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ÚSTAV JAZYKŮ

DRONES (UAVS) USED IN THE COMMERCIAL SECTOR

DRONY/ BEZPILOTNÍ LETOUNY POUŽÍVANÉ V KOMERČNÍ SFÉŘE

BACHELOR'S THESIS

BAKALÁŘSKÁ PRÁCE

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Make an overview of different types of drones (Unmanned Aerial Vehicles). Describe the technology and the specific areas in which they are used. Focus especially on the description of drones used in the commercial sector (e.g. in journalism; art - film industry and photography; advertising, etc.) .

RECOMMENDED LITERATURE:

Austin, R. (2010). Unmanned Aircraft Systems: UAVs Design, Development and Deployment. Chichester: John Wiley & Sons, Ltd.

Chamberlain, P. (2017). Drones and Journalism: How the Media Is Making Use of Unmanned Aerial Vehicles. New York: Routledge

Juniper, A. (2018). The Complete Guide to Drones. Extended 2nd Edition. London: Octopus Publishing Group

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Abstract

The goal of this bachelor's thesis is to provide a short overview of drone types in mainstream use along with several drone types in the prototype stage of development. The thesis then continues by listing drone uses in four major sectors which include the agricultural sector, which concerns drone use in farming and animal handling. The second sector is industrial, where drones are described to be used as monitoring devices and the work goes into detail on how drones can be used in the transport industry. The third sector is scientific and concerns drone uses in geology, forestry, archaeology, biology, and meteorology. The last sector to be analyzed is the entertainment sector where drone use in entertainment and personal use is described. The thesis also lists some of the other specific uses of drones, such as urban planning and disaster response. The last topic discussed by the thesis are the various issues associated with the use of drones in the commercial sphere. Namely, these are privacy concerns, technical limitations, and cases of airspace incursions due to insufficient government regulation.

Keywords

Drones, UAVs, Unmanned Aerial Systems, Commercial drones, Monitoring, Transport

Abstrakt

Cílem této bakalářské práce je poskytnout krátký přehled typů dronů v běžném provozu spolu s několika typy dronů ve fázi vývoje prototypu. Práce následně pokračuje výčtem použití dronů ve čtyřech hlavních odvětvích, mezi něž patří zemědělský sektor, který se týká používání dronů v zemědělství a manipulaci se zvířaty. Druhý sektor je průmyslový. Zde jsou drony popsány pro použití jako monitorovací zařízení a práce jde do podrobností o tom, jak mohou být drony použity v dopravním průmyslu. Třetí sektor je vědecký a týká se využití dronů v geologii, lesnictví, archeologii, biologii a meteorologii. Posledním sektorem, který je analyzován, je sektor zábavního průmyslu, v němž je popsáno použití dronů v oblasti zábavy a osobního použití. Práce také uvádí některé z dalších specifických použití dronů, jako je územní plánování a reakce na katastrofy. Posledním tématem, kterým se práce zabývá, jsou různé otázky spojené s používáním dronů v komerční sféře. Konkrétně se jedná o obavy o soukromí, technická omezení a případy vpádů do vzdušného prostoru v důsledku nedostatečné vládní regulace.

Klíčová slova

Drony, Bezpilotní letouny, Bezpilotní letecké systémy, Komerční drony, Monitorování, Doprava

Rozšířený Abstrakt

Úkolem této bakalářské práce je seznámit čitatele s možnými použitími bezpilotních letounů v komerční sféře. Úvod práce popisuje bezpilotní letouny rozdělené do tří kategorií.

Jako první je popsána kategorie bezpilotních letounů využívajících rotory. Dále je vytvětlena jejich klasifikace na jednorotorové a vícerotorové, přičemž u obou klasifikací je popsán jejich princip a technická specifikace.

Podobným způsobem jsou popsány i bezpilotní letouny využívající pevná křídla. Mezi tyto letouny jsou zahrnuty ty, které mějí motorový pohon, a ty, které využívají svá křídla k plachtění.

Poslední zmíněná klasifikace je všeobecná třída nestandardních dronů, jako jsou hybridní drony, ornitoptéry a paraglidingové drony.

Následně práce jmenuje jednotlivé využití bezpilotních letounů v zemědelství. Kromě jejich využití jako zařízení pro získání přehledu o stavu polí, práce opisuje možnost využití senzorů mimo viditelné spektrum pro analýzu zdraví jednotlivých rostlin a detekci chorob. Práce taktéž poukazuje na další specifické využití dronů. Jejich modularita je například využita k hnojení rostlin a krmení krevet.

Práce dál pokračuje popisem využití dronů v průmyslu, kde především splňují monitorovací roli. Mezi využitími monitorovacích dronů patří například bezpečná kontrola plynových potrubí nebo využití umělé inteligence na analýzu dat z kamer dronů pro automatickou diagnostiku elektrických vedení.

Dále je popsána vědecká oblast. Práce poukazuje na využití dronů v oblastech, jako je lesnictví. Zde jsou drony využitelné například pro statistické práce. Další oblast je geologie, kde je popsáno, jak jsou drony s pomocí fotogrametrie schopny detekovat sesuvy půdy. Poté se zmiňuje archeologie, kde je též využita fotogrametrie a složené fotografie na mapování. Využití senzorů na vertikální analýzu atmosféry se zase používá v meteorologii. Finálně se práce zabývá různými monitorovacími metodami v biologii.

Posledními komerčními oblastmi popsanými touto prací je zábavní průmysl a specifické využití, jako je územní plánování a záchranné operace. Jako součást zábavního průmyslu práce opisuje využití bezpilotných letounů pro soukromé využití, filmový průmysl a veřejné akce.

Poslední kapitola shrnuje jednotlivé problémy, na které narazili výrobci a uživatelé dronů. Práce zmiňuje například problémy se soukromím, nepovolený vstup do vzdušných prostorů a technické problémy. Kapitola následně uvádí výčet možných řešení na opsané problémy.

Bakalářská práce je zakončena závěrem, ve kterém se shrnuje a analyzuje zjištění v rámci výzkumu uskutečneného během psaní této práce.

ROMAN, Maroš. *Drony/bezpilotní letouny používané v komerční sféře*. Brno, 2022. Dostupné také z: https://www.vutbr.cz/studenti/zav-prace/detail/142536. Bakalářská práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků. Vedoucí práce Mgr. Šárka Rujbrová.

Prohlášení

Prohlašuji, že svou bakalářskou práci na téma *Drony/bezpilotní letouny používané v komerční sféře* jsem vypracoval samostatně pod vedením vedoucí bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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Contents

List of Images

Introduction

In recent decades, drones and unmanned aerial vehicles have become widespread thanks to advances in microcontrollers, batteries, and electrical engines. Furthermore, thanks to new GPS and radio control technologies, uses for these drones are expanding at a rapid pace.

Despite the fast growth of UAVs in the commercial sector, the area is still underdeveloped, especially in governmental regulations and certifications. Today, numerous companies invest heavily into the research of drones to replace expensive manned flight applications or to enable unprecedented monitoring capabilities in hard-to-access areas.

This Bachelor's thesis will focus on listing, categorizing, and explaining the various types of drones and the areas in which they are used to help direct potential manufacturers and customers in the commercial sector.

This thesis consists of four chapters. The first chapter focuses on classifying each drone type. For every drone type listed, technical specifications are explained and various capabilities are highlighted.

The second chapter focuses on the various uses of drones and UAVs in the commercial sector. It is divided into four large areas of commercial use, which are then further divided into smaller specializations within that area.

