Drone Remote Location Sensing

Galileo Information Centre for Mexico, Central America and the Caribbean

Implemented by:

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1. Introduction

The autonomous and semi-autonomous surveillance drone technology is about to revolution the surveillance (both security and nominal) over remote, elusive, or not easy to access sites. Both partially or fully automated drones (in case there is a minimal human intervention or only a planning activities and full autonomous flight) could directly integrated into existing security networks. They can be operated by security officers from their standard control interface (VMS/Hypervisor) like any other detection sensor. Today, thanks to both 4G and future 5G technologies, the autonomous UAV and the control center can be geographically dissociated around the globe. Remote monitoring by drone paves the way for new applications in security and safety.

Remote operations guarantee no need for on-site team while drones provide continuous aerial surveillance 24 hours a day, 7 days a week. The involved control teams can schedule remote patrols and follow live the drone's trajectory and video feedbacks on their remote interface. In the event of a security breach or safety issue (e.g. environmental), autonomous drones automatically take off to the alert point to remove doubts. The control teams can then take control of the camera remotely to investigate the issue and prepare for an eventual intervention.

This solution enables managers of sensitive/remote sites to pool their human, financial and material resources. Drones can be deployed on sites all over the nation (or the geographical area of interest) and be operated from a single control center (e.g. the GIC itself).

The use of remotely operated autonomous drones is suitable for many applications as for example the following ones:

- Monitoring of small or isolated sites:

  Some sites such as quarries, mines, farms, or wind farms usually have a limited remote monitoring system, without on-site security teams. Networks of detection sensors allow the detection of alerts but struggle to cover the entire perimeter, making the qualification of the threat very complex. False alarms are therefore numerous, not to mention the useless mobilization of intervention forces. Autonomous drones reinforce the capabilities of the remote surveillance system. They provide a 360-degree mobile vision without blind spots, enabling rapid detection and identification of the issue or the potential threat.

- Monitoring of temporary installations:

The remote surveillance by drone is also a relevant solution for temporary installations, such as construction sites, base camps, etc. Remotely operated drones make it possible to ensure the safety of these installations, without having to deploy a temporary guarding system or to install a complex and costly network of cameras.

- Monitoring of hazardous sites:

  The sites for production, storage or transport of hazardous materials have many safety and security needs. Human presence is often restricted and controlled by very strict security measures. Remote monitoring by drone makes it possible to ensure permanent surveillance of these sites (perimeter patrols, routine inspections, etc.) without jeopardizing the safety of teams dedicated to security or maintenance.

Before deploying a remotely operated UAV system, it is important to pay attention to several technological criteria:

- Internet connection: fiber or 4G/5G:

  The drone system connects to the Internet via a secure connection. The site must provide fiber access or allow the use of public or private 4G/5G mobile networks. This connection must guarantee sufficient debit to allow a smooth display of camera feedbacks and an acceptable response time to operator commands. When these conditions are combined with a high-quality data compression and encapsulation system, the latency level shall not exceed 500 milliseconds.

- Cybersecurity:

  Remote operation may expose sensitive site information, such as aerial images, on the Internet. A strict IT policy must be followed to ensure a high level of security. The communications must be encrypted to protect the data.

- Regulatory approval:

  Finally, authorizations for automated, BVLOS and remote-operated flights must be granted by Civil Aviation Authorities.

2. Drones: state of the art

In 2022, the global drone market is worth an estimated US$30.6 billion, and updated market model forecasts suggest a CAGR (Compound Annual Growth Rate) from about 8% to 15% (depending by who makes the estimation) until 2030. This figure encompasses both the commercial and the recreational drone markets. When analyzed separately, the commercial market is set to expand at a faster rate of 8.3% while the recreational market is likely to contract in many regions. However, the market analysis shows that the market in total (commercial + recreational) will be worth US$55.8 billion by the year 2030.

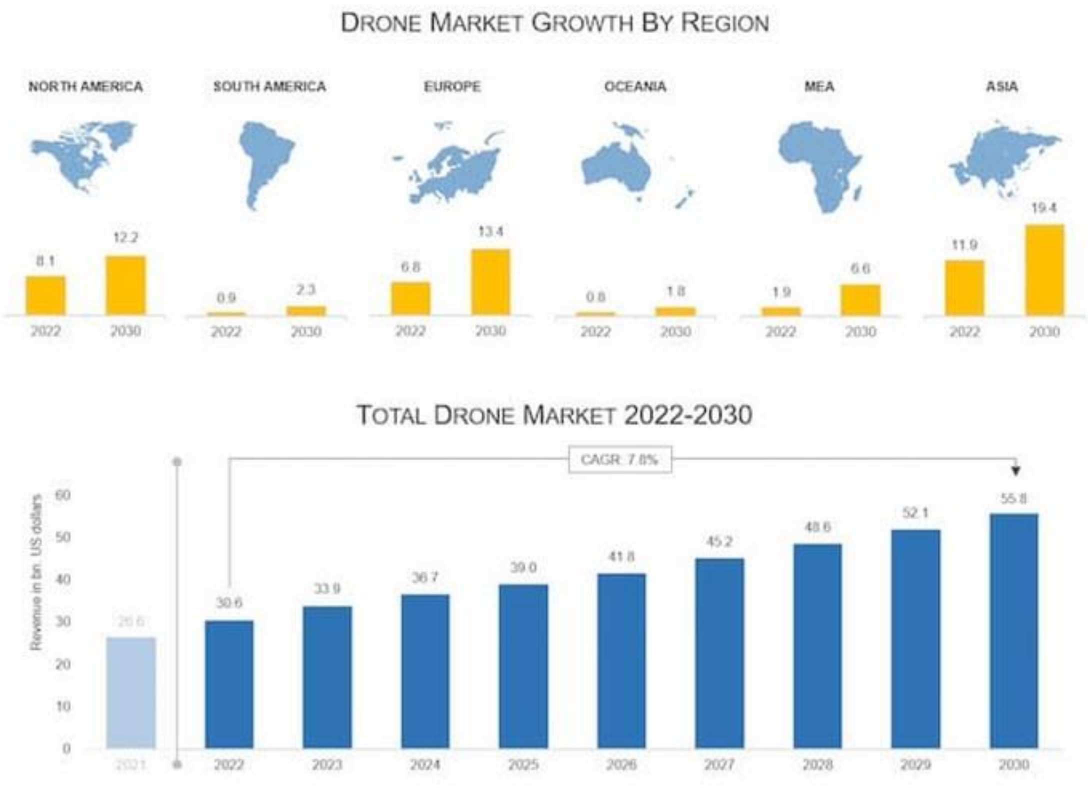

Figure 1: Total drone market forecast (source Drone Industry Inside 2022)

Technological advancements, in terms of payloads and electronics, are expected to augment the rapid growth of the market studied. The market studied is still in the early stages in several developing countries in terms of its mass adoption and usage. Various government and airspace regulations are currently challenging the growth of the market in several countries.

Drones are being adopted in various applications, including internet provision in remote places, aerial photography and video recording, survey and documenting wildlife, and public service missions. Several companies primarily offer small drones that are used in agricultural, aerial photography, and data collection applications. Home deliveries via drones have become a reality due to the efforts of logistics and retail companies such as Amazon and UPS toward rolling out the technology. As commercial drones can travel at up to 160 km/h and deliver goods under 2.3 kg, the delivery mechanism is expected to decrease delivery time and associated costs.

Enhanced investments toward drone technologies are also anticipated to foster long-term growth of the market. However, the growth of the drones' market can be hindered by technological constraints such as limited endurance, SWaP challenges, and the presence of non-uniform laws and regulations that can restrict the usage of such systems in the airspace of certain countries.

