**Integrating Activities for Advanced Communities**

# D8.3- Report requirement specifications for drones in arctic environments, including drone types, drone projects and sensor technology

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**Dissemination Level**

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# Publishable Executive Summary

As the Arctic environmental research has become a very important topic on the agenda, the scientists that are active in these areas will need several ways to utilize new technology.

One goal with this work is to present a great variety of examples of drones and how they can be applied in research purposes, in order to raise awareness and inspire station managers and scientists to seek for opportunities on how to take advantage of the possibilities presented by the drones and its various applications. The presented information will lower the thresholds for the introduction of drones in the organizations, in order to more easily make drones applicable for different types of remote sensing and for upscaling of scientific observations from plot scale to regional scale across and within a range of environmental disciplines.

A lot of inspiration and ideas to the report come from the extensive cooperation between industry, authorities, researchers and station managers, that all has contributed to the content. In addition to that, experience from the large drone community has been transferred into the report.

The reader will be given an overview of different drone systems; single rotor helicopter, multirotor and fixed wing and their basic technology and what kind of applications to apply the technology on. Further chapters will cover some of the basic technology behind, such as navigational aids, accessories and peripherals, as well as a variety of sensors and typical applications to be used for the Arctic environmental research activities. These applications will cover topics like snow measurement, laser scanning, different radar technologies, photogrammetry, among several others. The document will also highlight some of the most important things to have in mind when using drones in the Arctic climate. This will eventually give the user a better understanding on how to proceed with drones regardless of being a beginner or an experienced pilot.

# Acronyms

| | |
|---|---|
| AGL | Above Ground Level |
| ATC | Air Traffic Control |
| BVLOS | Beyond Visual Line of Sight |
| CAA | Civil Aviation Authority |
| CTR | Controlled Traffic Region |
| COTS | Commercial Off-the-Shelf |
| FPV | First Person View |
| GNSS | Global Navigation Satellite Systems |
| GHG | Greenhouse Gas |
| GCP | Ground Control Points |
| PED | Personal Electronic Devices |
| RPAS | Remotely Piloted Aircraft System |
| RTK | Real Time Kinematic |
| UAS | Unmanned Aircraft System |
| UAV | Unmanned Aerial Vehicle |
| VLOS | Visual Line of Sight |

# 1. Introduction

## 1.1. Background

Drones, or Unmanned Aerial Vehicles (UAV), have become an important tool in environmental research during the last years due to their ability to make observations, including remote sensing, at low cost and at intervals determined by the user. With appropriate sensors, drones can be used for different types of remote sensing for various land surface, aquatic and atmospheric measurements. Consequently, they can extend the study area of research stations and facilitate up-scaling of environmental observations from plot scale to catchment scale. Further, sensors on drone platforms can also be used in combination with satellite-borne sensors to scale up to the regional scale and beyond.

Drones are especially applicable for arctic research. The Arctic consists of vast areas with very limited infrastructure and often inaccessible places, which makes it difficult to gather spatial environmental information at regular intervals and with minimal environmental impact on the ground. With drones it is possible to make such investigations, and due to the very limited population density in most of the Arctic, drone operations can be carried out with less risk than is the case in areas more densely populated. At the same time, drones can increase safety in the field by avoiding walking over mountains, ice, snow and wetlands.

In the near future it is probable that drones will be considered as part of the equipment operated routinely by research station staff and visiting scientists.

## 1.2. Purpose of document

Knowledge about drone technology is still limited within the arctic science community and among Arctic research station managers. Also, there is a large number of possibilities to create new environmental research opportunities in combining drones with different types of commercially available sensors.

This document aims at providing an overview of:

- Identified Arctic research areas and activities wherein drones could be applied
- Drone technologies suitable for Arctic research
- Sensor technologies suitable for Arctic research
- Applications of sensors integrated on drones, with a potential for being utilized by Arctic researchers

## 1.3. Method

Interviews, surveys and a workshop have been conducted in order to better understand the need among Artic environmental researchers, especially related to specific research areas and related field activities.

Two seminar activities have been conducted with speakers and exhibitors from organizations and industry. These activities have brought together researchers and manufacturers of drones and sensors. Several presentations about the work package and the INTERACT project have been held at different occasions and events. This has spread the awareness about the Arctic research community and their requests.

Press releases and news articles have been written about the project which has further attracted an international interest from the industry, which has contributed to many contacts with suppliers and, as a result of this, a lot of information regarding UAV technologies and applicable types of sensors.

The work package has been present in several national and international media.

## *1.4. Terminology*

The term Unmanned Aerial Vehicle (UAV) refers to an aircraft without a human pilot onboard. This is also the general meaning of the more commonly used term drone.

The term Unmanned Aerial Systems (UAS) refers to a complete system, i.e. the drone including all the peripherals, e.g. remote controller and ground station equipment, needed to operate the drone.

Remotely Piloted Aircraft Systems (RPAS) is another term that sometimes is used to describe the same as UAS.
This document will mainly use the general term drone.

 

# 2. Arctic research areas and activities

Understanding the life and activities at arctic research stations is crucial in order to make technical recommendations regarding types of drones and sensors that could be utilized for research activities. A survey conducted in April of 2017 (Ader & Axelsson, 2017) charted the activities of researchers and other personnel at INTERACT stations. The initial recipients of the survey were asked to further distribute it to those whom they assessed to be appropriate respondents. A total of 29 answers from 24 different research stations were gathered.

The answers differed greatly between respondents. A checklist question about the types of samples/data collected resulted in only unique answer combinations. The results are shown in Figure 1.

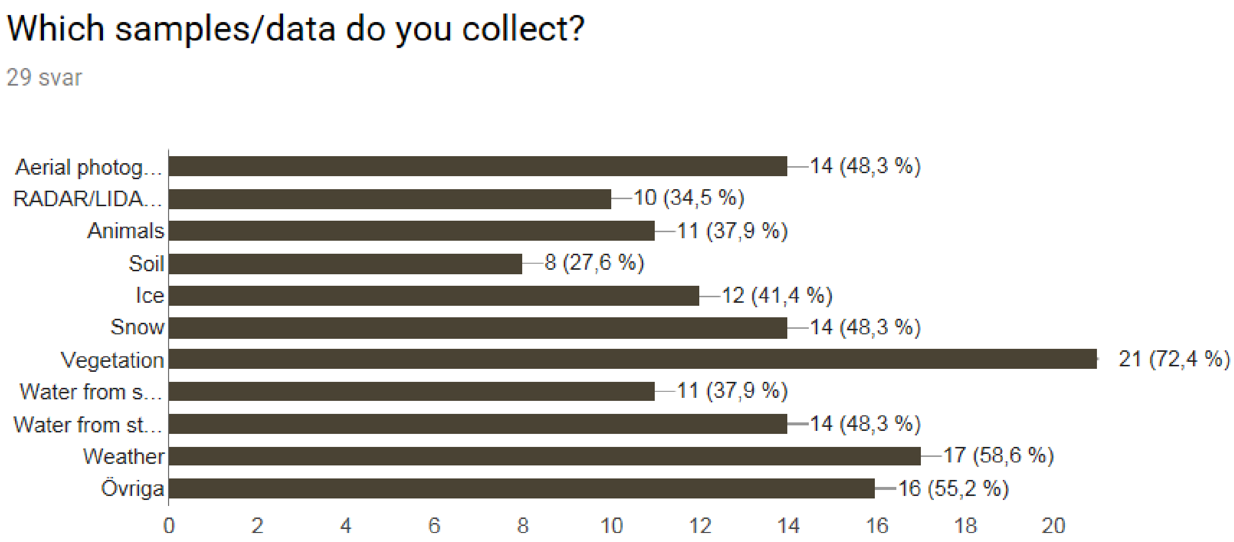


**Figure 1. Survey responses to the question "Which samples/data do you collect?" (Övriga=Other) (Ader & Axelsson, 2017).**

From the answers from the subsequent question: "Which methods do you use to collect samples/data", one can also conclude that the methods used for collecting this samples/this data vary considerably.

Interviews was conducted with some of the respondents in order to gain deeper insights about the work performed at the stations and to complement the findings of the survey. This, in combination with user-tests of drones by some of the researchers, led to some general conclusions:

- Most research activities that are carried out via satellite or helicopter can be replaced by a drone activity, given that the associated electronics (sensors and supporting systems) in question are light enough to be carried by the drone (most, depending on the size of the drone).
- Drone applications can also be used to replace analogue methods, such as snow depth measurements using a measuring rod.

Drone data could provide a good middle ground between manually collected field data and satellite data, and thereby fill a so-called scale gap. The scale gap and scale of UAV imagery is illustrated in Figure 2 (Olofsson, 2017).

