referral to Select Committee, *Dáil Éireann Debate*, 4 February 2021 (Last accessed 9 February 2021).

Conclusion

This paper has considered the current and newly emerging technology of civilian drones, their current uses, and the regulatory landscape in Ireland. As this *Spotlight* shows, it is clear that this technological trend is more than just a toy or a fad. It is instead a technological revolution that has the potential to impact every aspect of civil society in one manner or another. In the decade since the release of the first off-the-shelf consumer camera drone, these devices have been used in a wide range of industries, from film studios to farms. The COVID-19 global pandemic appears to have accelerated the adoption of drone technology, as demonstrated by law enforcement agencies beginning to use drones for policing purposes.

At the same time, drone technology has created a new threat to members of the public. In the wrong hands, civilian drones have been effectively and reliably used to violate privacy, assist in criminal activities, and cause severe disruptions to manned aviation. At their worst, these devices have been used as tools of war, giving their users the ability to kill and destroy.

As with many other sectors of the technological landscape, drone technology continues to develop at a breakneck pace. Drones are becoming more AI-driven and more capable with every passing year, which enables new opportunities for their use, and creates new challenges. Anti-drone technology is attempting to keep pace, with new means of combatting rogue drones appearing on the market for lawful authorities to use.

Due to the obvious risks involved with drone operations, these devices have been regulated in Ireland for the last two decades. To keep up with the rapid pace of development, drone regulations have been regularly amended. In the five-year period between 2015 and 2020, Ireland adopted two different sets of regulations governing drone use. As of 31 December 2020, drone regulations are governed at EU level, with EU-wide requirements for pilot competency training and drone operator registration. These new regulations recognise both the dangers associated with drones as well as their immense potential for civil society. They are designed to accommodate safe drone use whenever feasible. At the same time, work continues to develop an air traffic management system that will allow authorities to monitor and regulate drone flights in a similar manner to manned aviation. This system is intended to be rolled out in phases into the next decade.

While drone technology is being adopted by a number of organisations for use in their day-to-day operations, there have been concerns raised about the up-front costs of drone hardware, which have delayed its adoption.

The vision of drones autonomously delivering life-saving medication while flying alongside road traffic and manned aircraft is still years away, due to the current limits of the technology and its regulations. Nonetheless, the trend of drones becoming increasingly present in certain areas of civil society is clear. The rate at which this adoption will happen in Ireland will depend on how quickly the associated hurdles are crossed, as well as the policies and legislation adopted by Members of the Oireachtas on the use of drones in Ireland.

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