The application's list of drone technology is listed as follows:

- Construction
- Agriculture
- Energy
- Entertainment
- Law Enforcement
- Other

The proliferation of drones has revolutionized the operational processes in the construction industry. Drones are rapidly replacing the traditional land surveillance methods, as they offer a significant reduction in labour and time to capture the necessary data while eliminating the scope of human error. Drones are being increasingly utilized to perform the visual inspection of the high-risk areas of a construction site.

The efficiency of on-site communication and management is also bolstered by the ability to collect real-time data from drones. Drones also help engineers and surveyors inspect high-rise structures and visualize the project's progress through aerial shots. Additionally, they provide site managers with an overview of potential issues and facilitate key decision-making aspects to streamline the operations at a construction site.

The increasing demand has encouraged drone manufacturers to manufacture more drones, specifically for the construction industry.

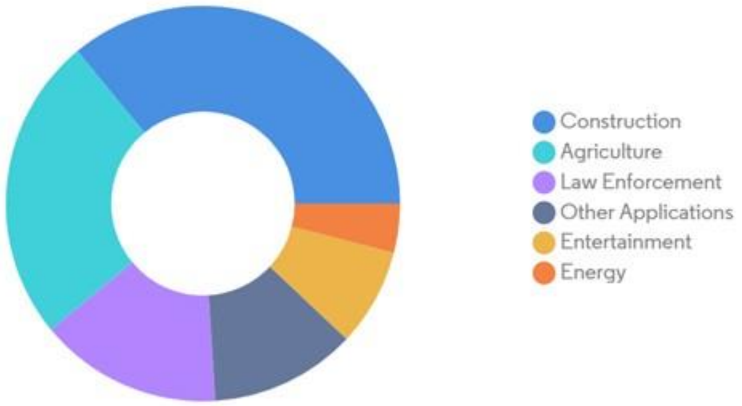

Figure 2: Drone market 2021 revenues by application (source Mordor Intelligence)

During the last six years China has become the global hub for drone manufacturing, since more than 70% of the global civilian drone market is provided by Chinese companies. The Chinese government is providing various subsidy schemes and other favourable domestic policies for drone purchases to promote the adoption of drones in various industrial sectors. Entertainment drones had dominated the Chinese drone market in the past. However, the increasing demand for drones for monitoring, inspection, surveying, and surveillance applications in the construction, agriculture, infrastructure, energy, telecommunications, mining, and insurance industries is propelling the growth of commercial drones in the country.

The Central America’s market is expecting a growth rate from medium to high during the 2022-27 timeframe according to various market analysts as the Mordor Intelligence (2022 report).

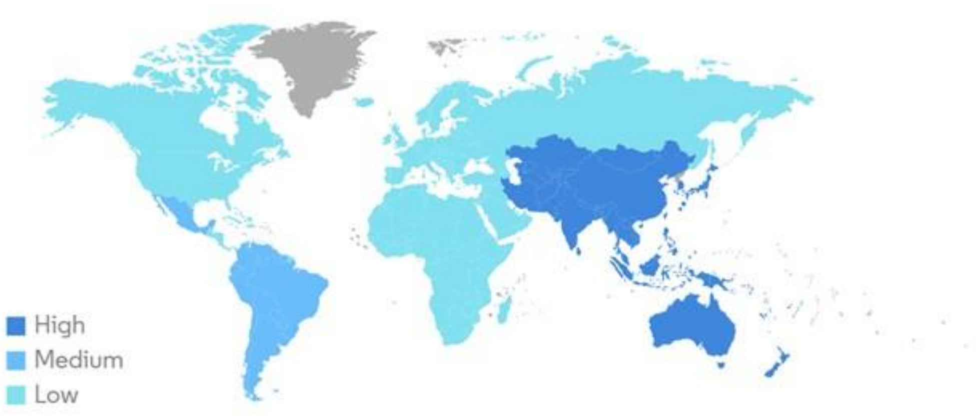

Figure 3: Drone market growth rate by Region 2022/27 (source Mordor Intelligence)

Some of the prominent players in the market are SZ DJI Technology Co. Ltd (DJI), The Boeing Company, Terra Drone Corporation, Intel Corporation, BirdsEyeView Aerobotics, Parrot Drones SAS, Yuneec, and Delair SAS. The market comprises a handful of established players, which enjoy a strong foothold in the market. SZ DJI Technology Co. Ltd (DJI) is one such company that controls a significant market share. However, there are many small companies and startups that entered the market in the past few years due to the high profitability in the market. Companies are competing to gain market shares and are developing advanced technology-integrated drone hardware and software solutions that reduce human effort in applications such as mining, construction, and aerial mapping.

Additionally, the entry of companies, like The Boeing Company, Alphabet, and Intel, into the commercial sector of drones is expected to make the market fragmented over the coming years. Since the payload, endurance, and flight range of a drone platform are the primary concerns of OEMs and operators alike, the emergence of alternative fuel-powered drones is expected to cause significant changes in the competitive scenario. Moreover, R&D efforts in terms of composite-based materials for the construction of critical components and parts of drones may increase the capabilities of the drone platforms and fuel their widespread adoption across different industries.

As follows a list of the most important worldwide drone manufacturers:

- BirdsEyeView Aerobotics
- Delair SAS
- Drone Delivery Canada
- DroneDeploy Inc.
- Guangdong Syma Model Aircraft Industrial Co. Ltd
- Intel Corporation
- Parrot Drones SAS
- Pix4D SA
- PrecisionHawk Inc.
- SZ DJI Technology Co. Ltd (DJI)

- Terra Drone Corporation
- The Boeing Company
- Yuneec

Recent Developments:

In December 2021, DJI introduced its latest agriculture drone in its crop protection series, the DJI AGRAS T20. The DJI AGRAS T20 can carry a maximum payload of 20kg and is equipped with eight nozzles and high-volume pumps that can spray at a rate of up to six l/min.

In November 2021, XAG Co. Ltd, a Chinese manufacturer of agricultural drones, launched its V40 and P40 Agricultural Drone globally. The XAG V40 and P40 are fully autonomous drones that can conduct mapping, spraying, and broadcasting on farms. The drones are built with a highly modular design that enhances their multi-functionality.

In August 2021, A2Z Drone Delivery, LLC announced the launch of its RDSX commercial delivery UAV named the A2Z Drone Delivery RDSX. The delivery drone was developed in collaboration with a leading global logistics provider to deliver dual payloads per flight, helping drone service providers streamline deliveries while mitigating consumer concerns with residential drone delivery.

3. Remote sensing survey

The current trend in drone's remote sensing capabilities could be resumed into three main type of sensor's technology, as follows ("UAV in the advent of the twenties: Where we stand and what is next" F. Nex, C. Armenakis, et al. - December 2021):

RGB Cameras

Multi and hyper-spectral sensors

LiDAR

3.1 RGB Cameras

Compared to the conventional airborne case, drones normally operate closer to the ground and have hard constraints given by the payload and the speed of the platform (particularly for fixed-wing aircrafts). The first drones inherited cameras adapted from terrestrial applications (i.e., compact cameras) while a new generation of dedicated sensors has been conceived over the last few years. Although 3D photogrammetric reconstruction should be possible with any kind of overlapping images, photogrammetric cameras typically follow special design rules to obtain high levels of performance and efficiency rules that are highly constrained by the weight and size limitations, making compromises inevitable.