The listed areas are Agricultural sector, which is concerned with crop care and monitoring, Industrial sector, which focuses on plant monitoring and transportation, Scientific sector, which includes meteorological applications, geodetic and geologic applications, and several other areas of interest such as archeology and biology. Lastly, it details the Entertainment sector, which lists uses for personal entertainment and commercial entertainment applications. For each specialization, examples of use are specified. Additionally, some specific applications of drones are highlighted at the end of the chapter.

The third chapter describes the various issues that appeared as a result of large-scale drone use in commercial applications. These include issues with airspace incursions, especially by drone operators of entertainment-oriented UAVs, the issue of public danger associated with UAVs, and the ethics and privacy concerns surrounding drone flight.

The fourth chapter concludes the work and summarizes the information written in the thesis. Suggestions for future research on the topic are offered as well.

1. UAV Classification

Over the decades of development, many types of unmanned aerial vehicles have been developed. As will be explained later in the chapter, these types have been designed with a specific purpose in mind. It must be noted that none of the designs is superior to all others.

Bladed UAVs, which include helicopters, bicopters, and drones with more than two rotors have proven to be versatile thanks to being able to move in any axis of the three-dimensional space.

Winged UAVs have shown that they are great at achieving high speeds and conserving fuel thanks to their wings, which generate lift. Winged UAVs are also more reliable thanks to their close relation to airplanes, which have been developed for over a century.

Other UAVs are a blanket term for any UAVs that do not use traditional wings or rotors for propulsion. In addition, among these are UAVs that lack propulsion entirely.

1.1. Bladed UAVs

The most prolific of all unmanned aerial vehicles is perhaps the bladed variety. These are usually synonymous with the word "drone" in common language use. However, they can be divided into several classes based on the position and amount, of rotors attached.

The single-rotor UAVs are the first notable class. UAVs with a single rotor usually come in the form of a drone helicopter with the main rotor which handles altitude, speed, pitch and roll, and a smaller tail rotor, which controls the heading and counteracts the angular force of the main rotor. It is, however, possible to design a counterrotating setup, where the tail rotor is not necessary, but two main rotors are required at the same location.

The following class consists of multi-rotor UAVs, which, as mentioned at the beginning of the chapter, include any UAV that has two or more rotors. However, it is important to note that while they are classified in the same group, each has significantly different behaviour and uses.

1.1.1. Single-Rotor UAVs

Single-rotor UAVs follow the design principle of helicopters. Consequently, these machines consist of very similar components. The first, and most important, is the main rotor of the drone. The blades of the rotor are made in the same way as airplane wings, therefore, when the blades reach any amount of speed, they generate a certain amount of lift. By changing the number of rotations per minute and the angle of the blade in relation to oncoming wind, the drone can control its position and speed (Brain & Harris, 2000, p. 3).

This change happens in two ways. When the drone needs to roll to the sides or pitch backward or forward, it uses cyclic controls, pitching the rotor disk in the direction it desires to travel in (Federal Aviation Administration, 2019, p. 3-3). This results in the drone to pitching and gaining thrust in the desired direction.

To change altitude, the drone uses collective controls. These controls modify the pitch of all blades of the rotor, which changes their lift force. This allows for vertical movement. Additionally, this movement can be modified using thrust controls, which alter the RPM of the rotor and increases or decreases thrust.

The last of the controlling elements of the single-rotor drone is the tail rotor. It controls the direction of the nose of the drone. Thanks to the amount of directional and vertical control, single-rotor UAVs have almost the same flight capabilities as multi-rotor UAVs.

According to Chapman (2016, paras. 12-13), the main advantage single-rotor UAVs have over multi-rotor UAVs is the efficiency of using a single large rotor as opposed to several smaller ones. A larger rotor needs fewer rotations per minute to generate the same amount of lift and it is possible to use a fuel-based engine to increase the operational time of the drone.

With a larger rotor comes greater lift capability, allowing the single-rotor drone to be fitted with large payloads such as a high-resolution thermal camera. The downsides mentioned by Chapman (2016, para. 14) are the complexity, cost, vibration, and the danger of the spinning blades.

Unlike simple multi-rotor drones or fixed-wing UAVs, single-rotor UAVs are much more mechanically complex and require maintenance and, in certain cases, a skilled pilot or autopilot.

1.1.2. Multi-Rotor UAVs

Multi-rotor UAVs have become popularized in recent decades thanks to advancements in electric motors and control software. This is because multi-rotor UAVs depend on differential thrust to achieve movement in each direction.

The pitch or roll of the drone is changed by lowering the thrust of the motors by a specific value in the desired direction. As an example, if a quadcopter desires to pitch down, the two front motors decrease their thrust by 50%. This causes the back motors to overpower them and raise the back of the quadcopter, pitching it down.

Thanks to having multiple independent motors where each has fully controllable thrust with instantaneous reaction, multi-rotor UAVs have significant control of their position in three-dimensional space unmatched by most other aircraft. Multi-rotor UAVs consist of several configurations, however, due to efficiency, UAVs with more rotors than octo-copters are rarely used.

When compared to single-rotor drones, their flight time is greatly reduced. This is due to the size of the rotor blades. As mentioned in section 1.1.1, smaller rotors require greater RPM than the larger variety. The electric motors which need to spin the blades to these high values, lose a lot of their efficiency in friction and various other mechanical losses. The aerodynamic properties of a fast-spinning small rotor are also different, further changing the efficiency of quadcopters.

In summary, this means that multi-rotor drones such as quadcopters and octocopters suffer from short flight times and long recharge times, making them unviable for long-duration monitoring assignments. Due to the short flight times and relatively low power of the rotor blades, large payloads are also unviable for multi-rotor drones (Chapman 2016, para. 3). There exists a number of long-endurance configurations of multi-rotor drones, which usually have larger rotor blades, increasing their flight time.

The most popular by a wide margin in both the personal entertainment sector and commercial sector is the quad-copter configuration. This configuration offers the most amount of control and stability when compared to the efficiency and flight time. Thanks to the unmatched stability, while hovering over a single spot, a large amount of multi-rotor drones are used for personal photographing purposes.

1.2. Winged UAVs

Winged UAVs, or Fixed-Wing unmanned aircraft, are a group of unmanned aircraft using "a wing like a normal aeroplane to provide the lift rather than vertical lift rotors" (Chapman, 2016, para. 5). Due to this, as opposed to the first two drone types, fixed-wing drones are limited in their movement capabilities, changing their uses.

Fixed-wing drones are incapable of hovering over a single location; however, this can be mitigated somewhat with a circling motion. This type of aircraft often requires a landing strip for landing and take-off. Depending on the size, the material of the landing strip may need to be hard, such as asphalt or concrete runway. This limited landing capability results in limited use for personal applications.

"Fixed-wing UAVs fly by utilizing the lift generated by the aircraft's forward motion and the shape of its wings. Fixed-wing UAVs can be self-propelled, pure gliders (vehicles whose free flight does not rely on a method of propulsion) or a mixture of the two" (Unmanned Systems Technology, n.d., para. 1). Unmanned glider aircraft have no propulsion on their own. As such, to gain the altitude necessary to complete the desired task, these aircraft, according to UST, must either be towed by a self-propelled aircraft, or launched by a winch. In certain applications, pneumatic catapult structures similar to a medieval ballista might be used to launch the drone, although this technique is mostly used for small gliders or self-propelled aircraft (see Fig. 1 and video by UKR in Appendix 1).

Figure 1. Pneumatic catapult for UAVs Reprinted from https://www.aeroexpo.online/prod/uav-factory-ltd-europe/product-174156-61637.html.