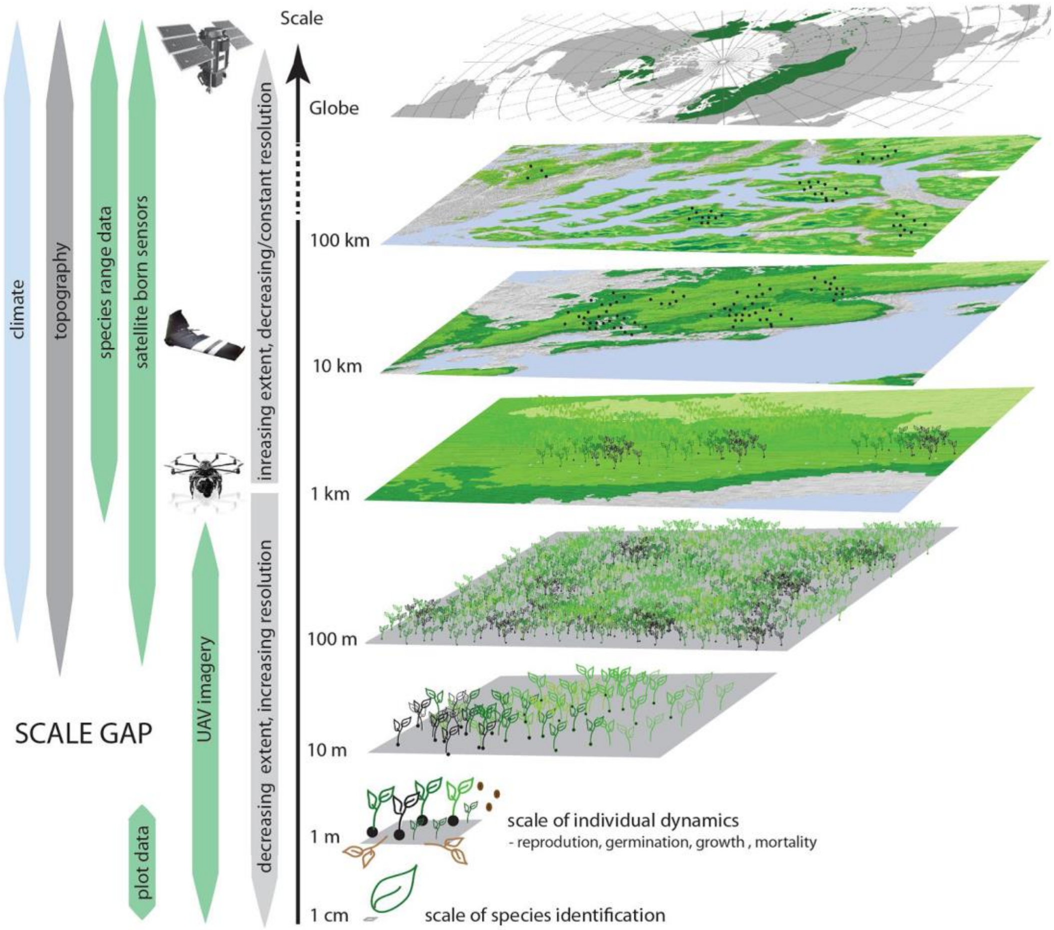


**Figure 2. Scale of UAV imagery compared to scales of other data collection methods (Olofsson, 2017).**

Drones complement traditional fieldwork with fast measurements collected over large areas but will in all likelihood not replace traditional field-testing; nor is it desirable, as many researchers enjoy field work.

All drone applications in which the drone observes and collects data without interacting with the surrounding environment can be referred to as *passive drone applications*. Uses for passive drone applications include measuring ground composition, snow depth, greening of plants, and many more. These passive applications hold great potential of improving both research quality and efficiency and will most likely be the dominating use of drone technology within the research community.

*Active drone applications* are applications in which the drone interacts with the surrounding environment. Collection of samples is one such application. Drones pose a smaller risk of affecting the surrounding environment than a human would. They can, for instance, collect samples from a lake or mire without trekking or rowing to the area in question.

Researchers often operate in remote locations. Collecting samples in these locations require them to transport equipment and personnel over difficult terrain. Some areas may be completely inaccessible but be valuable from a research perspective. Using drones to acquire information from these inaccessible places may be beneficial and could potentially help save time and resources. Drones can also be used for recognizance work, to inspect a path or trail for potential hazards.

# 3. Drone technologies

A drone is an aircraft without a pilot on board. A drone is often (but not always) capable of autonomous flight. In order to accomplish this, the aircraft needs several different sensors and input data, such as accelerometer and gyro information and be able to combine it with barometric and GNSS data so the avionics understand all orientations and positions.

## 3.1. Different types of drones.

There are several different types of drones. For the sake of simplicity, we will introduce the most common ones by categorizing them into these three main types of aircrafts:

- Single rotor helicopter or VTOL (Vertical take-off and landing)
- Mulitrotor or multicopter
- Fixed-wing

There is also a type called VTOL fixed-wing, which will be described later in this chapter.

At least two of these different types have traditionally been used as carriers for regular, manned aircraft, where the third one, the multirotor, has rarely been used for the purpose of transporting personnel.

### 3.1.1. Single rotor helicopter

A single rotor helicopter has typically a single lifting rotor with two or more blades which is best described as a traditional manned helicopter, Figure 3.


**Figure 3. Single rotor helicopter. Credit: Common Creative CC BY-SA 3.0.**

The directional control is maintained by varying blade pitch via servo-actuated mechanical linkage. A single rotor helicopter is generally more difficult to fly. These helicopters have traditionally been using combustion engines rather than electrical propulsions. Many of the large style single rotor drones are still using combustion engines even if there nowadays are battery powered machines available. Compared to electrical motors, this type of motors can induce a lot of vibrations in the fuselage due to the many moving parts. On the other hand, the liquid petrol will have a high level of energy content in relation to its weight, which will give the helicopter a long time and range of action compared to those that would use electrical battery propulsion.

The single rotor helicopter is fast, strong and efficient. It is generally more difficult to fly and usually require a skilled pilot.

Figure 4 shows the Yamaha RMAX helicopter, which is a remotely-piloted helicopter designed for agriculture purposes. It has a two-stroke engine, operating on regular gasoline mixed with two-stroke oil. It has a payload capacity of 16 kg.


**Figure 4. Yamaha RMAX helicopter. Credit: Yamaha**

Figure 5 shows the Skeldar V-200 which has a length of 4 meters and a payload capacity of 40 kg. It can be equipped with different kind of sensors for various tasks. This type of drone is primarily used for harsh environments and missions, typically military or rescue services, where high demands are expected.

**Figure 5**. **Skeldar V-200 VTOL UAV. Credit: UMS Skeldar**

### 3.1.2. Multirotor or multicopter

A multirotor is obviously a rotorcraft with more than one rotor. At least three rotors are necessary to allow the rotor to retain its position in the air but today the four-rotor aircraft is standard. A basic multirotor is shown in Figure 6.

**Figure 6. A multirotor of the type quad or X4. Creative commons.**

The multirotor is aerodynamically unstable, which require its rotors to be controlled by a computer or a *flight controller*. The flight controller takes inputs from several sensors, such as gyros and accelerometers and analysing their values in order to give the correct thrust to every single rotor. It simply would be impossible for a human being to control the individual thrust of all the rotors at the same time while trying to navigate the multirotor in all dimensions. Therefore, a multirotor can't be flown without a flight controller.

Each of the motors will give the ability to manoeuvre the multirotor in all three axes. The controls to this are called pitch, yaw and roll as can be seen in Figure 7.

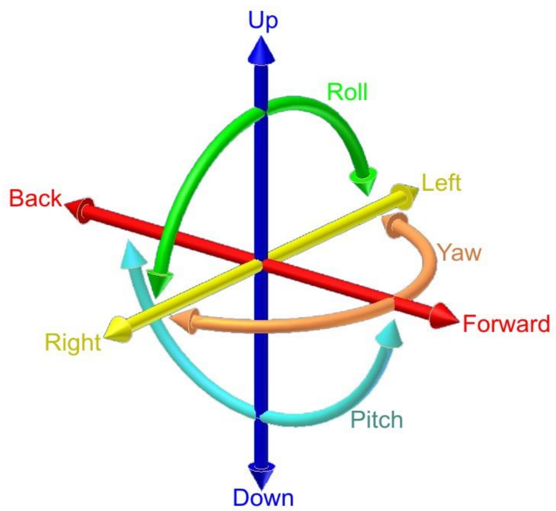


**Figure 7**. **Pitch, roll and yaw represented as a figure.**

The flight controller will also give many technical advantages for the pilot such as possibility to use autopilot features.

The recent decades of innovation with flight controllers and sensors is for sure a strong reason why the multirotor has become so popular and commonly used.

A multirotor named quad or the X4 is a fairly simple and easy design and also the most efficient of the multirotor family. It is designed with four rotors, each of them will spin in the opposite direction than its neighbour.

- The quad will control its *roll* and *pitch* by speeding up two motors on one side and slowing down the other two. For going left (roll) it would speed up motors on the right side of the frame and slow down the two on the left. The same applies if it wants to move forward (pitch): the two forward motors will slow down and the two back will speed up.
- Similarly, the copter can turn around its own axis, *yaw*, by speeding or slowing down motors diagonally across from each other.
- By giving thrust to all rotors altitude is controlled.

All movements are controlled with a remote controller if not flying in any automated flight modes.

Similarly, will the hexacopter and octocopter, which are aircrafts with six, respectively eight rotors, works but the flight controller will make sure to adapt every single rotor to the correct thrust.
The hexacopter and octocopter are also aircrafts that are able to carry more payloads and will be more redundant for the price of complexity and higher costs.

### 3.1.3. Quad or X4

The quad or X4, which is shown in Figure 8 is probably the most common drone today because of its relatively simple design.

**Figure 8. A Solo quad drone from 3DR.**

The airframe of a quad can be designed in different setups, as can be seen in Figure 9. The most common one will probably be the X configuration, which will be a good option for aerial photography as the design of the arms will not block the view of a camera mounted underneath its frame.

The basic and simple construction will make it relatively inexpensive with good flight performance, but it will suffer from no redundancy in case of a rotor failure and low payload capability.

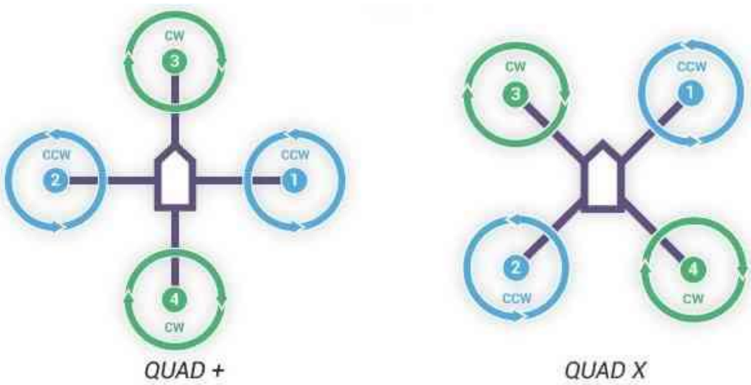


**Figure 9. Different frames will change the motor order diagram.**

The X configuration is also the most common used configuration on commercially sold drones today.

Four motors will not give any redundancy for the quad, which means if one rotor is out, the aircraft will crash.

### 3.1.4.Hexacopter

The hexacopter consist of six rotors in which can be configured in an Y, + or X configuration, as can be seen in Figure 10.