3.1.1 RGB Cameras general design

The most limiting factors for any kind of sensor equipment on drones are maximum-take-off-mass (MTOM) and size. This is also the reason why drone cameras do not simply copy the concepts of commercial large format mapping cameras. The image frame is not a limitation as most of the current drone scenarios are much more restricted in mapping area size, and more compact cameras with smaller image formats have fewer negative impact on smaller projects. If a drone has a Maximum Take-Off Weight (MTOW) of around 25 kg, 150 MPix camera is currently the best that can be integrated onto the platform. For a more standard drone (with MTOW < 5 kg) the image formats range between 20 and 60 MPix, nowadays. In addition, as the drone operates closer to ground and aims at a Ground Sampling Distance (GSD) of only few centimeters, the cameras placed on fixed-wing aircraft need to have fast shutter to avoid motion blur due to the absence of forward-motion compensation.

3.1.2 RGB Cameras optics

All the (typical) drone cameras designed for mapping are built as single cone systems, which automatically excludes the use of multiple channels for separate color bands. Single frame cameras often use special color filter arrays to arrange RGB color filters on the photosensor pixel matrix, called the Bayer-filter. Such Bayer-like color filter arrangements need de-mosaicking which reduces the original spatial resolution. In the first years of drone -based mapping almost all cameras were standard “off the shelf” cameras. These cameras were not specifically designed for photogrammetric mapping and quite often used focusable, sometimes collapsible lenses or even zoom lenses. Such non defined and non-stable lens geometry negatively affects the quality of the photogrammetric processing. As the use of drones in mapping increases and users gain more experience, drone suppliers changed their approach and tried to transfer some of the main design features of traditional mapping cameras onto drone cameras. The use of fixed focus lenses with no moveable parts, and with optical image stabilization and a stable camera body with rigid lens mount is now part of many systems to address mapping applications.

3.1.3 RGB Cameras shutter design

Traditional photography has central and focal plane mechanical shutters. The central shutter usually comprises several shutter blades or leaves that open and close in the same way as a classical lens aperture. Opening and closing can be regarded as instantaneous. Focal plane shutters, contrary to this, comprise two curtains moving one after the other to form a slit that captures the whole image in the focal plane. The width of this slit defines the exposure time. Unlike the central shutter, it takes some time to capture the whole image. Consequently, moving objects are distorted on the image plane, which is always the case when images are taken from airborne moving platforms. In digital imaging the global shutter and rolling shutter can be seen equivalently to the mechanical central and focal plane shutters. Similarly, the rolling shutter will introduce the same distortion effects as the focal plane shutter. This effect can be modelled mathematically as the six exterior orientation parameters of each image will not be as constant but variable over the exposure interval. This concept is adapted from the processing of line scanning sensors and ideally uses measured orientation information from Inertial Measurement Unit (IMU) data. If the true sensor movement is not observed by an inertial platform (especially the angular rate), the mathematical model only approximates the real change in sensor orientation over time and the full sensor performance might not be fully exploited here. When drone mapping first began, most of the metal-oxide semiconductor sensors (CMOS) were using rolling shutters due to their simple electrical design. Today most of the cameras designed for mapping feature electronical global shutters, and some of the high-end systems even use a mechanical central shutter or a combination of both.

3.1.4 RGB Cameras reduction of the blur/motion compensation

In airborne mapping, images are captured during the movement of the platform. This movement can be divided into translational and rotational components. Both will affect the sharpness and thus the quality of the image data. The problem is well known, and so-called forward-motion compensation (FMC) was introduced in the mid-1980s for analogue mapping cameras. FMC moved the film during exposure to overcome the blur caused by the forward motion of the plane. This linear correction was adopted for digital cameras too. The electronic design of charged-coupled-device (CCD) sensors used in the first generation of airborne large-format mapping mimics the analogue FMC by moving the charges on pixel during integration (exposure) time (so called time-delayed-integration, or TDI). For cameras based on CMOS imaging sensors, the sensor is physically moved as was done with film. In all these cases only the main part of the image blur can be compensated and deviations from mean flying height above ground or mean speed leave uncompensated effects. Additionally, any movements that are not aligned with the direction of the transport are not corrected. As a result, FMC only reduces image blur. As changes in rotation during exposure also generate significant blur, the FMC technique must be combined with fully stabilized platforms to actively compensate for the rotations of the carrier platform. Additional vibration dampeners compensate for the high frequency angular effects present in multi-rotor drones. FMC combined with fully stabilized mount is called full-motion-compensation. For practical reasons, small drones do not have true-FMC with moving components, which limits the ground resolutions for fixed-wing drones as a function of ground velocity and shutter speed. Thus, the reduction of forward motion is accomplished by minimizing exposure times, sometimes called the (radiometric) blur control technique. It is based on the radiometric performance of the sensor in combination with fast shutter speeds. This is not a specific modification in the sensor, it just relies on very-fast shutters and the extended radiometric performance of sensors based on larger pixels or higher sensitivity. This approach in principle can be applied for any kind of sensor but is often used for RGB frame cameras working with color mosaic filters. From technical point, micro filter arrays (one filter evaporated onto every single pixel, so-called Bayer-pattern mentioned above) are used to capture color information. Missing colors then will be interpolated from the neighboring pixels, the so-called de-bayering or de mosaicking. This pixel-wise changing colors prevents charge moving technologies like the TDI (Time Delay Integration) approach, and it is often preferred because it does not need any specific sensor modification, and the camera can be offered at lower cost using standard (off-the-shelf) sensors. Just recently methods known from medical external beam radiotherapy were adapted for the blur control in airborne mapping cameras.

3.2 Multi and hyperspectral sensors

Multi- and Hyperspectral (HS) cameras provide contiguous spectral signatures by acquiring tens to hundreds of densely placed narrow spectral bands. Multispectral (MS) cameras have a few (typically 3–10) spectral bands optimized on specific spectral regions, such as blue, green, red, red-edge and near-infrared (NIR). Looking at the drone domain, regular color (RGB) cameras and modified color-infrared (CIR) cameras equipped with Bayer matrix based mosaic filters (see above) capture spectral data, but they have less optimized spectral bands than the MS and HS cameras. On the other hand, MS cameras, such as MicaSense Altum8 and RedEdge and SAL Engineering Maia9, have entered widely on markets because of their affordability and efficient processing chains in the commercial software (such as Agisoft Metashape10 and Pix4D11). Drones' HS cameras are still used predominantly in scientific and research purposes, because they are relatively expensive, heavy, capture vast volumes of data and are more challenging to operate and process than the optimized MS cameras. Furthermore, understanding on how the more precise spectral characterization can be utilized in practical applications is still inadequate. As MS technology is already widely applied in practice, the rest of this section will focus on HS technology which represents our vision of the future, though many aspects are also applicable to MS systems.

3.2.1 Differences between hyperspectral sensors

HS technologies differ based on the approach used to achieve the spatial and spectral discrimination capabilities and thus in the arrangement, range, number, and widths of bands that they feature. They can be classified as:

- push-broom scanners
- 2D cameras using HS imaging techniques
- point spectrometers that integrate spectral signatures over the projected footprint of the sensor, thus not providing continuous images.