Once in flight, thanks to the specific wing airfoil shape where airfoil is the shape of the cross-section of the wing's side, the aircraft gains lift, depending on the speed of the oncoming air. Therefore, higher speeds mean higher lift, allowing for smaller wings on faster aircraft.

Conversely, larger wings generate enough lift even at low speeds. This can be seen when comparing glider aircraft to self-propelled aircraft, where gliders have a much larger wingspan, often more than twice the size of self-propelled aircraft (see Appendix 2). This gives gliders a large gliding ratio. "Glide ratio is the number of feet a glider travels horizontally in still air for every foot of altitude lost. If a glider has a 50:1 glide ratio, then it travels 50 feet for every foot of altitude lost" (Federal Aviation Administration, 2013, p. 3-8).

To summarize the flight characteristics of fixed-wing aircraft: instead of requiring engine power to keep in flight, wings are used to keep the aircraft flying, while the engine is used to gain speed or altitude. To guide its flight, the aircraft has control over its pitch, yaw, and roll. Pitch is controlled by its elevator, yaw is controlled by the rudder, and roll is managed by the ailerons. Thanks to the efficiency of this propulsion method, fixed-wing UAVs have much higher flight endurance. Furthermore, According to Chapman (2016, pt. Fixed-wing, para. 2), it is possible to use gas engines as the engine power source, giving the UAVs capability to stay in flight for more than 16 hours.

In addition to the downside of requiring a runway, the other downsides include a higher cost and the learning curve of piloting this type of UAV. Chapman (2016, pt. Fixed-wing, para. 8) notes that, unlike multi-rotor aircraft, fixed-wing aircraft need to be controlled from the moment they are in the air. Fixed-wing drones are often faster than other types, further increasing the difficulty of controlling them.

1.3. Other UAVs

Up to this section, standard drone types have been introduced. These were usable for most general applications. However, as with most technologies, special tasks require specialized UAV designs. Among the specialized designs are also various prototypes, intended to bring new ideas to the market.

The first example of such prototypes are hybrid-wing UAVs. Aerocorner (n.d., pt. Fixed-Wing Hybrid Drones) mentions that these drones are based on aircraft designs from the 1950s to the 1960s. However, the technology was considered too difficult to be usable in UAV form. As mentioned, this drone type is still in experimental phases, and less commercially available, compared to the standard drone types.

Hybrid-wing aircraft are capable of both hovering motion and winged flight. This is achieved by articulated wings, capable of changing their angle to be either horizontal or vertical in relation to the direction of flight. The rotor blades provide enough lift to enable vertical flight, while in a horizontal configuration, they can use much less power, enabling long-endurance flight. In theory, this combines the benefits of both fixed-wing UAVs and multi-rotor UAVs.

The obvious drawback in the case of hybrid-wing UAVs is both mechanical and piloting complexity. The recent creation of these hybrid-wing unmanned aircraft can be attributed to advancements in autopilot technology, allowing the piloting operator to focus on guiding the aircraft, while the autopilot handles the stability of the aircraft (Chapman 2016, para. 18).

Another example of an experimental UAV design is the UAV paraglider, also called a Powered Parafoil Unmanned Aerial Vehicle (PPUAV), developed by several independent creators. Examples include paragliding drones for personal entertainment and larger-scale prototypes intended for commercial and military purposes.

Paragliding UAVs use a parachute wing called a parafoil, made from a flexible material. The parafoil is hollow and has internal supports. Once enough airspeed is gained, air fills the hollow parachute wing, which forms a designated shape and chord. Further air is repelled from the wing, causing the parachute to act as a solid wing structure. Thanks to air forming most of the wing structure, the wing of the paraglider UAV is considerably lighter than a normal wing on a fixed-wing UAV.

The parafoil holds a frame with the payload of the drone, as well as the electric motor which provides thrust. The paraglider UAV is capable of controlling its pitch with its engine and its roll and yaw by using steering cords. The advantages of the design are long flight times (upwards of three to six hours), the capability of lifting heavier payloads, low costs for production, and simplicity of operation (Mil. Press, 2017, paras. 3-6). Due to the experimental nature of these UAVs, downsides specific to this UAV are not well documented. However, it is safe to assume that PPUAVs suffer from similar downsides as fixed-wing UAVs, namely a landing strip requirement and incapability of hovering.

The last specific type of non-standard UAVs mentioned in this thesis is ornithopters (see Fig. 2). By definition, “An ornithopter is a manned aircraft or an unmanned flying machine in which the driving airfoils have a flapping, reciprocating, or oscillating motion, instead of the rotary motion used in airplanes and helicopters” (Chronister, n.d., para. 1). This means, in practice, ornithopter UAVs gain lift by mimicking the motions of flying insects or birds. However, due to the complex motions of living creatures, it has been difficult to replicate this motion while retaining stability and the ability to guide the UAV to the designated location.

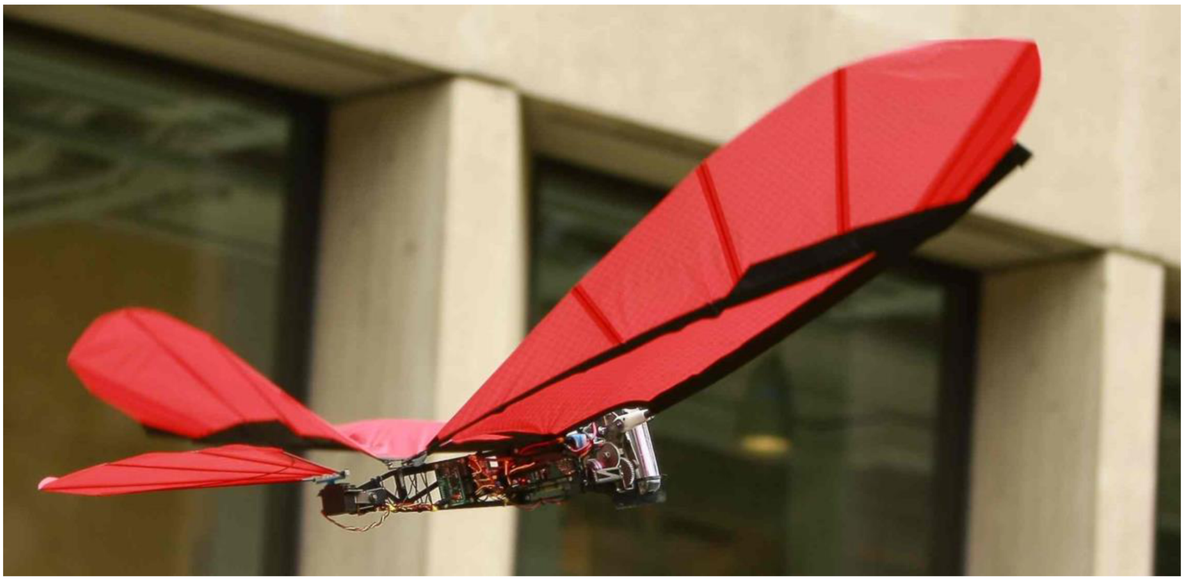

Figure 2. Four-wing Ornithopter by M.I.T. Reprinted from https://sites.google.com/site/bath139409680/

2. Commercial Uses

As with many other vehicles in use across the world, aircraft have wide use in most commercial sectors. During the last century, aircraft were considered difficult to control and required skilled, and, more importantly, expensive, pilots.

Thanks to the technological developments and diverse range of unmanned aerial vehicles developed in recent decades, corporations can employ aircraft, which are much cheaper to use and produce. Furthermore, thanks to their aerial nature, UAVs are also used to fill new roles previously infeasible, such as aerial reconnaissance and monitoring.