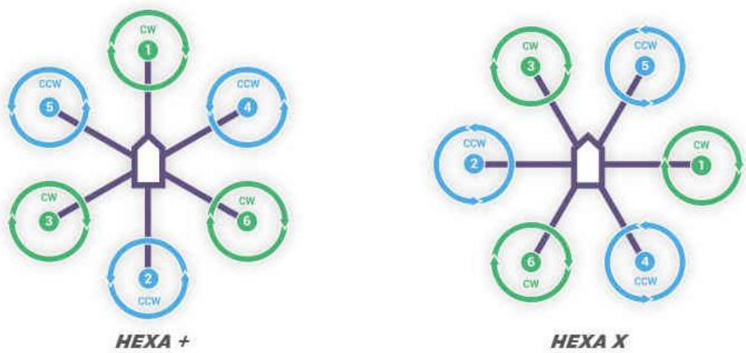


**Figure 10. Different frames for a hexacopter.**

Additional rotors will give the hexacopter more payload capacity than quadcopters. The six rotors will give the aircraft some redundancy and it will easily continue to fly with only five rotors or even four depending on the positioning of the motor outage. As they have more power due to the two extra motors they can reach higher speed.

Some drawbacks of the hexacopter compared to a quad are that they are more expensive, less efficient and increased complexity can make them more failure prone. It also has a larger fuselage means that they may be more difficult to handle, transport and store. In Figure 11 a hexacopter from Yuneec is shown.

**Figure 11. Yuneec Typhoon H hexacopter.**

### 3.1.5. Octocopter

The octocopter, one is shown in Figure 12, is usually a heavy lifter, which allows it to carry even more payload than its smaller siblings. Different setups for the octocopter is +, X or the X8 configuration.

**Figure 12. An octocopter, consequently with eight rotors.**

The X8, or octa quad, is actually a quad frame, in which each arm has two motors, each of them spinning in opposite directions. The setup is called coaxial mount and one of the motors on each arm is facing up and the other one is facing down, as can be seen in Figure 13. This will reduce the weight slightly and add more power and even more wind stability.

**Figure 13. An octocopter configured as X8 with two rotors on each arm.**

The octocopter is a highly redundant machine when it comes to motor outage. It can continue to fly with as many as four rotors failing. The stability in the air is very good and it can withstand a lot of wind and harsh weather conditions. The machine can be heavy and bulky to carry and store, and it also requires a lot of power and batteries, which also may lead to more peripherals and spare parts to handle. Overall this will make such a system more expensive.

There are rarely any octocopters reasonably priced for recreational use, most of the drones for the mass market today are oriented on quads or hexacopters. Still, enterprise drones for demanding users, will be available from several manufacturers that will provide octocopters for customers with specific needs. A large part of the market for octocopters is focused on professional cinematic and video production, where large and heavy cameras and gimbals are required together with reliability.

In (Gustafsson & Bendz, D8.5 Guidelines for drone useage in arctic environments, 2018) additional details and pros and cons for a few of the most common multirotors are described.

### 3.1.6. Fixed-wing aircraft

A fixed-wing aircraft must have air moving over their wings in order to generate lift. Therefore, they have to stay in forward motion all the time and will not be able to hover in one spot like a multirotor or single rotor helicopter can. Figure 14 shows a fixed-wing aircraft from Lehmann Aviation.

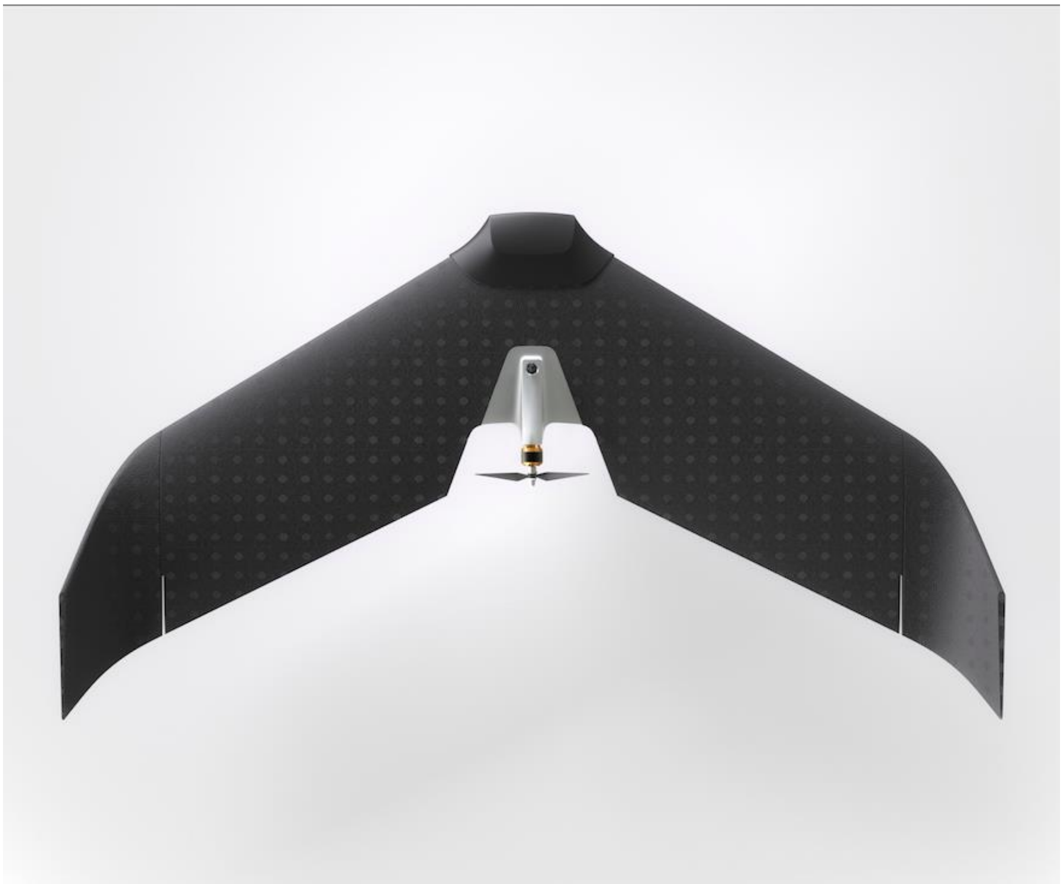

**Figure 14. Lehmann Aviation L-A series line of fully automatic aircraft released in 2016. Credit: Creative commons.**

In theory, the motion over ground can be zero, as long as the wind, passing over the wings, will exceed a certain level, which will then generate the lift. This means that a very strong wind, towards the aircraft, would be able to keep the fixed-wing aircraft in the air even though it is not moving forward.

Large style fixed-wing drones will use combustion engine motors. Wankel rotary engines are often used for this purpose, because of their small size, low weight, low vibration and high power to weight ratio.

A fixed-wing aircraft doesn't need a flight controller to perform a flight. For very basic flying it requires the propeller thrust, the throttle, to be configured together with the rudder on each wing. This will allow the fixed-wing to pitch roll and yaw. These movements are shown in Figure 15. In addition to that, there will be the throttle, which is basically the amount of thrust that is given to the propulsion, the propeller.

 

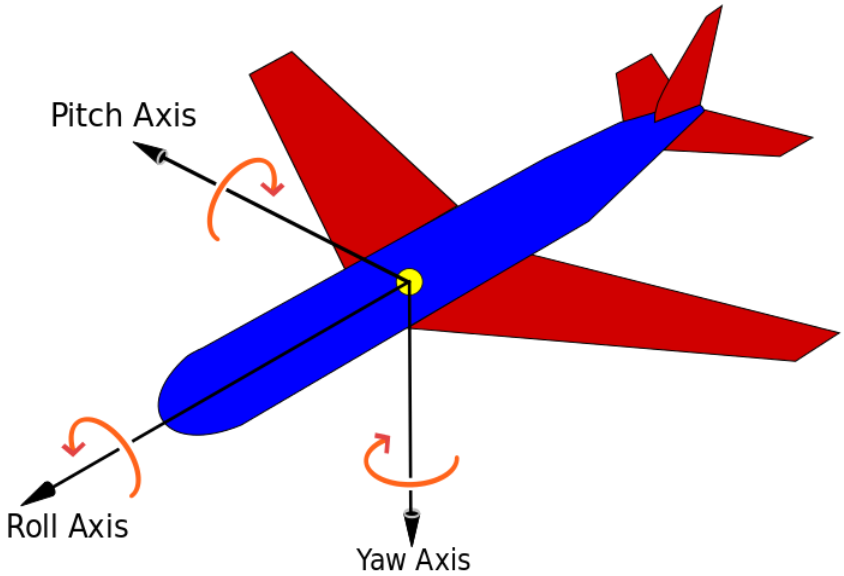


**Figure 15. An illustration of pitch, yaw and roll on a fixed-wing aircraft.**

Even though a flight controller isn't necessary, most drone fixed-wing aircrafts will be equipped with one. This will add a lot of extra features, for example exact positioning and autopilot which will allow the pilot to pre-program a specific route. The procurement of a fixed-wing drone for any Arctic mission should therefore include a flight controller at any time unless it is solely for training use.

A fixed-wing aircraft is usually a bit more forgiving in the air in the face of both piloting and technical errors. One example of that is that they have natural gliding capabilities with no power as long as the wings will generate lift. Fixed-wing aircraft also can carry greater payloads for longer distances with less power.

Fixed-winged drones traditionally utilize runways for take-off and landing. They can, however, also be launched by catapult and land with the help of parachutes. This will make it a bit less difficult for an unexperienced user.


**Figure 16. A large fixed wing drone with high payload capacity.**

For longer missions and to carry larger payloads with only minor requirement for precision, a fixed-wing aircraft is usually ideal. In Figure 16 the size of a large fixed-wing drone is shown in relation to a person.

### 3.1.7.VTOL fixed wing

In addition to the above described drone types there are also aircrafts that can take advantage of both the fixed-wing and the multirotor technology which will make it able to do VTOL and by the same time gain benefit from the fixed wing advantages. This is shown in Figure 17.


**Figure 17. A VTOL fixed-wing drone ready for take-off.**

The fixed-wing VTOL technology can be expected to take a greater part of the market as users may request easy to use drone systems in the future.

## *3.2. System components*

### 3.2.1. Propellers

One of the first thing one may notice on a drone is the propellers, no matter what type of drone it is.

Propellers are usually made of plastic, which on the very cheap models tend to be soft and flexible. The popular but low ranged priced drones, like DJI Phantom or Mavic models are shipped with plastic propellers that are reasonably stiff and non or low flexible. Plastic propellers will do for most of the basic machines and missions. They should normally not be replaced with any carbon fibre propellers as the user may not be able to take advantage of any increased performance and they can also induce unwanted vibrations or in the machine or cracks in the fuselage of the drone.