HS sensors can be further categorized according to their spectral sensitivities to:

- visible and NIR (VNIR: 400–1000 nm)
- NIR (1000–1700 nm),
- shortwave-infrared (SWIR: 1000–2500 nm)
- mid-wave infrared (MWIR: 3–5 μm)

- long wave infrared (LWIR: 7–12 μm)

State-of-the-art MWIR and LWIR cameras are still heavy and therefore seldomly used in UAV applications. In recent years, rapid development has taken place in miniaturized HS sensor techniques although the situation has not stabilized, and new solutions are expected in near future. Increasingly, the manufacturers are offering fully integrated turn-key systems, which will lower the threshold to start using HS systems while during earlier years the user him/herself often had to assemble the system from separate components. There is an increasing trend to integrate additional sensors to HS systems, particularly GNSS/IMU or additional cameras for georeferencing, irradiance sensors, and LiDAR. Comparing the modern miniaturized MS and HS cameras to the mature cameras operated with manned aircraft, several differences can be observed. The conventional spectral remote sensing sensors are predominantly push-broom scanners, while a variety of technical implementations are offered on drones. The miniaturization of the detectors and lenses in drone systems leads generally to poorer SNRs considering the radiometric performance. In general, it can be considered that the aircraft and drone-based technologies are complementary: mature and heavy aircraft solutions provide high-quality and stable spectral data and are feasible for infrequent capture over wide areas, while drone solutions provide higher spatial and temporal resolutions, and their technologies and applications are in a rapid development stage.

3.3 Drone LiDAR: evolution, present and future challenges

The first works using laser scanning from a drone were presented a decade ago. The flight times of these systems were typically only few minutes, and the scanners available had few kHz frequencies, much slower than sensors today. Since then, the positioning and LiDAR (Laser imaging Detection and Ranging) sensor technologies as well as the drone platforms and autopilots have advanced significantly. drone laser scanning has become a common tool for a wide variety of mapping and modelling applications, and the field is being rapidly developed by a diverse range of actors.

Drone laser scanning fills the gap between traditional airborne laser scanners (ALS) and terrestrial mobile laser scanners (MLS). Compared with ALS, Drone systems allow for

- denser point clouds
- easier operation
- lower cost in small area projects

- short response times than those typical for high altitude aircraft or helicopter

Compared with terrestrial and ground mobile systems, UAV laser scanning provides:

- a multi-direction perspective that frees the platform from moving on the ground.
- wider field of view of some instruments with 360-degree capacity
- improved capture of vertical features such as building walls.

There is a clear division in the market towards high-end and low-cost drone platforms and instrumentation. High-end laser scanning systems provide faster data rates with more accurate and dense point clouds through high-end drone platforms, positioning units and laser sensors, but they request a significant capital investment. Low-cost platforms use consumer sensors and are more affordable for many entry level users. These systems can reach similar point densities as compared to high-end systems, but the accuracy and precision of the acquired data is typically lower (e.g., point wise geometric accuracy). Residual vibrations of the platform, not “reconstructed” by the IMU, propagate into the point cloud, and are difficult to compensate as there is no overlap between the adjacent scan lines. ALS systems are vibration dampened, and often mounted on “2-axes-stabilised” platforms to maintain the sensor orientation towards the target regardless of turbulence, while drone payloads are only suspended by wire or rubber dampers. LiDAR sensing does not suffer from sunlight shadowing which can hamper 3D reconstruction and has better penetration through vegetation as compared to passive sensors. These systems seem to provide promising opportunities but their widespread adoption as well as the wide use of miniaturized multispectral LiDAR sensors will take several years to become the standard on drones.

The laser scanning sensors can be further categorized as single and multi-layer beamed instruments. Single beam 2D scanners typically direct the laser beam perpendicular to the mirror rotation axis, virtually spanning a single scan plane in 3D space. On the opposite, the multi-layer rotating scanners create a series of lines simultaneously. These systems often acquire along a set of parabolas when projected onto a planar surface as each beam draws a virtual cone with obtuse angle corresponding to its nominal off-nadir angle. The curvature of the parabola increases with the growing off-nadir angle of a particular laser line, which greatly affects the point pattern and density on the ground further away from the scanner nadir. When such a scanner is mounted in a tilted position, this effect is further amplified.

Beside the issues discussed above, UAV LiDAR has still some technological challenges to face, like the following ones:

- **Point cloud georeferencing**, since the GNSS/IMU integration allows for precise positioning and attitude determination of the sensors to be carried out during the flight.

- **Weight**, LiDAR instruments are still relatively heavy (payload with GNSS/IMU and battery easily about 1,5–3 kg) and their use is thus limited to larger drone platforms.

- **Flight time**, since LiDAR instruments are time demanding and most of the smaller drones' platforms have no more than 10-15 minutes of flight time.

- **Calibration**, LiDAR sensors necessitate maintenance/calibration during the life span, which typically are not under user's capacity.

4. Photogrammetry: image and real-time analysis

The drone photogrammetry technique uses one (or more) drone(s) to capture a large number of two-dimensional images over a geographic area and compiles them into accurate three-dimensional terrain models and ortho-mosaic maps with specialized photogrammetry software (JOUAV Unmanned Aircraft Systems, 2022). The drone photogrammetry makes it possible to see the same ground point from different angles and altitudes. From there, you can easily create a 3D map that includes a range of useful visual cues, such as color and texture.

Photogrammetry first originated during the World War I when pilots combined photography with manned flights to gather intelligence from behind enemy lines. Without context, photographs alone were of little value, so these pioneers used local landmarks and landscape features to determine the direction of objects in images. During the following decades, these techniques would be evolved with the appearance of new tools, from stratospheric U2 aircraft to advanced weather satellites to modern drone photogrammetry.

Today's photogrammetric maps are constructed using advanced GIS software to produce surveyor-level measurements of landscapes and infrastructure. These maps are detailed enough to provide valuable insight into environmental conditions in the field. The drone photogrammetry is a two-stage process, including image capture and image processing as follows:

- **Image capture**: The first step is to capture the images needed for the project. This can be done with a still camera or video camera mounted on a drone. The drone will capture high-resolution photos of an area that overlaps each other to make the same point on the ground visible from different angles and elevations.

- **Image processing**: The aerial photos are then processed manually or using photogrammetry software, which combines or “stitches” the images into a single high-resolution ortho-mosaic aerial map and 3D models. Photogrammetry software corrects for distortions in the camera sensor and lens as well as errors caused by variations in the terrain, resulting in high-quality maps and 3D models.

As introduced above drones can be a useful tool for photogrammetry, resulting in the following benefits:

1. The drone photogrammetry makes it possible to obtain a large amount of detailed information about the target area quickly and remotely. Since drones can fly lower than manned aircraft and are also equipped with the most advanced technology, which delivers a 3D model with accuracy up to centimeter level.

2. Photogrammetry drones allow you to capture images from remote locations and transmit them securely to computer systems, allowing surveyors to easily access data in hard-to-reach or unsafe areas, such as places with severe volcanic activity, and crime or war, complex terrain, and harsh weather conditions.

3. The drone photogrammetry is an accessible method. Due to the financial factor, aerial photogrammetry was restricted to large engineering companies and public agencies. With the arrival of drones, values have dropped considerably, which makes it possible to hire this type of service even by small and medium-sized organizations.

Each step in the process of collecting data and creating output from the drone has the potential to add an error to the result. Several variables affect the overall accuracy of drone photogrammetry, including camera size, number of photos collected, photo overlap ratio, flight altitude, GPS signal strength, and ground sampling distance (GSD).

An overview of drone applications of photogrammetry as follows:

Oil & gas

Oil and gas companies use drone inspection typically for pipeline construction and infrastructure maintenance and rely on them to remotely inspect and observe equipment, infrastructure components, and other company assets. Drones can provide a 360-degree view of objects to monitor site operations and keep a close eye on new facilities. The AI tracking function of the drones can also automatically identify and locate damage or leaks, helping to speed up repairs and minimize local impact. In addition, remote monitoring with drones is now making fully automated offshore oil and gas inspection a reality.