2.1. Agricultural Sector

Despite being considered one of the oldest commercial sectors, modern agriculture is characterized by large advances in crop care technology. Among these advances, unmanned systems play a large role. Because of the large area associated with farming, UAVs are a tool, which fits well into the intended role.

With good speeds and a "bird's eye view" of the crops, aerial drones can quickly detect crop damage. It can also offer perspectives for human operators, which gives them a significantly better overview of the crop state compared to the view from the ground. As per Milics (2019, p. 93), in the early 21st century, an overview of a field was obtainable via satellite images. These, however, had bad spatial resolution. Higher resolution images were taken by balloons and planes. Unfortunately, they were too costly for purely agricultural use. Thanks to UAV technology, field monitoring became much more accessible to farmers and agricultural advisors.

2.1.1. Monitoring

Monitoring of crops is considered among the most important aspects of farming work. This is because most crop problems are difficult to identify without extensive research of the crops, while once identified, the solution is often simple, using currently available tools.

Therefore, the primary function of most UAVs in agriculture is crop monitoring. Due to this, as said by Milics (2019, pp. 94-95), various types of sensors are required to be mounted on the drones. These include visible light sensors, near-infrared sensors, infrared sensors, and multispectral and hyperspectral sensors. Each of these sensor types fulfills a different role and, except for multispectral and hyperspectral sensors, are not replaceable by the others.

The first type of sensors used are visible light sensors. These capture the red, green, and blue channels (wavelengths) of visible light. When these are combined, the operator received an image usual for the human eye. These sensors or cameras are required to have low distortion and high-quality optics. The technique of mosaicking might be further used to provide an overview of a larger area.

The following listed are the near-infrared sensors (NIR sensors), which collect information in the 720 to 1000 nm and 680 to 730 nm wavelength ranges, which provide valuable information about the vegetation, such as vegetation stress and chlorophyll content.

The last sensor is the infrared sensor (IR sensor). This sensor collects information in the infrared wavelengths of light, therefore providing temperature readings. These are useful for both acquiring information about vegetation, as well as animal and water management.

As a result, the data gathered using the various types of sensors can be used for several applications within the agricultural practice. Among the practices are farm overview, inland water mapping, vegetation status mapping, wildlife damage, and weed mapping, among others (Milics, 2019, pp. 94-95).

2.1.2. Crop Care

While the main use of drones in agriculture is crop monitoring, recent developments in drone technology have promoted new uses of UAVs in agriculture, which replace physical work, instead of helping with analysis.

The first such use is crop protection. According to AgroNews (2021, para. 3), as of 2020, crop protection UAVs have become a standardized farming tool in some Chinese regions, where in some regions up to 90% of the rice fields have been served by drones.

Thanks to the higher payload capacities of modern drones, spraying mechanisms can be fitted onto the drones, which in turn serve the crops with a significant speed compared to traditional spraying methods, such as tractor trailers.

Furthermore, thanks to the modular nature of UAV payloads, in addition to crop protection, drones have seen use in seeding and fertilizing crops. The use of drones has also included fish and shrimp pond feed spraying and grassland seeding (AgroNews, 2021, para. 4).

2.2. Industrial Sector

Similar to agricultural applications, the industrial sector also benefits from the speed and range of UAVs. Most industries cover a large area, especially industries which process fluid and require long pipelines.

Industries with long electrical lines, such as power plants have similar requirements. As stated by Airobotics (n.d., para. 2), automated UAVs are usable in industrial facilities for security, surveillance, infrastructure inspections, and even emergency response. UAVs have several uses in mining operations, seaports, warehouses, and oil and gas facilities.

Other notable uses include tasks dangerous to humans, such as methane sensing. While most of these applications focus on monitoring, new advances allow for physical intervention as well.

2.2.1. Monitoring

As mentioned above, the main use of UAVs in the industrial sector, similarly to the agricultural sector, is monitoring. This particular use is especially important in industries such as the oil industry, where oil pipes can cover a large area and it is time-consuming to inspect them in their entire length.

Another example of industries well suited for drone use is the mining industry, especially large above-ground mining operations, which require the good overall view of the state of the mined location.

For the second example, drones can be used in particular for detecting landslide-prone locations or loose stone. According to Wingtra (n.d. para. 4), drones can be fitted with an RGB camera to survey a mining location from different vantage points. These images can then be processed using a process called photogrammetry, where each photo will have its coordinates and create a 3D map of the location. Specialized industry software may also be used to generate data, such as elevation data, slopes, and road boundaries.

For the oil industry, according to Johnsen et.al. (2020, p.4), drones might be used for photography and recording of components for both site inspection and overview, but also training. UAVs might also be fitted with gas sensors to detect dangerous emissions or dangerous levels of temperature. Drones may also be used for transporting critical cargo in a short time window. According to Airobotics (n.d.), drones may be also fully automated, removing the need for skilled drone operators to provide routine inspections and real-time data on pre-programmed routes.

Using UAVs to monitor power lines has also been considered a viable area of interest because high-voltage powerline inspections can be dangerous to human operators, especially if faults are not detected early enough. Jenssen, R., & Roverso, D. (2019, pp. 12-13,19-21) present a monitoring solution using UAVs to inspect power lines and analyze their output using machine learning to detect faults, such as missing top caps and rot damage. Jenssen, R., & Roverso, D. further propose that this use of UAVs together with machine learning techniques provides a way to create self-diagnosing smart grids.

Figure 3. Output of machine-learning algorithm on top of UAV visual footage. Reprinted from Jenssen, R., & Roverso, D. (2019, p. 19)

Combinations, such as the aforementioned machine learning algorithm used on drone output data, which can either be visual or on other spectra, show specifically the usefulness of UAVs in monitoring in any sector, including but not limited to industrial applications.

2.2.2. Transport

Despite being associated with small sizes and low payload volumes, UAVs are not limited in size, except for regulations. This means that UAVs can range from personal use drones up to and over aircraft, reaching the size of a commercial jet airliner. The shipping industry has noted this, and independent research and development is being carried out to explore the feasibility of UAV usage in high volume cargo shipping, replacing expensive plane transport.

According to Aleksey Matyushev in the CNBC (2019) report "The future of shipping looks very much unmanned". This is because UAVs offer faster shipment, with less manpower necessary, which can ease the high load of land shipping using trucks, while also providing a faster option compared to sea shipment. According to CNBC (2019), in 2018 the global drone logistics and transportation market size accounted for 24 million dollars and is expected to grow to 1.6 billion dollars in 2027.

In addition to offering a method of high-volume shipping, with the growing demand for fast shipment to end customers, smaller drones are also required, such as Prime Air, and low payload hybrid-wing drones proposed by Amazon. The latter is capable of traveling several kilometers from a local warehouse directly to the household of the customer, providing fast shipment with low transport costs and minimal human involvement, lowering the amount of road traffic, and, if an all-electric drive system is used, lowering the environmental impact of the shipment (CNBC, 2019). A similar use has been described by Moshref-Javadi, Lee & Winkenbach (2020, pp. 1-4), where a delivery truck contains one or more drones to speed up delivery times by serving multiple customers at once

A similar use in emergencies can be envisioned, where an example could be the requirement for a non-local anti-venom treatment. CNBC (2019) further explains that air freight in the US as of 2016 only accounted for 5 million tons of freight, as opposed to 11.6 billion by truck and 1.8 billion by train. With aerial drone freight transports, a larger amount of freight could be transported notably faster and from more remote locations. The usage of UAVs in the transport industry could also solve a pilot bottleneck problem that some transport companies are facing, for the reason that a single operator could maintain several long-haul flights.