Carbon fibre propellers are usually shipped with high end and heavy lifting machines. The carbon fibre propellers are extremely hard and will not flex like a plastic propeller will and therefore give the drone a very good performance and better efficiency. Carbon fibre propellers are more expensive, and the pilot should take extra caution. If a rotating plastic propeller will slice half of a finger, a rotating carbon fibre one will easily cut a finger in case of an accident.

There are also wood propellers that may seems a bit old fashioned but in fact they have similar characteristics as the carbon fibre ones but with slightly less price.

### 3.2.2. Flight controller

The multirotor is an aerodynamically unstable drone and where the user wants to use features such as autopiloting and sensor integrations in a drone, there is a need for a flight controller.

A flight controller, shown in Figure 18, has an inertial measurement unit (IMU), which is a unit that measures and reports the angular rate, acceleration, and sometimes the magnetic field surrounding it. The flight controller takes the IMU data and combines it with inputs from the pilot together with data from several other sensors, such as compasses and GNSS. The result will be that the flight controller can give the correct motor thrust to each propeller in order to keep the drone in desired position.

The flight controller is, for most modern multi rotors that can be found on the commercial market, an integrated unit that the pilot doesn't need to care about. All the features are loaded into the unit during the manufacturing of the aircraft. New features can be automatically updated with less or no interaction from the user. In fact, the terminology flight controller is seldom used, as they are an integrated part of the drone nowadays and the user seldom need to care about it.


**Figure 18. A Pixhawk 2 flight controller from ProfiCNC.**

However, there are several flight controllers that can be modified and adapted as requested by the pilot. The flight controller will be equipped with several inputs and outputs which will also allow external hardware such as sensors, motors and other peripherals to be connected to the unit. This will give the operator the ability to custom configure his or her aircraft and, from scratch, design the drone for a specific mission or task.

For some scientific missions in the Arctic, a custom-made drone with a specific flight controller, may be the only option and it will also allow the scientist to retrieve several useful parameters collected during the flight.

### 3.2.3. GNSS

Global Navigation Satellite System (GNSS) is without doubt one of the most important technologies for UAV navigation.

GNSS primarily covers the American system GPS and Russian GLONASS together with the European Galileo and Chinese Beidou.

GNSS is based on distance measurement between GNSS satellites and GNSS receivers. The measurement technology is passive, which means that the user only receives signals from the satellites. GNSS satellites have at all times known positions in a global reference system. By measuring the distance to a large number of GNSS satellites, the user can determine the position in the same reference system.

Most GNSS, including those in drones available on the market today receive and combine signals from GPS and GLONASS. The accuracy are about one meter or even better as long as good receiver signals from the satellites are available.

The received GNSS signals in the Arctic areas are usually of less signal strength than on other places on earth, which makes flying with GNSS support in the Arctic a bit riskier. The reason for this is the longer signal path from the satellites to the northern parts of the globe which attenuates the signal a bit more, in combination with a more noise prone atmosphere by the poles.

The utilization of GNSS in drones is usually combined with (and often even requires) an additional magnetic compass.

In addition to support with position, GNSS can also support the drone with how the aircraft is positioned but only if the aircraft stays in any motion (for example a fixed-wing). Information regarding how the drone is positioned is normally given by the compass.

### 3.2.4. Compass

While GNSS such as GPS and GLONASS will give the position of a drone, the compass will tell how the drone is positioned. This is specifically important for a multirotor, which relies on a compass to tell how it is positioned, with other means: what is the front and what is the back of the drone.

Data from GNSS may tell how a unit is positioned but only under the circumstances that it stays in motion. As a multirotor may not always stay in any motion, as a fixed-wing aircraft will do, the GNSS won’t be able to tell how the multirotor is positioned.

There are some certain error sources with the use of a magnetic compass. One is of course that there may be magnetic interferences nearby the area where the drone is flying. This is called magnetic deviation. Another is that the geographic north pole and the magnetic north pole are located in different positions. This is called magnetic inclination. The inclination varies according to where you are located on the globe and will give a large inclination in the Arctic regions compared to lower latitudes.

The compass inclination and deviation, together with the error sources, described under the 3.2.3 section, will all contribute to the difficulties of flying drones in the Arctic.

Gyroscopic compasses (gyrocompasses) are not affected by the magnetic location; they are, however, heavy, bulky and relatively expensive. Digital gyrocompass systems provide a lightweight option for the price of a minor loss in accuracy (Gyro developments, u.d.).

### 3.2.5. Real Time Kinematic

Real Time Kinematic (RTK) is a precise form of positioning with GNSS that requires at least two interoperable GNSS receivers, a fixed base station that sends out correction information and a moving rover, which, thanks to the correction information, can calculate its position. Normally, a user will encounter an inaccuracy of position of up to several meters, especially in Z direction (altitude), depending on the GNSS equipment, but with RTK it is possible to get centimetre accuracy relative to the base station.

The corrections can be sent via radio link, telemetry or mobile internet.

Many geographic areas in several countries have established a network for this purpose, which is called network RTK. Usually a mobile cellular network based on GSM is used to distribute the correction signal.
As many of the Arctic areas will neither have any established network RTK, nor even a GSM network, the user itself would need to establish a local base station. The Rover, which will be placed on the drone, will then receive correction signals from the base station, which will be used to add precise positioning for the drone.

The market for drones equipped with RTK is relatively small but slowly growing as drones becomes a more important part for projects that involves ground measurements and positioning of any kind. Small RTK systems are now affordable to add to a drone solution.

### 3.2.6. Remote controller

The remote controller, hand controller or ground controller is the very important unit that will give the operator ability to interact and give control to the drone from a remote area. For basic operation, a remote control that will transform the pilot inputs from the sticks to the drone is the least requirement. The pilot must monitor the aircraft during the flight mission, either by the software that may come with the drone or by visual, to determine that the input correlate to the desired movement of the drone.

Nowadays, nearly all remote controllers that comes with a drone kit are combined with a feature that will present relevant flight data from the drone, including a video feed, on a tablet or a telephone attached to the controller. This can be seen in Figure 19.

**Figure 19. A remote controller with an additional tablet running specific software on it (DJI).**

The pilot connects the tablet to the controller and thanks to a specific software, running on the tablet, many of the features of the drone will become available directly on the screen. Some controller comes with an integrated tablet or video screen, which reduces the need for an external tablet. This is a very good option to avoid hassle free operation and nearly instant take off.

Still, some custom-made drones will come with generic remote controllers, like the one shown in Figure 20, that will need a deep knowledge in order to configure it correctly.


**Figure 20. An advanced remote controller from Futaba.**

From the software on the tablet, the pilot can set up auto piloted missions, persons/vehicle tracking, camera settings and many more of the features provided. This can be seen in Figure 21.

The tablet isn't really necessary to control the drone itself and the machine can still be manoeuvrable if the tablet or telephone fails. However, the drone then needs to be controlled all by manual sticks input and within visual line of sight. This is an important reason to always keep the drone within line of sight.

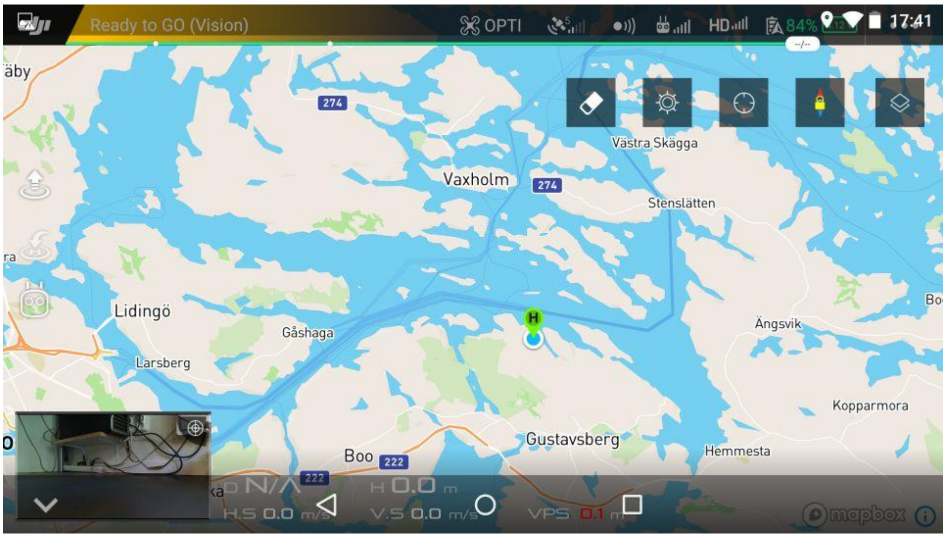


**Figure 21. Screenshot from the software running on the tablet to be able to control the drone.**

Even though a photo mission may not be the primarily reason for flying, the pilot is likely to have a camera for safety and to assist the navigation through the mission.

### 3.2.7.Ground station

There might be a fuzzy line between a ground station and a remote controller with a tablet (described in section 3.2.6), where the remote controller and tablet in fact is a ground station. To clarify the difference between the remote controller and a ground station, it is said that a ground station includes a typical software application, which can be combined with some specific hardware needed and running on a tablet or a computer.

**Figure 22. A ground station from Riegl. © Riegl.**

The ground station communicates with the UAV through a wireless link. Sometimes the ground station can be complex and advanced and involves additional equipment used for the mission. The most basic solution will however be at least a tablet or a computer, which normally are compatible only where custom made drone solutions are acquired. A ground station often refers to a complete set or a box, where a manufacturer has bundled a complete system for field use. Such a system is shown in Figure 22. In Figure 23 a screenshot from a ground station software is shown.


**Figure 23. Screenshot from a specific software used as ground station.**

The complexity of setting up and use a ground station more extensive than what's described above, leaves us to the recommendation that it should be performed by advanced and experienced users if not acquired by a supplier or contractor.

### 3.2.8. Wireless communication

All drone systems will need to use any type of wireless communication between the drone and the pilot. This is usually done with equipment using frequencies around 2.4 GHz and 5.8 GHz. Sometimes mobile telephony and the cellular network is used for controlling the drone. There are also some systems that uses 433 MHz, 868 MHz or 915 MHz for communication which can be in combination with the higher frequencies above.

Some wireless communication systems can interfere with other, even though it is rare.

Manufacturers of COTS drones today will have their equipment adapted to different regions, which will have different regulations. North America and Europe are using slightly different specifications and frequencies.