Mining

There is a wide range of real applications of drones in mining, from surveying, inventory management, and stockpile estimation, to hazardous gas and leakage detection. Drone photogrammetry can be used to generate detailed digital surface models, digital terrain models, and 3D models of a mining site, so you can easily perform very accurate volume calculations. Using accurate site models generated from aerial drone imagery, mine managers can now more effectively design and manage the state of road construction at mines and monitor site progress on a weekly or monthly basis. With the high-resolution images from drones, mining companies can inspect hard-to-access places for identification of crevices, erosion, wall damage, and any other potential damages. This has gone a long way towards preventing accidents and ensuring the safety of workers.

Agriculture

For companies managing large areas of land, drone photogrammetry can be used to capture images of crops. With these bird's eye views, they can detect crop growth, estimate crop yields, and identify issues like soil erosion and crop diseases. The drones can carry different payloads at the same time, providing farmers with real-time and accurate diversified data that they can act on immediately.

Utilities

Photogrammetry is often used by utility companies to measure infrastructure in remote areas such as power line inspection, solar farm inspection, and wind farm inspection. Photogrammetry with drone can be used to prepare for maintenance work and repairs before engineers arrive on site, greatly reducing the manpower and resources required for infrastructure safety and improving worker safety.

Environmental monitoring

There is also a strong demand for UAV photogrammetry in environmental monitoring. It is possible using photogrammetry to study issues such as land change, pest infestation, invasive plant growth, wildfire risk, and more. Drones are increasingly effective with first responders, who can use drone footage of the aftermath of a flood or fire to develop rescue strategies and reduce risks.

New trend emerging photogrammetry vs LiDAR

Although digital photogrammetry is the most used measurement method by drone users around the world, drones with LiDAR technology have been gaining popularity for generating 3D models for several commercial applications. The was introduced in the previous section and it stands for Laser Detection and Ranging, is a remote sensing technology that has been gradually incorporated into aerial drone mapping for a range of specific applications. If aerial photogrammetry is based on the overlay of 2D aerial images used to generate a 3D model, the LiDAR approach is based on direct measurements. LiDAR uses a high-power laser to emit precise laser pulses at a target object. By measuring the timing and intensity of the returned pulse, it provides a dense cloud of points on the terrain and ground that can be used to generate a 3D model in specific software.

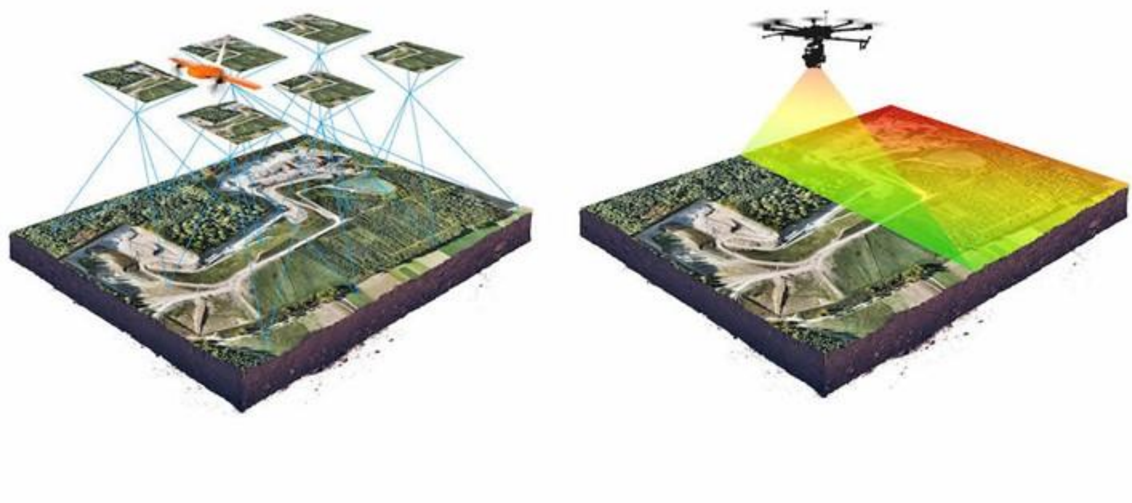

Figure 4: Drone photogrammetry vs drone LiDAR

With the development of LiDAR technology, the weight and size of these devices have been reduced significantly, making the LiDAR drone increasingly common. drone photogrammetry and LiDAR are both technologies capable of producing excellent data results for aerial mapping, however, they differ significantly in their price and applications will depend on many factors that must be evaluated beforehand to make a technical decision.

Below are introduced the main differences between drone photogrammetry and LiDAR:

- *Drone photogrammetry is cheaper than LiDAR:* Digital photogrammetry and LiDAR are both technologies capable of producing excellent data results for aerial mapping from drones, however, they differ significantly in terms of applications and price, etc. By far the main difference between these two aerial survey methods relates to the cost of acquiring the equipment. A drone-based LiDAR system can cost you $60,000 or more for the hardware alone, as this equipment is far more expensive than conventional sensors and drones that carry out photogrammetry. This means that although LiDAR is a good option in very specific circumstances, the best option in terms of cost will always be traditional photogrammetry.

- *LiDAR can see through vegetation*: LiDAR can provide high vertical accuracy when conducting aerial surveys in densely vegetated areas. This is because LiDAR emits many laser pulses in the near-infrared spectrum, which can penetrate dense foliage, directly acquiring high-precision 3D terrain data of the ground surface. This makes LiDAR an ideal method for aerial surveys of forestry management. The device has replaced traditional forest inventory methods and has been used to estimate the amount of planted and native forest. However, LiDAR is best suited for sparsely vegetated areas or for projects where 3D modeling of the forest structure is not strictly required. For this reason, photogrammetry is used to manage volumes and structures in mining and civil construction. In these fields, conventional aerial photogrammetry methods are economically more accessible solutions, producing outputs with the same level of detail and accuracy.

- *LiDAR can be used in low-light or no-light environments:* as they are self-illuminating devices, LiDAR systems can operate in low or no-light environments, and even perform aerial surveys at night. Photogrammetry, on the contrary, is highly dependent on sunlight and aerial photogrammetry can only be carried out when there is sufficient light and is very sensitive to occlusion. This can be frustrating when you will not be able to carry out aerial photogrammetry on cloudy overcast days as the clouds will block the sunlight from entering. Under these circumstances, LiDAR would be the best option, even if they are more expensive equipment. Depending on the extent of the area to be mapped and the financial return these projects will provide, LiDAR systems can be a good long-term investment option.

- *LiDAR cannot capture RGB colors*: the biggest disadvantage of LiDAR systems in terms of detail is that these systems cannot capture RGB colors and you will not identify the texture characteristics of the mapped area in the 3D model generated by LiDAR. To overcome this obstacle, 3D models by

LiDAR often use fake RGB colors, however, the visual quality is always not as good as the data results generated by drone photogrammetry. If you need a model that is consistent with the visual features, LiDAR will not work. However, there are already LiDAR drones on the market that combine LiDAR technology and RGB sensors, and while they are a little more expensive than traditional models, it is possible to generate 3D models with true colors.

5. GNSS data acquisition for precision pointing

Based upon a drone survey data obtained in April 2019 (National Center for Biotechnology Information, 2022) is the first representative sample from this close-knit global community across the specialisms of climatology, ecology, geology, geomorphology, geophysics, and oceanography. The survey results derived from 16 countries revealed that:

- 14.71% of scientists used GALILEO,
- 27.94% used GLONASS
- 45.59% used GPS.

Many used a combination of two or more GNSS. Multiple regression analysis showed that there is no strong relationship between a specific pattern of GNSS augmentation and greater positioning accuracy. Further polar drone studies should assess the effects of phase scintillation on all GNSS, therefore BEIDOU, GALILEO, GLONASS and GPS.