An additional advantage of UAV freight transport aircraft is their optimization for cargo transport. While current aircraft are designed for passenger transport first and refurbished for cargo later, cargo UAVs can be designed with freight transport in mind, such as modular cargo bays or aspect ratios of interior cargo space to fit standardized containers (CNBC, 2019).

The main problems with using unmanned cargo aircraft are their capacity, global air traffic regulations, and the requirements for a specialized workforce of drone operators. The volume issues stem from two areas. The first is that it is simply much harder to haul a large amount of cargo by air, as opposed to by ship for example, since aircraft must stay in the air and safely maneuver for the whole journey, and wings provide much less lift compared to the displacement of water for ships.

The second issue mainly occurs for smaller drones, on the report of CNBC (2019), current battery technology is heavy and takes up a serious amount of the payload capacity of the drone. This issue can be mitigated by using hybrid power systems, where electric power is used only for certain maneuvers, such as taking off and then using fuel for level flight.

The second issue is with the workforce necessary to use drones for freight transport. These include mechanical engineers, drone flight operators, who fly the drones themselves, trained dispatchers, and even own traffic control officers if the company decides to build their own air infrastructure for their drones.

2.3. Scientific Sector

The scientific sector is particularly well suited for drone use, especially considering the amount of innovation typical for the sector. The amount of viable roles for UAVs in science is substantial, practically encompassing most non-theoretical fields. Of particular note are UAVs used in natural studies, especially forestry and biology where these drones are used for analyzing climate change tracking animal movement, or monitoring forest fires.

2.3.1. Forestry

As mentioned above, UAVs are used extensively in forestry. This is because forests are hard to traverse on vehicles, and surveying forests on foot takes time. In a video by UC Santa Cruz (2015), NASA Program Manager Chris Naftel explains that in past, only manned planes were used for many years to survey the forests and gather data. However, they recently added UAVs into the fleet, citing their ability to go to locations unreachable for manned aircraft as the main advantage, such as reaching different altitudes and ranges.

These UAVs, along with manned planes, enable monitoring of forest health, as well as provide fast information for firefighters during forest fires. According to Ted Hildum (2015), a staff scientist at UCSC, these UAVs are fitted with IR cameras that allow scientists to see the terrain under the smoke and find the exact location of the fires.

This information can be passed on to emergency services for a better response during firefighting operations.

In addition to helping with firefighting activities and large-scale surveying, small quad-copter drones are used by foresters to increase effectiveness, such as, instead of gathering information by hand, where the forester measures the height and diameter of a tree and runs calculations on this information in his office, drones give the ability to use image recognition to assign spatial points to trees and foresters can interpret that information without calculations (Alberta forests, 2019).

2.3.2. Geology

The ability to mount heavier payloads to aerial drones enabled geologists to use technologies, such as LiDAR scanning to detect landslides under vegetation or using high-resolution cameras to map debris flows (Giordan D. et al., 2019, p. 3455). Giordan D. et al. further states that LiDAR scanning was previously carried out using ground-based facilities or aerial and satellite platforms. However, recent surveys made by UAVs have been able to replicate the results thanks to the UAVs being fitted LiDAR scanners and hyperspectral sensors.

2.3.3. Archaeology

Among the more outlying uses of UAVs in the scientific field, is the UAV use in archeology, where they were used to record archeological works and topographical surveys of large areas (ex. 2km^2) in a short amount of time, with reliably repeatable flights (Campana, 2017, p. 285).

The inexpensive bird's eye view of UAV-mounted cameras allows for a good overview of the studied area. Hamilton, S., & Stephenson, J. (2016, p. 19) also described how UAVs could be used in conjunction with photogrammetry to create digital heightmaps of the studied area. If more precise heightmaps were required, there is also a possibility of using a LIDAR mounted on a UAV.

Hamilton, S., & Stephenson, J. have verified, that when using a UAV to take a large number of images with a significant enough overlap (up to 90%), the resulting compound image might be used as a site or feature map for archaeological study. An example of such an image can be found in Appendix 3.

2.3.4. Biology

Drone speed and the wide area of sight allows for their implementation in biology as well. In particular, UAVs are well suited for wildlife monitoring, where they can fill the role of observers, closely following wildlife movements to analyze their behaviour and bring valuable data to scientists.

A particular use is mentioned by Wolinsky (2017, p. 1284), who describes a team of whale researchers using drones for tracking whales, instead of using invasive darts or expensive aircraft. These drones not only track whales, but Wolinsky also states that the team hovers the drone above the whale during its blow, collecting biological material of the whale such as its DNA and microbiomes (see Fig. 4).

Figure 4. Drone collecting whale mucus Reprinted from Wolinsky (2017, p. 1285)

Similar to the forestry specialization, drones might be used to monitor the biophysical properties of vegetation, which means the density, volume, height, and width, among other properties. In this area, satellite and manned airplane imagery resolution are insufficient for certain applications, which has prompted the use of drone technology. These drones are used to frequently acquire imagery of vegetation at different developmental stages, thanks to their low altitude, the resolution of aerial images is satisfactory for the application (Nowak, 2018, p. 62).

According to Anderson, K., & Gaston, K. J. (2013, p. 138), in the field of ecology and wildlife research, researchers require data from particular spatial and temporal resolutions for a wide area of studies. They argue that compared to manned aircraft, similarly to other fields, the survey revisit periods are not limited to the requirements for manned aircraft and can be controlled by the drone user. Furthermore, low-altitude flights are possible to collect finer resolution data and observe targets of study in close proximity. One of the main advantages mentioned is the low operating cost of UAV operation.

2.3.5. Meteorology

An area of study well-suited for drone use is meteorology, thanks to the small profile, ease of use, and the ability to move freely on any axis. In particular, drones may be used by ground crews of airport meteorological services for a quick overview of atmospheric data directly above the airport, an activity that would be difficult to achieve using conventional aircraft due to its size and flight profile, as well as the necessary coordination with other air traffic. UAVs are often highly modular and can be outfitted to fulfill several roles in the area of meteorology such as vertical temperature, wind, and aerosol profiling

Chiliński, M. T., Markowicz, K. M., & Kubicki, M. (2018, pp. 3325-3327) document that the use of drones for vertical aerosol profiling using miniaturized aethalometers and particle counters returns values for black carbon concentrations, particle size, and distributions and absorption coefficients up to a 2km vertical range. Chiliński, M. T. et.al. further state that drones proved useful when they returned data on carbon gradients below the ground ceilometer at minimal detection altitude.

The use of drones for atmospheric study has also been endorsed by Abrahamsson, M., Norberg, O., & Noone, K. (2003, pp. 535-536). They describe that UAV flights enable direct contact between the scientists and drone operators, as well as enable shift-based work to prevent long-duration presence inside an aircraft.

As with all other applications of UAVs, the main advantage of their use in meteorology is their cost efficiency compared to manned flight. It is however important to note that drone use in meteorological applications is underdeveloped since commercial drones and miniaturized versions of sensors are still not considered reliable enough for regular use, either for long-duration atmospheric studies by fixed-wing UAVs, or airport atmospheric studies by rotor-based UAVs. This underdevelopment is additionally attributed to the susceptibility of drones to weather events, making weather profiling impossible during high winds, storms, or extreme temperatures.

2.4. Entertainment Sector

Arguably the most known use of UAVs in popular media is the entertainment sector, especially personal entertainment, and their use for photography and video production. The use of drones is especially notable in the production of online media platforms, such as YouTube, where according to Gang (n.d. para. 5), drones have been used to allow for a significantly different perspective on ordinary events, and have gathered a sizeable viewership.