The use of electronic communication within a specific country must comply with the national legislation for the country. Normally, a national post and telecom agency will have the responsibility for that.

For the users and pilots there is, in most cases, no need to worry about this. Today COTS drones will adapt to the region where it should be used, but there may be situations where the user has to ensure that the specifications meet the legislation. This applies to primarily high-end drones or custom-built ones and for this specific case the user should consider support from the manufacturer or service provider.

When it comes to using drones in INTERACT research stations, the above will apply for most situations but there are some exemptions, like in Ny-Ålesund in Svalbard, which is a radio-silent area and all use of wireless equipment is prohibited. This will of course include drones, as they use wireless communication, but also mobile phones and wireless equipment on laptops needed to control the drone.

### 3.2.9. Batteries

Today, nearly all batteries for modern drones are some sort of lithium batteries. Two common battery types are lithium-ion battery (LIB) and lithium polymer battery (LiPo). LiPo batteries are commonly used for drone applications. Figure 24 shows a typical battery for a mobile telephone.


**Figure 24. Lithium battery for a mobile telephone. Credit Creative Commons.**

Different types of batteries have a nominal voltage, which varies slightly depending on the type of battery it is. Usually, several battery cells are connected in serial to increase the voltage or in parallel to increase the current rating. A battery pack will be two or more batteries with a total output voltage that is multiplied with the nominal voltage and the number of cells.

Many consumer drones have a battery pack that consists of 3-6 lithium cells, thus making the output voltage of the battery to be somewhere between around 12-25 Volts. Moreover, apart from the voltage, the energy content of a battery will be dependent of another factor which is the current (A) rating. A large nominal current of a battery will have a greater energy content. Fortunately, these parameters are something that a user rarely need to reflect on, but it can be good to remember at least that large and heavy machines requires more power and usually use batteries with many cells and high current (A) rating unlike small machines that will use just a few cells. The battery capacity will highly affect the total price of a drone system.

Multiplying the current and voltage rating will give the Watt-hour (Wh) rating and this is probably the only thing a user need to be aware of. The Wh rating is normally printed on the battery. This is important when transporting batteries on a commercial aircraft, as the rating will need to correlate with the guidelines issued by IATA. This is covered in IATA DGR (IATA Dangerous Goods Regulations, u.d.) and is described further in (Gustafsson & Bendz, D8.5 Guidelines for drone useage in arctic environments, 2018).

A lithium-type battery requires a very accurate charging process. Few persons need to worry about this because most consumer batteries are so called smart batteries. Examples of smart batteries can be seen in Figure 25. Smart batteries means they have built-in electronics that take care of charging and monitoring. Thanks to internal sensors they can report faulty battery cells and also report if the temperature becomes too high or too low.


**Figure 25. Two types of smart batteries.**

Safety precautions when handling, charging and using lithium batteries must be taken. Smart batteries are good options because they will always monitor the battery, reducing the risks to handling and transporting them correctly.

A burning lithium battery is extremely difficult to extinguish and requires specific fire extinguishers. They will burn with a high temperature, will initiate a lot of smoke and unfortunately surely ignite other combustible materials, leading to a chain reaction if other batteries are nearby. The devastating result of a LiPo fire can be seen in Figure 26.

**Figure 26. Burned out lithium batteries on a workbench where nearby batteries have been ignited from the others.**

One important thing to remember with smart batteries is that some of them have a built-in feature that automatically discharges the batteries when they haven't been used for a period of time. This is normally set to around ten days but can usually be set up as desired. The batteries will discharge to about 70% and the reason for this is that long time storage of fully charged lithium batteries should be avoided, as they may expand, and their life-span may be shortened. Therefore, if the drone and the battery haven't been used for a while, make sure to check and if necessary, always charge the batteries prior to a mission.

## 3.3. Obstacle avoidance

Many drones today, even the smallest and cheapest ones, come with obstacle detection and collision avoidance sensors.

The obstacle detection and avoidance can spot objects in front, behind, below and on the side of the drone, depending on where the drone has its sensors. The technology to achieve this does often use one or several cameras that constantly will monitor the surrounding terrain and by advanced image processing, calculate what is actually an object or obstacle. Other methods of collecting this information can be with infrared or ultrasonic sensors. Laser or microwave sensors are also possible to use, even if they are not that commonly used yet.

The data from the sensors can tell the drone and the pilot either to stop, or if in an automatic flight mode, to fly around, above or else avoid colliding with the detected object.

The pilot must always remember that even though the obstacle avoidance technology today is quite well developed, there will always be a slightly influence from error sources, as some objects may not be possible to clearly identify as dangerous. One specific example of this might be a tree. A tree with leaves on all the branches may be detected, while a tree without any leaves might not, which may of course lead to a collision.

### *3.4. FPV googles*

First-person viewing (FPV) means seeing what the drone sees in real-time, which is of course the case when watching a video feed on a tablet connected to a remote controller for the drone. However, more often FPV refers to the use of so called FPV googles, with the camera view from the drone monitored inside the googles instead of on a tablet screen.

Flying FPV will give a bit of another flying experience, more like being "on board", but it requires a bit of training to adopt to the situation where a pilot cannot suddenly switch focus to the drone in the sky because the eyes are locked up in the FPV googles. At the same time, FPV flying opens up for getting rid of problems that can be common when flying in Arctic environments, like intense sunlight or lack of contrasts. A typical set of FPV googles can be seen in Figure 27.


**Figure 27. FPV googles from Fat Shark.**

It is important to remember that since the pilot is actually not able to see the drone in the air, this makes it difficult to discover other flying objects as well as obstacles. FPV flying is not allowed under several countries legislation. When flying FPV, relevant navigational data can be displayed with an on-screen layout, like in Figure 28, reducing the pilot to rely solely on those parameters. Therefore, it can be necessary to bring a spotter, someone who can look at your drone and support you with relevant flight data parameters while you fly via FPV. This will reduce the risk of crashing the drone.

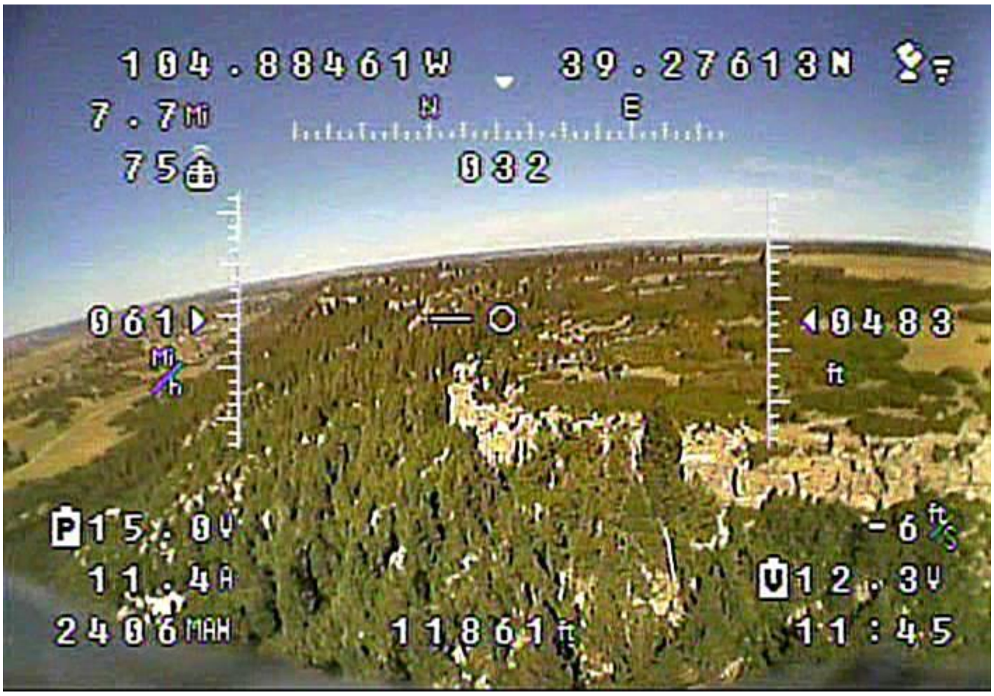


**Figure 28. Typical FPV video feed with on-screen display (OSD). Creative Commons, Patrick McKay.**

FPV flying has become a large sport, drone racing, involving many peoples around the world, flying small racer drones equipped with cameras (The Trippy, High-Speed World of Drone Racing, 2018), (Drone racing, u.d.).

## *3.5. Operating in cold temperature*

Usually consumer electronics, which includes many of the drones on the market today, are classified within an operating range between 0-40 degrees Celsius (32-104 F). This means that the manufacturer will guarantee that the unit will work as expected within that range. Still, it doesn't put any constraints to the units to be used outside that range. In the Arctic, there might of course be temperatures well below zero degrees Celsius. Generally, even if many flights in the Arctic may take place when the temperature is outside the specifications from the manufacturer, it can be good to remember that it is still just a specification where the manufacturer will guarantee its functionality. The drone will, for most cases, be able to operate as normal. Still, it is important to comply with the other requirements and recommendations typical for the Arctic, described in this document.

## *3.6. Ice, snow and precipitation*

A risk factor for all types of aircrafts is icing. Traditional helicopter systems have solved these issues through automatic de-icing systems or by avoiding flights under meteorologically risky weather conditions. Figure 29 shows clouds and mist during winter time and where the temperature is below or just below zero degrees Celsius. Flying under this condition with a multirotor will likely generate icing on the propellers and possibly also on the fuselage.


**Figure 29. Clouds and mist in a suburban area during winter.**

There are several methods for de-icing – the removal of snow and ice from a surface, and anti-icing – snow and ice removal that also delays the reformation of ice, e.g. applying glycol to the wings (Beisswenger) or leading the heated exhaust (of a combustion powered machine) through vulnerable parts.

Commercial aircrafts will have their wings and fuselage treated with hot glycol mixture before take-off if conditions require it.

Kim Sørensen is a Postdoctoral Fellow at the Norwegian University of Science and Technology (NTNU) whose research area is “icing and anti-icing of unmanned aerial vehicles (UAV's)”. Sørensen states that anti-icing systems can be divided into three categories: Chemical, Electro-thermal, and Mechanical; each are explained in-depth in his Ph.D. thesis (Sørensen, 2016). He has developed his own electro-thermal system, seeking to optimize the heating algorithm. Electrical heating can otherwise be problematic, as battery capacity is both the most crucial and most finite resource for airborne drones.