Whatever the precise research, all scientists need to navigate a drone from a known point of departure to perform specific research tasks. The drone must then return safely with data or samples or both. In the atmosphere of Earth, aerial drones navigate and verify accurate positioning based on one or more Global Navigation Satellite Systems (GNSS). Furthermore, other satellite systems and diverse augmentation methods refine the accuracy of GNSS measurements. Therefore, a common denominator of drone navigation is to understand how each GNSS operates.

In April 2019, a global drone survey of scientists was completed (hereafter ‘the drone survey’). The target sample of 211 scientists was a balanced international mix: Asian, European, Latin American, North American, and Russian institutions. Out of these 211 scientists, 42 responded with detailed answers on their choices of GNSS, GNSS performance and GNSS augmentation accuracy achieved

All aerial drones used at high latitudes and in cryospheric regions rely on GNSS. While not the only basic navigation or data positioning systems available, GNSSs are the primary means of both navigation and positioning for scientists. GNSS signal availability is determined by three key factors: the altitude of the orbit, the inclination angle of the satellite and the Earth ground-level ‘field of view’ width of the signal transmitter attached to the satellite.

Each satellite is transmitting two pieces of information: (i) its position in space, and (ii) its clock time. All satellite clocks are synchronized and accurate to one millionth of a second. Applying the equation distance = speed × time, the speed of light (2.99792458 × 108 m s^{-1}) multiplied by the time taken for a satellite signal to arrive at a GNSS receiver, provides the altitude (distance) of the satellite from the user.

$$\left.\begin{aligned} & t = \frac{d}{s}, \\ & t = \frac{26\,600\,(\mathrm{km})}{2.99792458 \times 10^{8}\,\mathrm{m\,s^{-1}}}, \\ & t = 26\ 600\ 000/299\ 792\ 458, \\ & t = 8.8728 \times 10^{-5}\ \mathrm{s} \\ \text{and} \qquad & t = 0.000088728\ \mathrm{s}. \end{aligned}\right\}$$

The concept of pseudorange is critical to explaining how GNSS works with such high precision. Pseudorange refers to the difference between the satellite clock time and the user clock time when the user clock time is always relatively imprecise. The Achilles heel of GNSS is the inaccuracy of the receiver. The fourth satellite in any position fix is required to determine how far off precisely the receiver clock is compared with the satellite clocks. To underline how important this is, if the receiver clock is off by 1.25 s (≈300 000 × 1.25), the position would be in inaccurate by 375 000 km—the same distance as the moon's orbit from Earth.

$$\rho_i = |r_i - r_u| + c \times b_u + \varepsilon_{pi}$$

where ri is the satellite position at transmit time; ru is the receiver position at receive time; bu is the receiver clock bias expressed in seconds and εpi the combined calculation for all the estimated or measured ionosphere and troposphere delays, clock mis-modelling, ephemeris and multipath.

It is well documented that any GNSS requires at least four satellites for a full position fix and time or altitude fix. From the leading authority on space mission analysis and design, the task of maximizing the precision of a satellite constellation is a daunting one requiring highly detailed budget, equipment, and orbit calculations. However, three common denominator components are critical to minimizing errors created because of the geometry of satellites. These are the spacing, altitude and attitude of the satellites. The quality of spacing of satellites has been termed as the geometric dilution of precision (GDOP). The errors experienced by GPS users at high latitudes can significantly depend upon GDOP.

$$\text{GDOP} = \frac{1}{\sigma}\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2}$$

As a rule, the wider the spacing of satellites the higher the quality of signal consistency. The lower the GDOP, the better the accuracy. By contrast, a constellation of satellites has a poor geometry when they are close together. Therefore, the GDOP is higher. For any scientist operating in high latitudes or cryospheric regions, the task of determining GDOP before drone use may make sense because the drone can then be switched to the GNSS with the lowest GDOP. A GDOP between 2 and 5 is good and a GDOP of 1 is excellent.

The fundamental aim of the drone survey was to target respondents that would meet the three quality survey implementation criteria of:

- Reliability
- Validity
- Representativeness

The criterion of representativeness was the most challenging of these three, because it involved attempting to avoid over-concentration on clusters of researchers. To maximize representativeness, five specialisms were finally selected:

- Climate & Climate Change
- Ecology & Biodiversity
- Geomorphology
- Ice & Ice Movement
- Oceanography

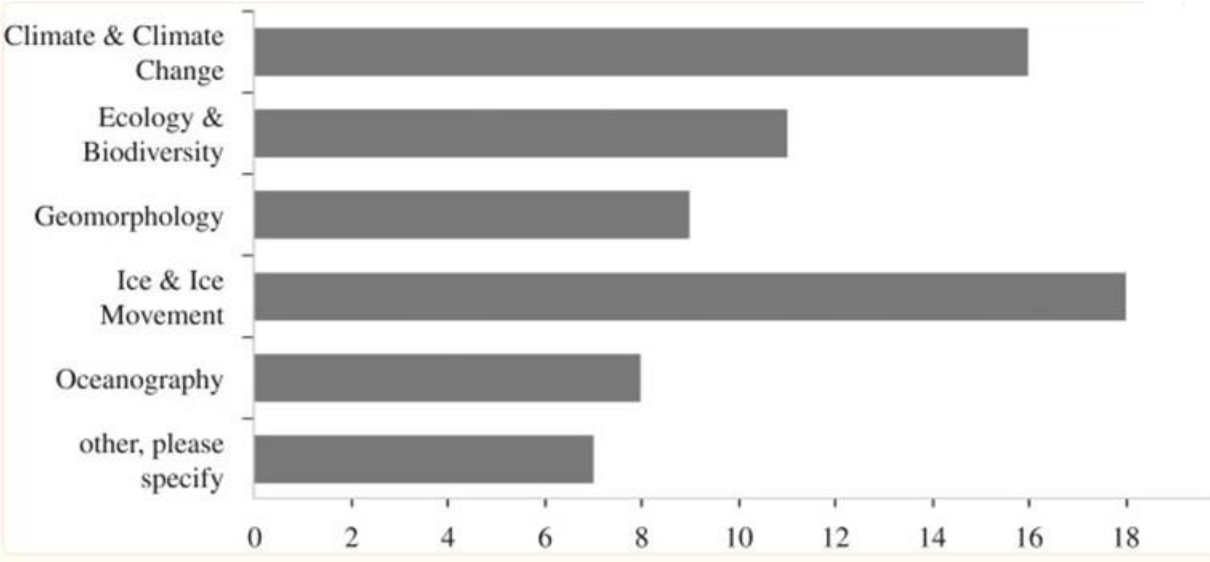

Figure 5: GNSS research areas (ncbi.nlm.nih.gov – 2019)

For 33 scientists using only aerial drones were asked the following question and options:

When using your aerial drone for research applications, which of the following GNSS do you use for its navigation and positioning?

- BEIDOU
- GALILEO
- GLONASS
- GPS
- IRNSS
- Other, please specify
- Don't know

sensor type	percentage
BEIDOU	5.88
GALILEO	14.71
GLONASS	27.94
GPS	45.59
IRNSS	1.47
other, please specify	1.47
don't know	2.94
total	100

Figure 6: Aerial Drones science survey results (ncbi.nlm.nih.gov – 2019)

An important aspect of this survey was the aim of establishing if there is an over-reliance by scientists on GPS (45.59%). At first glance, the 45.59% using GPS underlines that GPS is certainly important. However, for an inference to be drawn that there is an over-reliance on GPS, it was important to know what percentage of aerial-only GPS users were using GPS and GLONASS; or GPS, GLONASS and GALILEO.