This possibility has been especially enabled thanks to advanced autopilot capabilities of newer drone models, allowing drone functions, such as automatic hovering, automatic landings, and even preset path patterns. Thanks to these capabilities, drone users do not have to be capable drone operators and can use drones purely for aerial operations, such as photography, without the necessity of controlling them during flight.

2.4.1. Private Entertainment

While UAVs are mostly used with a specific goal, it should be noted that a significant portion of UAV use is in the model aircraft enthusiast area. In addition to this, UAVs might also be used for various competitive use, such as performance flights of custom-made UAVs and drone racing competitions.

The first area of private UAV use were model aircraft flights. These can be of any class, however, early model aircraft were mostly fixed-wing UAVs with some single-rotor designs. These types of drones are flown especially for the sole purpose of entertainment. These types of drones are typically built by the user according to a manual or custom-built. UAVs meant for private entertainment may also be targeted at the children demographic and used as toys.

A more goal-oriented use of UAVs for entertainment is their use in competitions. These can either take the form of model aircraft competitions, where custom built UAVs are presented and compete in various disciplines, such as endurance, visual appeal, and performance.

With the technological advances of multi-rotor drones, a new area of competition has also been introduced. Multi-rotor UAVs might be fitted with a real-time video feed linked directly to a headset. This allows the drone operator to have a first-person sight of the drone. These types of drones are called the FPV (First person view) drones and might be flown at rapid speeds in drone racing competitions. (Dean, G., 2021, paras. 4-5).

2.4.2. Film Industry

A similar use of drones is found in the film industry, where drones are being used for film production, especially in scenes that are hard to film using handheld or static cameras. An example of this is fast-moving shots, shots of pyrotechnics, or recordings, which require aerial footage but cannot be filmed with a helicopter or plane. As stated by Gang (n.d. para. 7), there have been instances of a movie being filmed entirely by autonomous pre-programmed drones.

2.4.3. Public Performances

Another area of entertainment that is well suited to UAVs is the use in large performances, such as concerts, sport ceremonies, and various celebrations. A recent example are the drones used in the opening ceremony of the 2020 Olympic Games in Tokyo (see fig. 5), where 1800 drones were following preprogrammed paths to create holographic images in the sky. Thanks to the precise nature of drones, and the very high maneuverability of

Figure 5. Drones in Tokyo 2020 Olympic Games ceremony Reprinted from https://marketresearchtelecast.com/how-many-thousands-of-drones-have-they-used-in-the-balloon-of-the-tokyo-2020-ceremony/111062/

quadcopters, drones can be used to form various shapes and perform routines similar to human dancers.

2.5 Specific Uses

While most uses of drones in commercial applications can be fit under the general term of a sector, it is important to highlight specific uses of drones by government-contracted or non-profit groups or organizations. These include medical applications and UAV use in disaster response scenarios. Additionally, drones might be used by local governments for urban planning and monitoring.

2.5.1. Disaster Response

Thanks to the ability to control drones from a large distance, as well as very short turn-around times, emergency shipments and deliveries of components, which are necessary to be delivered at very short notice, are possible. An example of this is the delivery of critical medical goods described by Yakushiji et.al. (2020 p. 3), who successfully proved transporting goods, such as an external defibrillator or a glucose meter by UAV is viable and reliable. A similar use in emergencies can be envisioned, where an example could be the requirement for a non-local anti-venom treatment (CNBC, 2019).

In addition to the transport of emergency goods, UAVs are also useful thanks to their advanced monitoring capabilities. This means that UAVs can be used for search and rescue operations, such as searching through wide areas for people that need rescue. This would effectively replace the helicopter as a search vehicle, allowing it to focus on rescue operations, saving fuel and man-hours.

Another example of drone use in disaster response scenarios is the use of drones for waste management and identification of dangerous goods. Leizer, K., & Károly, G. (2018, pp. 361-362) describe that in cases where visual identification is not feasible, drones might be used to rapidly identify rail carriages with RFID chips, quickly revealing their contents. Thanks to the rapid identification, rescue units would be able to prepare appropriate equipment for the specific danger. This would additionally allow rescue teams to formulate a strategy before their deployment (Leizer, K., & Károly, G., 2018, p. 362). However, it should be noted that these RFID identification systems are not yet present in most European carriages (Leizer, K., & Károly, G., 2018, p. 364).

2.5.2. Urban Planning

The high point of view enabled by drones is also greatly usable by local government institutions and civil engineering corporations. Among these uses is geodetics, a significant element of urban planning requiring a reliable overview. There have already been some experiments and applications of drones in the road and railway planning. Among these was an application of UAVs for mapping the condition and location of roads in Poland (Piech, I., Kwinta, A., & Krzyszycha, M., 2018, pp. 85-86, 90-91). This application of UAVs has shown their use in creating digital maps which contain important information and prevent mistakes in land surveying.

Another area of land surveying, already touched on by the uses of UAVs in geology, is landslide and erosion detection in relation to urban planning and construction. It has been shown that UAVs are useful for obtaining digital models by indirectly measuring elevation using high spatial resolution and accuracy (Sestras, P., Bilaşco, Ş., Roşca, S., Dudic, B., Hysa, A., & Spalević, V., 2021 pp.13-16). Comparing hand measurements and digital models created with the help of UAVs allows for the creation of highly accurate models of landslide movement and other geological factors at play in urban planning.

3. Issues

With an ever-increasing number of unmanned aircraft in the air, especially around populated areas, many issues connected to the handling of drones appeared. For the average personal drone user, this appeared in the form of government regulations on drone use, either by specifying allowed flight levels or mandating drone identification in the same manner as regular aircraft.

For larger corporations employing larger drones, more regulations were created, making certain drone use cases similarly limited to manned aircraft use. However, these regulations were moved in place due to the large hole in the airspace regulations regarding drones, such as privacy concerns, airspace incursion, ethical concerns, and the endangering of the public.

3.1. Airspace Incursions

One of the main examples of issues arising from the use of commercial drones are airspace incursions. These include not only drone use in controlled airspaces, such as areas close to airports, or areas above the Class G airspace (see Fig. 6), but also drone flights directly within airspace in the immediate vicinity of the runway or even restricted airspaces such as airspaces above military installations.

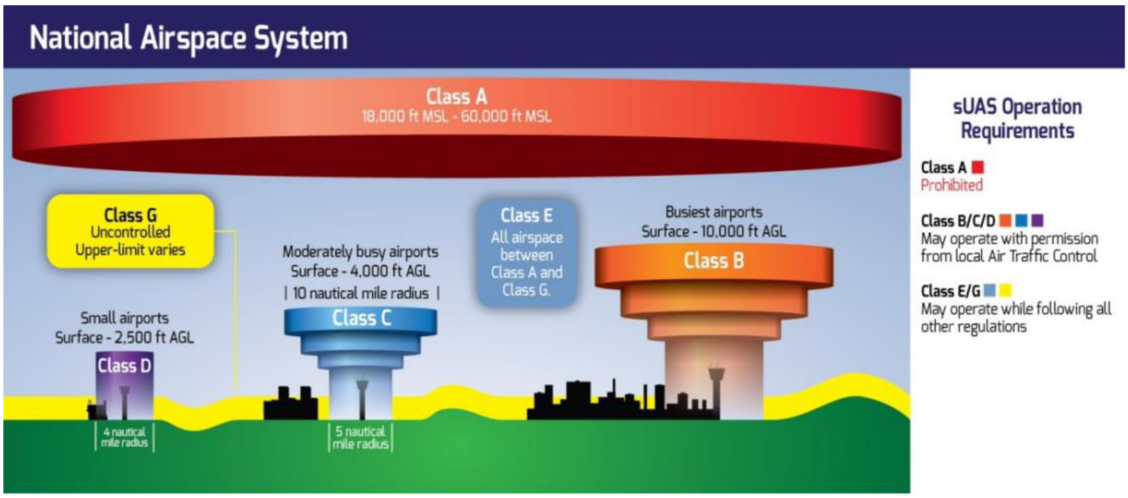

Figure 6. Airspace type description Reprinted from NPSTC (2017, March, p.14)

Drone flights within the aforementioned areas can cause damage to civilian and military aircraft and, in the worst scenarios even loss of life. Rao, B., Gopi, A. G., & Maione, R. (2016, p.86) state that the FAA reported over 900 incursions of controlled airspace by UAVs that were uncertified. Rao, B. et. al. also continue to mention that these incursions were frequently reported by airline and general aviation pilots that had these drones in their line of sight during flight, including cases where air traffic controllers had to divert aircraft.