## *3.7. Different drones on the market*

The following examples of hardware will not present any high-end enterprise drone systems as those solutions will require a deep and long-standing knowledge together with an extensive tender and procurement process.

The sections will instead provide a few examples on drones that are fairly easy to obtain. A user with no or little experience will probably need a few advices prior to the first purchase, while the already experienced

pilot can find it useful to get an opinion about what to start looking for.
The development of the drone technology is very fast and within a few years, the market will be very different. A good advice for a beginner is to not focus on technical parts and start with the lower priced models and further on instead learn the basic knowledge like how to operate a drone and to comply with common and specific legislation. This will give a good balance to develop on the learning curve. Starting small scale will also reduce the risk of burning a large budget on incidents or crashes, which will eventually occur.

Even though there are several drone manufacturers on the market today there is no doubt that the Chinese company DJI has become one of the leading providers and have set a de facto standard for beginners as well as professional that want to use drones. Their models are well developed and their competitors having a hard time to challenge their market position. This guide will present a few of them together with others drones that might be useful for the Arctic research.

Many of the technical details and specifications has intentionally been omitted in favour of regular body text.

### 3.7.1. Hubsan X4 and Ryze Tello

For about 50 Euros it is possible to buy a Hubsan X4 and for the double price it is possible to get a Ryze Tello.

For a scientist, there is probably only one reason to buy any of these two drones for professional use, which would be learning to control and fly the drone. The low price, of course, means rationalization. Even though the price is low, any of the two drones will be an excellent training platform without risking the budget for a project. Ryze Tello, in Figure 30, has a camera with a simple stabilization but for a machine like this, the camera is hardly able to be used for any scientific work.

**Figure 30. Ryze Tello.**

Hubsan X4, in Figure 31, comes with or without a camera and a hand controller. The Ryze Tello needs to add an optional hand controller. The battery life is limited and no one of them will have advanced features like GNSS navigation or advanced obstacle avoidance but that means that learning to fly these aircrafts will ensure that the pilot will be skilled enough to step up to any larger multirotor drone.

**Figure 31. Hubsan X4 with hand controller.**

These are two aircrafts for beginners and any of them should be mandatory as a first purchase for any person that are about to start using drones. Fly them indoors and continue outdoors any day with less or no wind.

### 3.7.2. DJI Mavic 2 Pro/Mavic 2 Zoom

When DJI released the first Mavic many were amazed by its small size and good performance. Generation 2 of the Mavic has evolved a few times since its first versions. The Mavic 2 was released in the end of August 2018 and they have now even better specifications than its predecessors.

The Pro 2 version has a 1” 20 Megapixels sensor while the Mavic 2 Zoom have a slightly smaller one with 12 Megapixels but on the other hand, the camera features a 4x zoom lens, which will make it possible to catch details from a distance. The camera on the Pro comes from the famous camera manufacturer Hasselblad. This means that there are two choices for the user which can be seen in Figure 32.


**Figure 32. Mavic 2 Zoom to the left and Mavic 2 Pro to the right.**

The drones have other similar or identical features like Phantom or Inspire and a 3-axis gimbal will make sure that the camera will deliver smooth and nice movie shots in 4k resolution.

These drones are not recommended to be used for photogrammetry due to their electronic shutter.

The aircraft is extremely portable, with foldable arms and propellers and together with the hand controller, which will require an additional tablet or telephone, it will almost always fit.

The pilot can also take advantages of an omni obstacle avoidance sensors, which mean that the drone will automatically assist to not fly into any objects or obstacles.

Overall, the DJI Mavic 2 Pro/Zoom are two very affordable and neat drones that will fit perfect inside any scientist’s toolbox when going out for an expedition.

### 3.7.3. Parrot Anafi

The Parrot Anafi is a small quad that is orientated on the market for adventurer. Unlike many other drones in this category it has a 2,8 x optical zoom for the camera. The drone is shown in Figure 33.
The Anafi is very compact and foldable which makes it easy to transport and according to the manufacturer it has a robust construction that also will withstand low temperatures.


**Figure 33. Parrot Anafi.**

The drone has some other innovative features like charging from a standard USB-C charger and a gimbal and camera that can be tilted 180 degrees, which allows it to record movies or taking pictures underneath constructions or obstacles which can be useful in some situations.
The drone hit the market during July 2018 and only a few reviews of the drone has been published yet and of course the DJI Mavic series are one of the main competitors in this case, which may consider the user to choose that one instead of the Anafi. In any case the Parrot Anafi may be an alternative for a user that wants to try something else and wants a small and compact drone for taking basic pictures and movies.

### 3.7.4. DJI Phantom 4/4 Pro

The DJI Phantom series has demonstrated several classic machines throughout the years, of which all of them has contributed well to the drone trend. Figure 34 shows the fourth generation Phantom, which delivers a mid-compact drone with excellent flight performance for up to about 25 minutes and sensors that will support with navigation and obstacle avoiding. The software will allow several advanced and automated flight modes, for example object tracking.

Like most of the COTS drones, there is no possibility to replace the camera with any other sensor unless the drone undergoes a rough do-it-yourself modification.

However, the camera will deliver excellent 4k movies and reasonably good quality still pictures. With a bit of knowledge, it can be used for photogrammetry missions even though there might be better options for such a task.

**Figure 34. DJI Phantom 4 Pro.**

The Phantom 4 will come in different models and it can be tricky to distinguish the difference between them.

The Phantom 4 Pro and Advanced will have a slightly better camera with 20 Megapixels camera instead of 12.4 Megapixels for the Phantom 4. If in doubt about still picture quality, choose the Pro or Advanced version.

If there is a "+" marking after the model, for example Phantom 4 Pro +, the drone will come with a built-in display on the hand controller. The screen is very bright and will increase readiness in bright sunlight which is excellent for any Arctic mission with lots of sun and white snow. It will also make the operation very easy, just put the drone on the ground and turn on the power buttons and the pilot can take off in a minute. The downsides are that the built-in display has a rather small screen and it will be a bit more difficult to install other software than what DJI has bundled it with.

The Phantom 4 and Phantom 4 Advanced have obstacle avoidance sensors at the front, while the Phantom 4 Pro has additional sensors on the sides, and on the rear. This means you can fly it side to side and backward, while still taking advantage of its obstacle avoidance technology. This drastically lowers the probability of a crash with the Pro version. All of the Phantom 4 drones have downward vision systems to support with landing.

### 3.7.5. DJI Inspire 2

The DJI Inspire series will, like the Phantom 4 product line, have several different models to choose from.

DJI Inspire 2 is the second generation, mainly used by professional or semi-professional cinematographer, which in the Inspire series find an excellent aircraft, with the possibility to use two hand controllers, one for controlling the drone and one for controlling the camera with all the settings and the gimbal movements.

The resolution compared to the Phantom will extend to up to 6k for movies and flight time and maximal control range will be more or less as good as with a Phantom. For scientific research it might find a place in the Arctic as it has a self-heating technology, which allows it to fly in low temperatures. The Inspire 2 can be seen in Figure 35.

**Figure 35. A DJI Inspire 2 with detachable camera and gimbal.**

Like the Phantom, it will also have different cameras but unlike its smaller sibling, it will be possible to replace the cameras and gimbals. There are numerous of both different gimbals and lenses with various focal length making up several different combinations adapted to what the user wants. One great advantage is that it is possible to mount a thermal camera underneath the drone. This will of course expand the use for scientists doing research in the Arctic, requesting this possibility.

The drawback with the Inspire series is that, besides from the much higher price tag, it is a bit bulkier aircraft. It can be operated by a single person but will need two persons to use its fully potential.

Summarized, the Inspire 2 is a great aircraft for making high quality recordings and taking great pictures but for some specific scientific research tasks in the Arctic, it might not be spot on, bearing in mind that the price tag is quite high and the benefit of high quality recording capabilities for an Arctic scientist could be discussed. More or less the same amount of money could rather be spent on any other drone for the industrial market or even a custom made one.

The price will start a bit over 3000 Euros for just the drone but will easily add up to at least the double with a camera, a gimbal and few accessories.

### 3.7.6. DJI Matrice 200 series

The Matrice 200 series may seem to be flirting directly with the users in the Arctic as it has several usable features such as preheated, dual battery system, IP34 ingress protection, a flight time over 30 minutes and a maximum payload capacity of 2 kilograms.

**Figure 36. DJI Matrice 200 series.**

There are several possibilities to configure the drone with custom payloads like sensors and different cameras which also can be thermal cameras. It even allows the pilot to have dual cameras with the option to use an upward gimbal with camera which may be ideal for inspections under obstacles. Figure 36 shows the drone with a camera mount on a gimbal underneath the drone. For photogrammetry missions or other operations that requires precise navigation, there is a RTK option for the Matrice.

Yet, it is important to remember that the payload needs to be DJI compatible, which means that custom designed payloads may not fit without advanced modification. This is a drone for professionals or organizations that know how to use it and will use it for that purpose. It is also a drone with quite high price tag, which means that it isn't affordable for everyone.

DJI is a large player on the drone market for cinematographer and others interested in media and movie production. The Matrice is a product for the industrial sector, where DJI historically hasn't been a great player of that market. All users should take a good look and do a proper research of the enterprise drone market before any procurement of an Matrice as there may be even better options. Buying a Matrice or any other similar drone in this segment is also a typical example on when a complete drone solution, including support and service is desired and indeed recommended.

The price starts around 6000 Euros but will end up with at least the double or even triple when the optional sensors, cameras and accessories are added.

### 3.7.7. Trimble ZX5

Trimble is a large world-wide company within the land survey, construction, agriculture, and Telecommunications sector. The Trimble ZX5 in Figure 37 is a drone that is prepared and adapted to fit directly into the set of software that Trimble offers to produce orthophotos, digital elevation models, point clouds, volume calculation and 3D models.

**Figure 37. Trimble ZX5 equipped with a camera.**

This drone is close to be something between a custom-made drone and a drone solution but where the users can operate the system by themselves. In addition to that, Trimble offers training packages and often also the possibility to rent equipment for land surveying. The price tag will be much higher that any COTS drone on the market.

One of Trimble's main competitor is Leica, which will provide similar solutions together with their partnership with DJI and offers high-end systems for the same disciplines as Trimble.