Analysis of the 33 scientists using only aerial drones showed that 12 (36.36%) relied solely on GPS. Nine relied on GPS and GLONASS (27.27%). Another nine (27.27%) relied on GPS, GLONASS and GALILEO. Only one scientist used GPS and GALILEO, but not GLONASS. By contrast, when the 3.03% of scientists who did not answer the GNSS survey question are factored out, 60.61% of scientists use more than one GNSS.

Scientists were also asked for information about:

- their current precise measurement choices
- future planned measurement choices.

precision research method	current (%)	planned (%)
differential GNSS using own base station	28.33	23.88
geo-referenced ground control points	26.67	23.88
inertial navigation system	11.67	10.45
iridium satellite constellation	1.67	2.99
NASA global differential GPS (GDGPS)	1.67	*10.45*
post-processing positioning	20.00	16.42
other, please specify	5.00	4.48
don't know	5.00	7.46
total	100	100

Figure 7: Precision measurement methods survey results (ncbi.nlm.nih.gov – 2019)

An exception was the planned use of the NASA GDGPS service. After the drone survey completed in April 2019, on 7 May 2019, an email was sent to the NASA Jet Propulsion Laboratory (JPL) to understand if there was any reason known to JPL for this increased interest among polar users for GDGPS. The JPL technical manager replied that there was no specific reason or reasons known to them. Having checked all the individual questionnaires, none of the current users intended to stop using GDGPS, so the real planned change (8.78%) indicated a significant increase in its use.

no. GCPs used	no. scientists	no. scientists as % of sample	avg. accuracy (m)	range (m)
0	13	39.39	8.06	0.10–100
1	4	12.12	2.33	1–5
3	2	9.09	0.10	0.10–0.10
4	1	3.03	0.40	0.40–0.40
5	2	15.15	0.05	0.0001–0.10
>5	1	3.03	0.50	0.50–0.50
>10	10	30.30	1.38	0.0005–10
totals	33	100	1.76	0.0001–100

Figure 8: Ground control points survey results (ncbi.nlm.nih.gov – 2019)

In conclusion an important point is the increasing reliance on a trio of GNSS was the significant use of GALILEO (14.71%). This choice is consistent with engineering and mathematical analysis that the different ‘orbital inclination and the flight altitude of the GALILEO satellites will considerably increase the coverage of the polar regions, not so well achieved by GPS.

6. Drone regulation in Mexico

The latest Mexican law available (**NOM-107-SCT3-2019**, released on 14th of November 2019) issued by the "Secretaria De Comunicaciones Y Transportes" flying unmanned aerial systems is possible within the following conditions. The two entities involved in drone operations are:

- Agencia Federal de Aviacion Civil (AFAC)
- Dirección General de Aeronáutica Civil (DGAC)

Drone classes are the following ones according to the Mexican law:

- **Micro Drones**: drones in this category weigh 2 kilograms (4.4 pounds) or less. Micro UAVs can be flown without authorization from the AA, but if used for commercial activities they should have third party liability insurance, among other conditions. They can be flown up to 122 m (400 feet) above ground level and no more than 457 m (1,500) feet from the operator within the visual line of sight.
- **Light Drones**: drones in this category weigh between 2 kilograms and 25 kilograms (55 pounds). Light drones flown for recreational purposes can only be flown on the grounds of a recognized model aircraft club. Light drones flown for commercial purposes must be registered with the DGAC and must display license plates. In addition, each individual commercial drone flight must be authorized by the AA beforehand.
- **Heavy Drones**: drones in this category weigh over 25 kilograms. Heavy drones must adhere to all the rules that apply to light drones. In addition, heavy drones must follow the terms and conditions approved by the AFAC. Heavy drone operators must have a pilot's license.

The Mexican law encompasses the following general rules about drone conductions and operations:

- Only Mexican (by birth) citizens can obtain the pilot drone license, after an appropriate training and after providing a good psychological-physical health certification (not older than 90 days before license request). Potential foreign operators shall contact directly AFAC.
- All drones weighing over 250 grams (.55 pounds) must be registered with the DGCA. Registration requires an official ID proving Mexican citizenship, therefore prohibiting registration by foreign persons. Learn more about registering your drone in Mexico here.
- Fly only in daylight.
- Do no fly over people or animals.
- Do not fly at historical sites such as Chichen Itza.
- Do not exceed the maximum operating speed for the drone based on its maximum takeoff weight.
- Drones must not drop objects that may cause damage to people or property.
- Be sure to follow the drone policies for the hotel or resort at which you are staying.

To register a drone in Mexico it is necessary to apply the following instructions:

- Fill out the form APPENDIX “K” REGULATIONS: REGISTRATION OF RPAS BY THE RPAS OPERATOR.
- If you are a natural person, you must prove your personality by attaching a digitized copy of your official identification.
- If you are a legal person, you must prove your personality by attaching a digitized copy of the articles of law and power of attorney.
- Review the data provided (the waiting time to obtain your registration depends on it).
- Prepare a scanned copy of the documentation proving ownership or possession of your RPAS (supported formats .pdf, .docx, .jpg or .png).

- Send an email to rpas@sct.gob.mx requesting registration for an RPAS, attaching the complete form in format (Excel) provided below, along with its printed version signed by you and adding in an autograph way your Federal Register of Taxpayers with “homoclave” (taxpayer identity number), if you have it; as well as digitized copies of the documentation proving the ownership

- Wait for your registration sheet or the considerations to be covered to obtain it, at the email address provided, within 10 business days from the date of entry of your application.

- Use the space within your email to mention if you had any difficulties or problems filling out the form. Include the comments you have not been able to add, indicating which question on the form they refer to

- If necessary, we will contact you to solve the problem. Otherwise, their appreciation will serve to improve the tool for future editions.

- For any questions about it, please contact Tel: (55) 57239300 EXT. 18111, 18113, and 18125.

Authorization for photography and recording in areas, monuments, and museums of “Instituto Nacional de Antropología e Historia” (INAH):

It is necessary to get permission to take photographs, film, or record in areas, monuments, and museums of the National Institute of Anthropology and History (INAH) for professional or commercial purposes. There is also a fee for taking photos or videos in INAH areas. To apply for permission to take photos and videos in INAH areas, is needed to provide the following to INAH:

- A written document addressed to the National Coordination of Legal Affairs with a brief synopsis of the project

- Any Script, storyboard, or dummy sketch

- Application form INAH-01-001

- Start application process online. It will complete the application at the INAH service offices.

7. Commercial opportunities

7.1 Mexico Area

Mexico continues to have a busy market for private flights, both rotary and fixed wing. Full of wide-open spaces, with mining, agriculture and other remote industrial operations, Mexico also historically lacked a safe, modern road network. It is still the 2nd most active market in the world after the United States for private jet travel and for air/Heli taxis. Mexico's top cities are all busy for helicopter traffic, as is the Gulf region, which is the hub for offshore oil activity.

Because of the level of private flight activity, and because as an aerospace manufacturing location Mexico attracts strong investment in components production, Analysts put about 7% of the world's drone market in Mexico. Revenue in the Drones segment amounts to €17.21m in 2022. The market is expected to grow annually by 7.02% (CAGR 2022-2027). Currently, as in the global marketplace, US-made drones dominate in the military sector, while Chinese drones dominate civilian. The Drones segment is expected to show a volume growth of 17.8% in 2023 (VEDP International Trade 2020 and STATISTA 2022).

The Mexican drone market is growing rapidly, both for consumer and business use. Commercial drone applications are numerous in Mexico. Together with the greater North American region, Mexico is expected to have significantly more demand for drones than other parts of the world due to its level of business activity related to land resources. Off-grid energy is one demand sector, and the report mentions many more.