3.2. Technical Limitations

While UAVs are cost-effective and easily deployable in hard-to-reach areas, they still have the same limits as manned aircraft. This, in most cases, means weather limitations, such as susceptibility to temperature changes and, especially, negative wind conditions and precipitation. Gao, M., Hugenholtz, C. H., Fox, T. A., Kucharczyk, M., Barchyn, T. E., & Nesbit, P. R. (2021 pp. 1-4) have verified that the global median flyability (i.e., the maximum possible time in the air) of general use drones is only 5.7 hours a day and only 2 hours per day if limited to daylight hours. However, Gao M. et. Al further state that the weather-resistant variety of drones is capable of spending up to 12.3 hours per day if limited to daylight and up to 20.4 hours per day if flown at night as well. It is stated that the time in air varies significantly, depending on the latitude, where latitudes closer to the equator have higher flight times compared to others.

3.3. Ethics of Drone Flight

The lack of physical presence of an onboard pilot raises several ethical concerns around UAV use. Perhaps the most mentioned case of ethical concerns would be privacy violation concerns.

As a particular example, there have been cases, where drones equipped with cameras were flown above private property, such as an enclosed garden, to spy on its inhabitants. Since in most countries there are no laws forbidding drone flight above private property, it is more complicated to solve this occurrence. Rao, B., Gopi, A. G., & Maione, R. (2016, pp. 86-88) say that a person's ”reasonable expectation of privacy” only applies to private property not visible from public areas. However, this expectation is meant for eye-level height.

With drones capable of flying high in the sky, it is possible to capture images and sound from a public area or a private area. On one side, this raises concerns of people who fear that their privacy can be violated without any repercussions, however, on the other side of the argument, if a law forbidding such activity is created, drone operators will have problems with regular drone use, since technically any camera recording generally pointed towards a residential area could be considered as a violation of privacy laws.

Another type of privacy violation occurring during drones' use are information leaks. According to_Rao, B., et. al. drones can be compromised by long-range hacking tools, which can be relatively cheap, to intercept communications between the drone and the operator. Rao, B., et. al. further explains that as of 2016, even the military couldn't mitigate this type of information leakage. They continue to say that this fact raises concerns over whether private companies, police forces, or consumers are safe from these kinds of attacks, where private data might fall into the wrong hands.

In terms of liability, Rao, B., et. al. mention that gathering sufficient data and evidence required for insurance companies is complex. These companies require the location of take-off and landing, the flight path, intent of the flight, and altitude among others.

Further, drones can record large amounts of data which can be transmitted directly to the operator without being stored. This means that it can be difficult to ascertain the true intention of the flight.

Furthermore, most countries lack the required regulations for liability. Since drones are modular, where there are several types with different flight characteristics (see Chapter 1.), the current regulations in place are considered insufficient.

In addition to the grey area that drones operate in, a topic commonly mentioned is the ethics of cargo and passenger UAVs. A common opinion among pilots is that while a pilot of a manned aircraft will do everything in their ability to avoid a crash, an operator of a drone aircraft might not output as much effort to save the aircraft. It is often argued that since modern aircraft depend mostly on autopilot software, pilots are becoming redundant.

On the other hand, pilots currently fill the role of decision-makers, deciding where to land in an emergency, and how to deal with passenger problems. They are also needed for split-second corrections to the course of the aircraft in the event of an emergency.

Modern automated drone software is not yet advanced enough to fill these tasks and having a drone operator fly the aircraft leaves it vulnerable to a large number of potential dangers. These include software malfunction, hacking attempts, signal loss, or insufficient visual feed. When taking into account the danger of information leakage or even hijacking of drone control, it is necessary that the technology of such UAVs would be advanced enough to have several fail-safes for its software and signal hardware and have high-grade encryption to prevent any tampering with its controls.

3.4. Issue Mitigation

Since the use of UAVs in large-scale commercial applications, including that of private entertainment, is such a new phenomenon, new regulations and certifications are drafted each year to mitigate new issues as they arise.

Among the issue mitigation methods is policy development for any commercial entity creating a UAV system. NPSTC (2017, pp.5-7) states that a UAV program should document all records of pilot training, maintenance, and certification of UAV systems, as well as all obtained data during flight. In addition, all mission specific information, such as incident reports, should be documented, including pre-approved pre-flight briefing checklists. Such documentation can help when dealing with incidents involving insurance and liability, providing sufficient information for a complete incident report and successful insurance claims.

Privacy concerns are difficult to mitigate due to the ambiguity of privacy rights. As mentioned before in chapter 3.3, a video recording of a residential district could technically be considered a breach of privacy of all residents present in their backyards at the time of the recording.

In addition to mitigating issues related to policies, airspace, and law, an important area that requires issue mitigation is the physical domain. This includes making UAVs more resistant to physical damage, developing new battery technologies, and making the drones weather resistant.

Conclusion

To conclude this paper, it must be noted how versatile unmanned aerial vehicles are. While aircraft suffer from lower load capacity compared to ground and sea vehicles, new technologies have provided low-weight tools for most applications. Among these, cameras of several spectra were shown to have a large number of uses. Visual cameras, LIDAR, photogrammetry, and photograph compositing might be used for heightmaps and terrain analysis.

Another great advantage for UAVs is the introduction of machine learning algorithms and artificial intelligence to commercial applications. When used in conjunction with video recording and photography from drones, visual learning might be used to analyze patterns. One example of this was the power line analysis application, which enables the creation of self-diagnosing smart grids.

It should be noted that most drone applications covered by this thesis were under the monitoring category. This is due to the unprecedented ease of use and inexpensiveness of drones when compared to manned aircraft. Several private companies previously were not able to gain high-resolution images taken from above, either defaulting to low-resolution satellite imagery, or expensive manned flights. Relative to this, drones have also been introduced into fields where images taken from the air were not previously utilized, most likely due to cost considerations. This allowed for unprecedented accuracy in some cases, such as geology and forestry, where complex formulae were replaced by air imagery analysis.

The second most populated category has proven to be transportation. Similar to manned aircraft, UAVs have proven to be versatile at rapidly transporting cargo, especially in emergencies, where UAV turnaround times are significantly lower than manned aircraft. UAVs have also been described as viable for transport because it doesn't require accommodation for human crews, which allows for airframe designs focused purely on cargo transportation.

However, it has also been shown by several applications mentioned in this thesis, that UAVs might be used in applications previously unconnected with aircraft. Due to the modularity of modern UAVs, various tools might be fitted, such as fertilizer sprayers or FPV antennae. As a consequence, it is impossible to consider that the uses of drones are limited to the ones mentioned in this thesis. Modern UAVs are being developed at a rapid pace enabling new uses each year.