### 3.7.8. Riegl RiCopter

Another example of commercial drones for the professional market is the Riegl RiCopter, an adaptable platform with support for a multitude of sensors, such as laser scanners or infrared and multi-spectral cameras. The RiCopter is a large drone, as can be seen in Figure 38. Riegl is at its core a laser measurement company, offering laser solutions for terrestrial, airborne (both unmanned and traditional aircraft), mobile and industrial use. This is an example of drones being marketed, not as a vehicle, but rather as a solution for transporting specific equipment.

**Figure 38. A large ocotocopter built as X8 from Riegl. © Riegl.**

### 3.7.9. eBee and eBee SQ from Sensefly

The eBee Plus, shown in Figure 39, and eBee Classic are two fixed-wing aircraft from the company Sensefly, which is commercial drone subsidiary of the Parrot Group. Parrot is a large drone manufacturer, both for the private and business market, and might be one of the few companies that are large enough to be compared with the dominating DJI.

**Figure 39. eBee Plus fixed-wing drone from Sensefly.**

A well-developed autopilot will make the flying easy going, even for beginner who is new to fixed-wing drones. The eBee's can cover large areas, delivering high resolution pictures, which makes them ideal for producing digital terrain models, point clouds and 3D models.

There are a few options when it comes to cameras for the eBee's; traditional cameras optimized for photogrammetry mapping as well as infrared and multispectral ones.

Photogrammetry software like Pix4D or Airware will match and process the results that comes out from the hardware of the eBee's.

eBee SQ is the agriculture drone and can be used to capture actionable crop data across four multispectral bands, plus RGB imagery. The size and dimensions are similar to the other eBee Plus/Classic but the SQ version is designed to be used with the Parrot Sequoia multispectral sensor.

The price for a system like this will be in parity with any other enterprise systems, which means several times higher than a traditional COTS drone for recreational use.

### 3.7.10. Wingtra

WingtraOne is a Vertical Take-Off and Landing (VTOL) drone and is what could be described as the best of two worlds: the fixed wing for a high endurance and speed with long flight time while the two rotors will allow the drone to take-off and land vertically. The drone can be seen inFigure 40.


**Figure 40. WingtraOne fixed wing ready for VTOL (Wingtra, 2018)**

While some other fixed-wing drones needs both a catapult and a parachute, WingtraOne will need just a 2x2 meter area from where it can take-off. A typical site for this may be a vessel or a small roof.

Equipped with a Sony RX1RII camera the drone will take high resolution images that can be used to do aerial mapping with 1 cm/px and 1 cm accuracy.

This is another enterprise system, that attracts customers that care a bit less about the price tag.

# 4. Sensor technologies

In order for the drone to really contribute to environmental research in the Arctic, the drone needs to be equipped with some sort of sensor that can record the specific type of data of interest for a researcher.

There are innumerous types of applications for research in the Arctic environment. Interviews with researchers indicates a variety of different areas such as; detailed 3D mapping, counting animal populations, measure snow coverage and depth, vegetation mapping, temperature measurements (air, ground, water), collect samples, radar measurements, greenhouse gas (GHG) measurements, etc.

Finding the right sensor for a particular application is not trivial. There are a lot of questions that should be considered before deciding upon any specific sensor. Some of these questions could be as follows:

- Do we already have a sensor or at least a similar kind of sensor?
- What are the requirements on the sensor?
- Can we build one or do we buy/rent one?
- Should we choose the sensor to fit any existing drone platform or vice versa?
- What to do with the collected data?

This document, together with (Gustafsson, o.a., 2018), contains descriptions and applications of different types of sensors that have been identified as having a potential for being useful for environmental research in Arctic environments.

## *4.1. Gas, pressure and temperature*

Sensors for measuring e.g., gas concentration, pressure, temperature, and humidity can be made physically small and lightweight. This is advantageous for smaller drones with payload limits and restricted power supply. Bosch has developed a combined sensor for barometric pressure and temperature which is only a few millimetres in size (Bosch, 2017).

There are solutions for integrating a drone with a combination of several sensors on a main board. One such system can combine measurements of e.g. temperature, $CH_4$, and CO (International Met Systems, 2017).

## *4.2. Photography*

### 4.2.1. Cameras

Like any modern digital camera, a camera for a drone will consist of the most vital parts: a sensor, a lens and some kind of electronics that will collect and process the values from the sensor and send these values to a location for storage. Cameras designed for cheaper commercial drones, which are sold as a package, are in most cases integrated in the drone platform and non-replaceable. Some more high-end drones will have cameras with interchangeable lenses, which allows the operator to choose different focal length and quality as desired.

Additionally there are standard cameras available at the commercial market, which sometimes are attached to the drone.

### 4.2.2.Gimbals

The single most common sensor on a drone today is the camera. Nearly all commercially available drone come equipped with some sort of camera.

A common item is also to have the camera mounted on a gimbal. A gimbal is a pivoted support that allows the rotation of a camera lens around its axis, like can be seen in Figure 41.

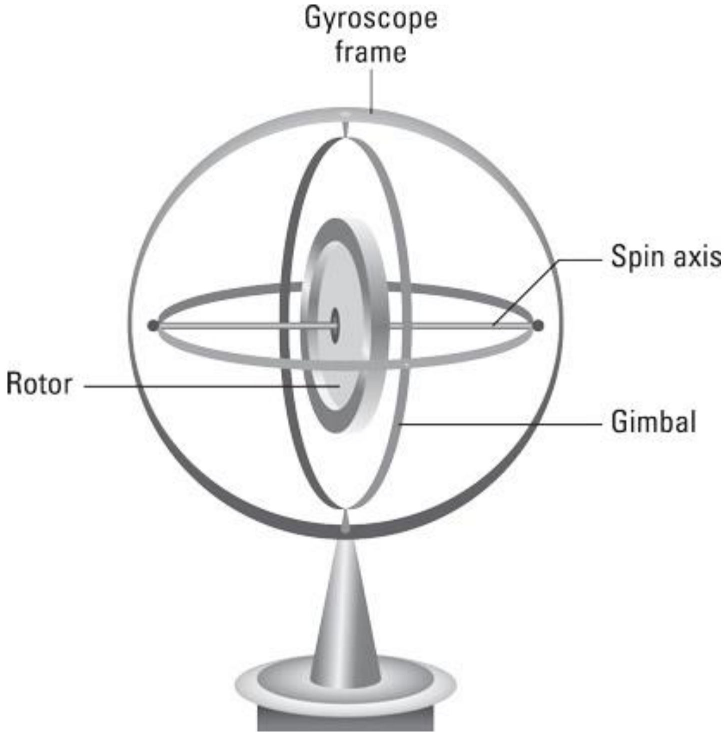


**Figure 41. Basic illustration of a gimbal. Credit: LucasVB/Creative Commons**

The gimbal will ensure that the lens will remain in its position, regardless of any motion that is transferred from what it is attached to.

As Figure 41 will show the basics of a passive gimbal, any modern gimbal for a camera will have a servo motor for each axis that will compensate for any movement. Sensors and a microcontroller will assist to give the correct position for the lens.

There are 2-axis or 3-axis gimbals on the market but today, most of commercial drones are equipped with a 3-axis gimbal.

A 3-axis gimbal will give smooth and gentle shots when recording movies. It will also give the possibility to tilt and control the camera in all axis and directions. A gimbal from DJI is shown in Figure 42.

For taking still shots with a camera, a 2-axis gimbal is usually good enough. Some drones aren't even equipped with a gimbal. These drones are usually fixed wing aircrafts with a camera for taking vertical ground pictures for photogrammetry.


**Figure 42. 1 A DJI Zenmuse gimbal with a camera sensor but without the lens.**

The gimbal is a rather complicated and sensitive piece of equipment and this especially applies for those that are included in most of the commercially available drones. Specific caution should be taken when transporting them and usually there are some kind of transport protection to apply to the unit.

### 4.2.3. Infrared camera

An alternative to the standard camera operating in the visible spectra (0.4-0.7 µm), is the infrared (IR) camera with sensors designed to capture IR-radiation, typically somewhere in the range of 0.7-12 µm. These cameras can be used for inspection of facilities when looking for heat leakage. Another application is within search and rescue operations for finding missing persons in darkness (night vision) or in woods, Figure 43. Further applications is within the area of agriculture where it is possible to monitor the crops.

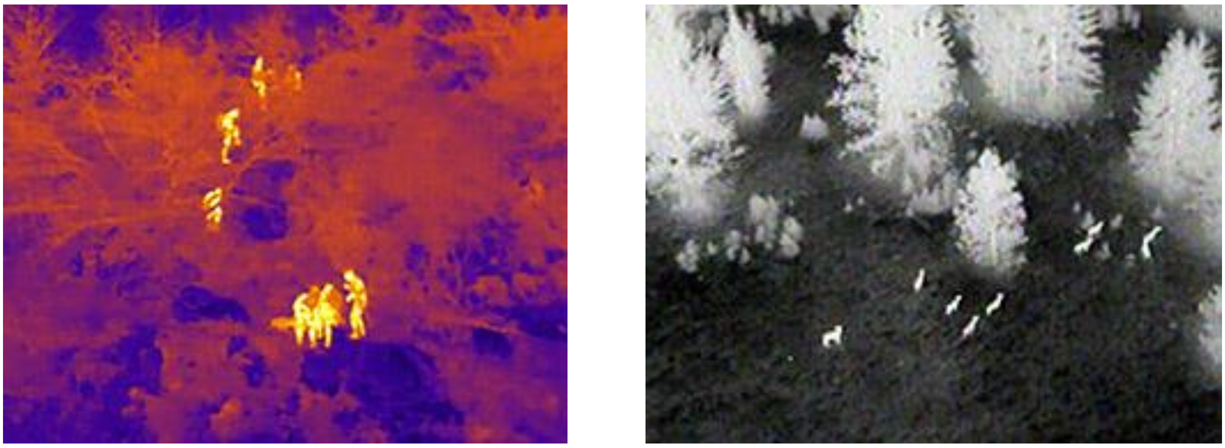

**Figure 43. Pictures taken with IR camera, search and rescue (left), herd of deers (right) (Systems F. , 2017).**

The advantages with a thermal camera is clearly demonstrated, however there are also some limitations to be aware of. The most important is probably the fact that a low-resolution camera (as a thermal camera is compared to a traditional camera) will need the photographer to be very close to the object that is going to display on the screen. As a drone usually will be positioned at quite a large distance from any object, this will make it difficult or impossible to spot individual objects with a low-resolution thermal camera.