Entering the Mexico market is normally most efficient via forming a strong relationship with one or more local sales partners, although there are exceptions depending on the product or service.

7.2 Caribbean Area

Considering the wide basin of the entire Caribbean Area, rather the Mexico alone, a lot of commercial opportunities arise considering the different features and needing of each single state. In such framework more difficult is to trace common themes that could interest the whole Caribbean area rather than two or three (or more) single states. Looking at such area with wide angle only two potential common commercial opportunities come into sight:

Commercial opportunities in the Caribbean area:

- **SAR emergency applications**: taking into account the large number of islands (from big to small) and the large number of awful meteorological events, a fleet of SAR drones integrated with Galileo and Copernicus systems could play a key role in both accidents and disasters recovery.
- **Police enforcement applications**: taking into account the large of vehicles moving in the area and taking also into account the drug smuggling activity, a fleet of Police Enforcer drones integrated with Galileo and Copernicus systems could play a key role in crime stopping and its prevention.

The above potential opportunities should be both sustained by the EU and Galileo/Copernicus teams by the offer, to the potential clients, of a specific free software that shall directly interface their products (drones, control centers, end users etc.) with the two constellations, making them more appetible than their concurrent (GPS, GLONASS, BeiDou).

7.2.1 SAR Emergency Applications

As drone technology has advanced in recent years, drones are playing an increasingly vital role during natural disaster response efforts for many public safety agencies across the United States. They've also seen increased deployments in pre- and post-disaster efforts, as well. (ref. P. Ip – 2022)

In addition to providing improved situational awareness and operational response, drones also allow relief workers to operate remotely in disaster areas normally inaccessible to humans or manned vehicles. When mere seconds could mean the difference between life and death for those unfortunately caught within a disaster area, the roles that drones play cannot be overstated. Below are some examples of natural disaster response scenarios within which drones have been utilized:

- **Search and Rescue:** when natural disasters strike, Search And Rescue (SAR) missions are often the top priority. Every second counts when lives are on the line. Each passing second feels like an eternity for those caught in the heart of natural disasters. Thankfully, disaster response drones can be deployed much more quickly than traditional manned disaster response aircraft. This gives first responders the opportunity to carry out mission-critical reconnaissance and threat assessment of the disaster area prior to sending relief workers into the area to perform search and rescue operations. They also allow relief workers to cover large search grids much more efficiently than traditional ground relief teams. Disaster response drones (in terms of an entire fleet or swarms) can also be outfitted with thermal imaging cameras and spotlights. This allows relief workers to locate heat signatures that are otherwise invisible to the naked eye. Emergency responders can also use drones to provide aid and relief by flying in emergency supplies (food, water, medicine, etc.) and communications equipment to victims that are trapped in difficult-to-reach locations. The advantages that disaster response drones provide are clear. In this scenario some drones of the fleet could carry on a proper SAR mission while other ones (in the very same fleet) could carry along relief equipment (food, water, medicines, etc.) to deliver it directly to the afflicted populations.

- **Pre- and Post-Disaster 3D Mapping of an Area**: aerial imaging and 3D mapping of areas prone to large-scale natural disasters such as earthquakes, flooding, hurricanes, and wildfires can prove invaluable for disaster response efforts as well as insurance purposes. Emergency responders can utilize this data to help coordinate search and rescue efforts. Meanwhile, insurance companies can compare pre-existing data against those generated post-disaster to assess the damage and speed up the claims process more accurately. This data can be gathered much more quickly and cost-effectively using drones rather than traditionally manned aircraft. The resulting data are typically much higher in resolution than what's achievable through satellite imaging as well.

- Real-World Examples of Drone-Use in Natural Disaster Response:

  The 2008 earthquake in Sichuan, China was one of the most destructive earthquakes in recorded history. It led to the collapse of many buildings, bridges, and other infrastructure in the area. Drones were used to help rescue teams target priority areas by identifying population-dense buildings (such as schools and hospitals) that had collapsed as well as routes that were made unusable due to caved in tunnels or bridges.

  The 2015 Nepal earthquake, many airstrips and refueling facilities throughout the country sustained significant damage, making the use of crewed rescue aircraft challenging. In addition to creating 3D maps of the disaster area to aid in damage assessment, drones equipped with thermal cameras were also used to facilitate search and rescue efforts.

  The 2022, severe flooding of the KwaZulu-Natal (KZN) and Eastern Cape provinces of South Africa. Due to the challenging terrain and inaccessibility of the region, the South African National Defense Force (SANDF) is using drones to help gather intelligence and capture aerial photographs to help analyze and assess flood-damaged areas.

7.2.2 Police enforcement applications

As drone technology evolves and their capabilities allow a wide range of activities, police and law enforcement became a hot topic for every nation, regarding the following areas (ref. S. Rice Forbes, 2019 and N. Klein/R. McLaughlin, 2022):

- *Mapping*: Mapping highly frequented locations is a common use for police drones around the country. Instead of paying $500-600 per hour for a helicopter to cover the entire city, a police department can instead purchase a few drones to do the same job for the price of electricity in the batteries. These maps can then be used for all future events or crime scenes. They can also be used for before-and-after images of natural disasters.

- *Chasing suspects*: hundreds of police departments buy drones each year to aid in chasing down suspects. When a suspect takes to the roof, it can be difficult for the ground units to know where he or she is. Having an eye in the sky provides critical intelligence and guides the ground units to optimal positions. Reducing uncertainty also helps to reduce the stress levels of SWAT teams. Suspects often report not even being aware of a drone since they are so small and much quieter than a helicopter. Drones can also help to identify suspects and what weapons they might be carrying. In a case where a man holed up in a hotel threatening to detonate a grenade, the police were able to identify the grenade as inert and prevent loss of life when the man finally appeared.

- *Crime scene investigation*: drones can help crime scene investigation in a variety of ways. They can be used to collect evidence that may be difficult to reach from the ground. Two drones can survey a crime scene and provide maps and 3D images within minutes. They can be used to provide lighting at night or low-light conditions. They can manually capture 60+ frames per second from a still camera, or record 4k video as needed. All this can be done in a fraction of the time it takes a ground unit to conduct this same investigation.

- *Event Management*: events can draw huge crowds and moving ground units through these crowds is slow and tedious. Cities that host large crowds are finding that having a handful of drones in the sky during the event allows them to see the big picture, watch people move in real time, and zoom in on singular events that may need a ground unit backup. They are great for detecting trouble before it gets out of hand, and communication between units is exponentially faster.

- *Seizing illegal drones*: lastly, police drones can help to identify illegal and unregistered drones that may be hazardous to the surrounding environment. Many private drone operators do not have the proper training and licensing necessary to fly their drones on public property. In fact, if you don't understand the images below, then you probably should not be flying a drone.

Once an illegal operation has been identified, a ground unit can be sent to find the operator and give them a choice between education about the laws or arrest and fines if they refuse to cooperate.

In particular such last activity could be potentially appealing to all the Caribbean countries since it could be aimed to intercept and to stop the drug smuggling traffic, in particular the one carried on by unmanned drones and even more and more increased in the last years. These remote-controlled "narco-drones", "narco-subs" or "underwater drones" herald a new era in international drug trafficking. Drugs and other illicit goods can now be transported across the oceans, controlled by a remote operator located anywhere in the world. The new technology will likely become a critical component for countries wanting better information about who's doing what and where.

It's not entirely clear, for example, that the "seafarer" definition could currently cover maritime autonomous vehicle operators. The simplest response to this new criminal enterprise might be destroying any narco-drones captured at sea. International law doesn't prohibit such a response, although environmental considerations would likely arise.

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