On the other hand, the unregulated use of UAVs has also shown the shortcomings of government policies. Drones used widely across the private sector have caused privacy concerns, as well as danger to government institutions, such as military bases. In addition, drone traffic has been shown to interfere with manned aircraft traffic on a significant number of occasions, going as far as to endanger the lives of the passengers onboard of these aircraft.

Therefore, while the use of UAVs is unmistakably wide, it must be regulated similarly to other rapidly evolving technologies in the past.

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List of symbols quantities and abbreviations

UAV – Unmanned Aerial Vehicle

GPS – Global Positioning System

RPM – Rotations per minute

IR – Infra Red

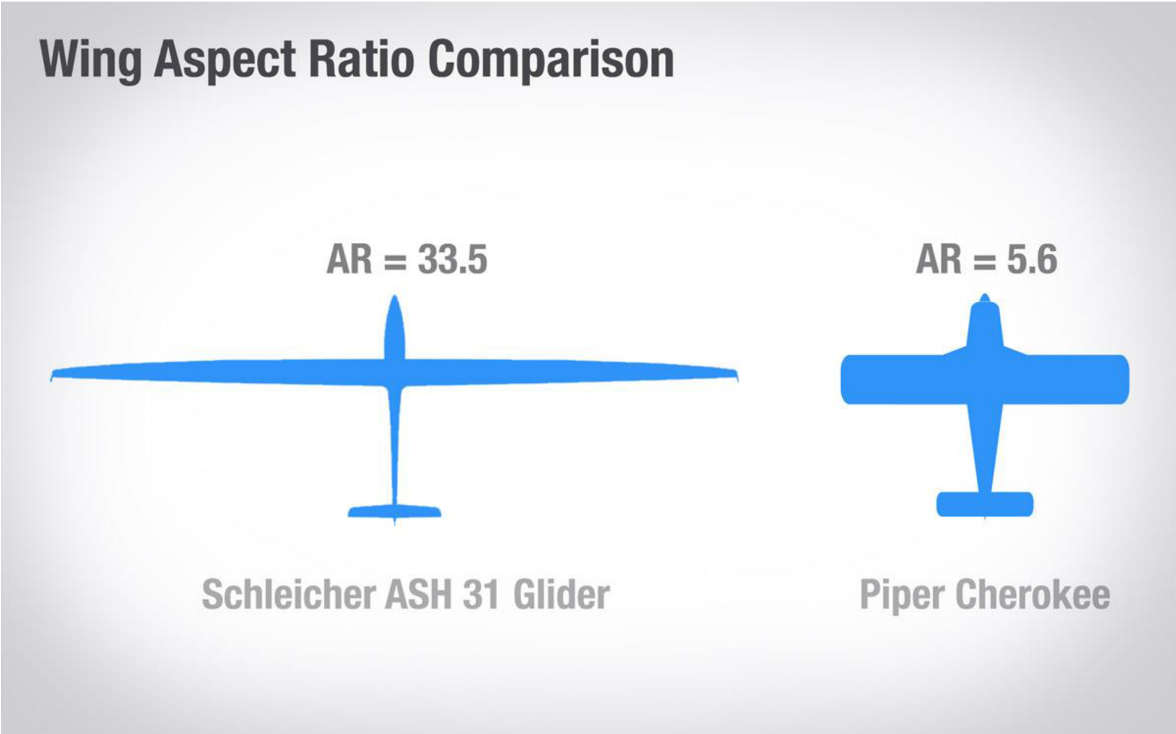
LiDAR - Light Detection and Ranging

RGB - Red Green Blue (Visible spectrum of light)

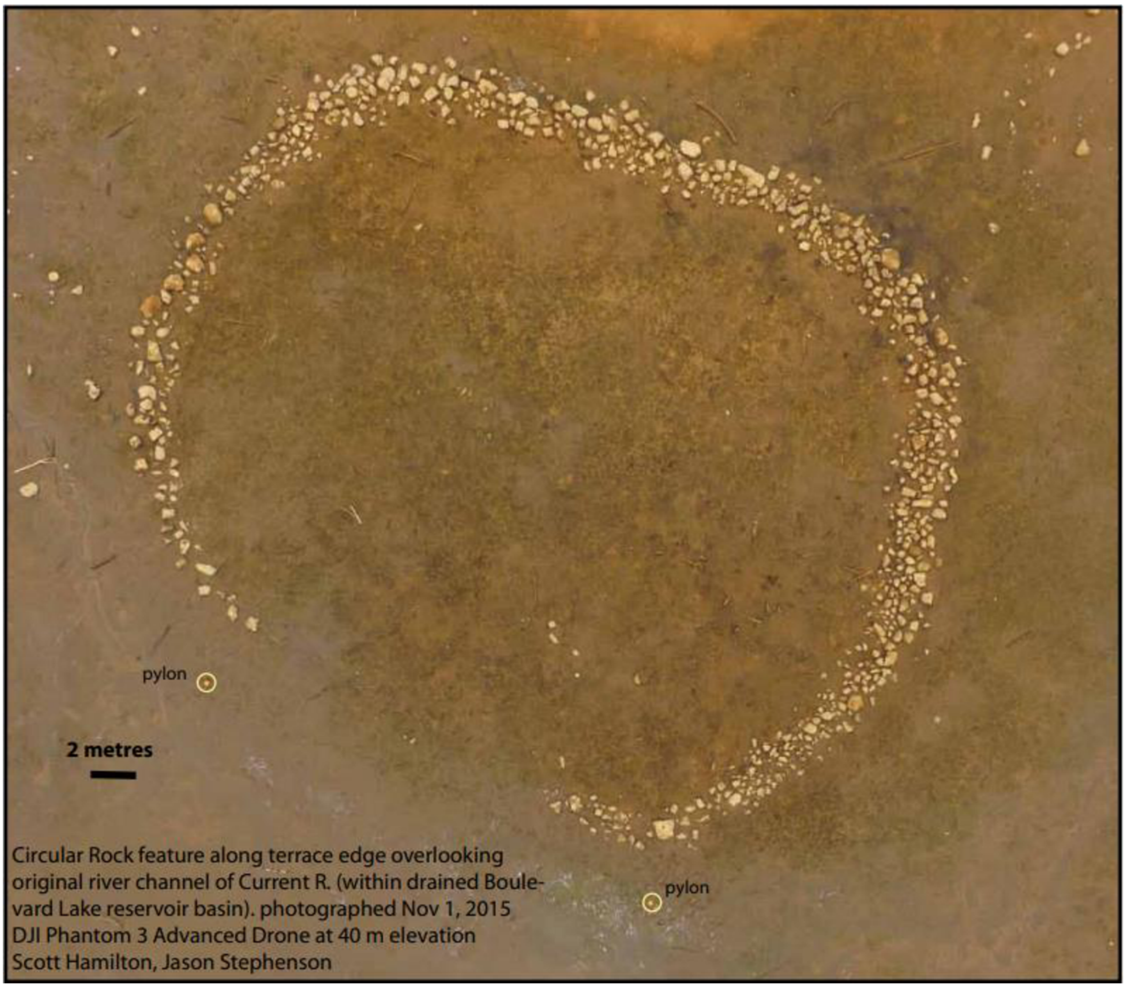
FPV - First person view

Appendix

Appendix 1. UAV catapult launch and parachute recovery
https://www.youtube.com/watch?v=wd9whgfbYic.



Appendix 2. Glider wing comparison Reprinted from https://www.boldmethod.com/blog/article/2015/02/your-guide-to-glider-flying/



Appendix 3. Example of archaeological site map created by splicing together images taken by an UAV Reprinted from Hamilton, S., & Stephenson, J. (2016)