Today most people are used to work with modern high resolution digital cameras. Typically, more than 12 megapixels is achieved on even any standard mobile telephone. In comparison a thermal camera may have less than one megapixel. This immediately leads to a discussion regarding the ratio between price and resolution for IR-cameras, which eventually means that a drone operator cannot have too high expectations on a simple IR-camera when using it far from the intended object to be observed.


**Figure 44. Flir Vue Pro 640 with 13 mm lens.**

Figure 44 shows a Flir Vue Pro 640 with a resolution of 640 x 512 pixels (approx. 0,3 MP) which is an IR-camera especially designed to be mounted on a drone platform. A typical price for such a IR-camera unit will be around 4000 Euro. There are also several drone manufacturers that provide their products equipped with an integrated thermal camera out of the box.

Before procuring any equipment for use in the scientific research one has to carefully take all the above mentioned factors into consideration.

### 4.2.4. Stereo camera

A stereo camera has two lenses, which gives it the capability to accurately make distance measurements and also the ability to capture 3D images. The distance between the lenses is sometimes chosen to match the distance between the human eyes (i.e. 60-70 mm), thus it will capture images in a similar way as humans do.

If the stereo camera is combined with some sort of artificial intelligence (AI), it can be trained and used to make decisions in a similar way as humans make decision based on visual information. One such system is the Intelligent Vision System (IVS) from Unibap (Unibap, 2017). Figure 45 shows a picture of the IVS-70 system. Applications for this system is e.g., industrial automation, quality control, surveillance, and robot or drone guidance. Its size is approximately 150 mm long and the weight is roughly 1-2 kg depending on casing. It is robust and features aerospace safety critical technology. Given some of the performance stated above, this system (or any similar) is suitable to integrate with a drone.

**Figure 45. Intelligent Vision System (Unibap, 2017).**

A possible application for the Arctic environmental research could be to train the IVS to make it able to count populations. Through machine learning, the IVS could thus be utilized to count animal populations such as reindeer, birds (in air, at cliffs, nesting), seals etc. or even different types of plants.

 

### 4.3. Radar

Radar (Radio Detection and Ranging) is an equipment and technique for detecting and measuring range to objects. The basic idea is emitting radio waves (electromagnetic waves) and to measure the reflected radio wave that bounces of an object. The frequencies of the radio waves that typically can be applied to radar are in a very wide range from 100 MHz up to 100 GHz, depending on application. The higher the frequency, the smaller the wavelength of radio wave, and consequently a better measuring resolution is obtained.

One important advantage of radar is its ability to perform measurements under basically any weather conditions and during night time as well as daytime. As a result of this, radar has become one important sensor for the realisation of self-driving cars. Such radars can e.g. look for obstacles on the road during any type of weather conditions, as opposed to an ordinary camera that works best during daytime and good visibility.

The automotive business has been driving the development for cheaper radars at higher frequencies. An example of this is radars with frequencies from 77 to 81 GHz, this give higher accuracy and the devices are also smaller in size due to the smaller frequencies. One example of the results of using such a radar is shown in Figure 46 (Acreo, 2016). Here the four cars seen in the smaller picture are represented by the four colorful sets of measuring points.

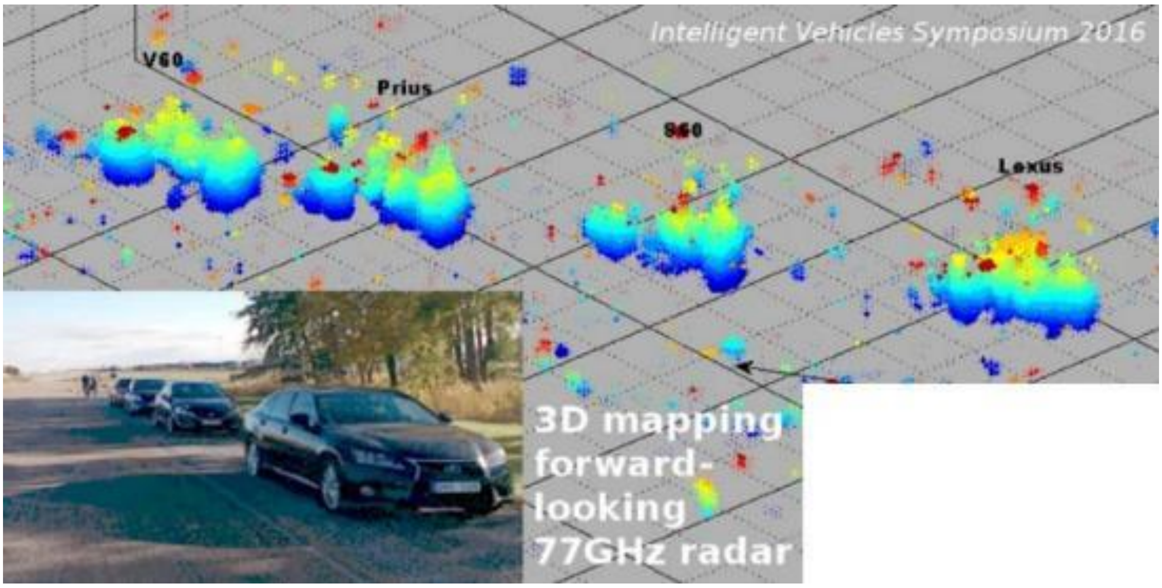


**Figure 46. Results from a stationary radar, frequency at approximate 79 GHz, with the application of creating an image of the four parked cars seen in the inserted photo.**

One application for such a radar can be on rail road crossings to secure that there are no unwanted objects on the tracks when trains are arriving. The radar could of course also be a part of any solution for a drone, performing similar tasks.

## 4.4. LiDAR

LiDAR (Light detection and ranging) is another way of detecting and measuring range to objects. As opposed to radar that uses radio waves, LiDAR uses light in form of lasers. In its basic application LiDAR is used to measure distance to an object, but also e.g. the concentration of aerosols in the atmosphere can be measured.

In the last decade a very popular application of this technique has been laser scanning of objects with the purpose to make a digital model of basically any types of objects such as buildings, forests, mines, and industry plants. Laser scanning of a 3D object can be done in a very accurate and precise manner. Digital models of a real world object with mm-precision is possible. Figure 47 shows the principles for 3D laser scanning (Edition Truth, 2017). A mirror or prisma points the laser in thousands of directions per second. Each reflection is registered and typically some reference points are used for the post processing of data. All these registered points make up a point cloud. From this point cloud software is used to render the digital model to any preferred scale of details.

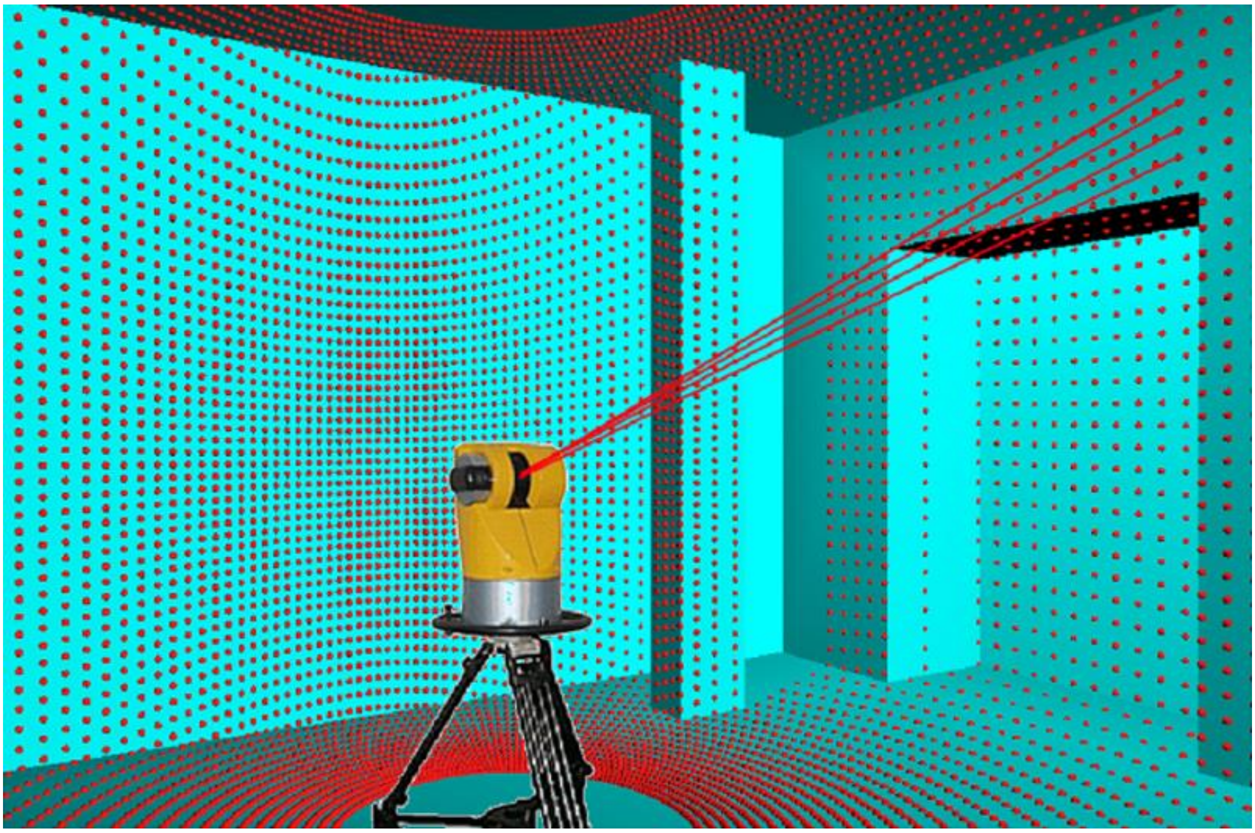

**Figure 47. The basic principle of laser scanning, where a laser emits rays in different directions and measures the reflected signals for various points of the object (Edition Truth, 2017).**

Terrestrial Laser Scanning (TLS) can be used to make models of for example trees in a forest, Figure 48. Such models can then be used to make estimates of the biomass or look at horisontal (mid) or vertical (right) cross sections of a tree (Forest Inventory Research Group, 2017).

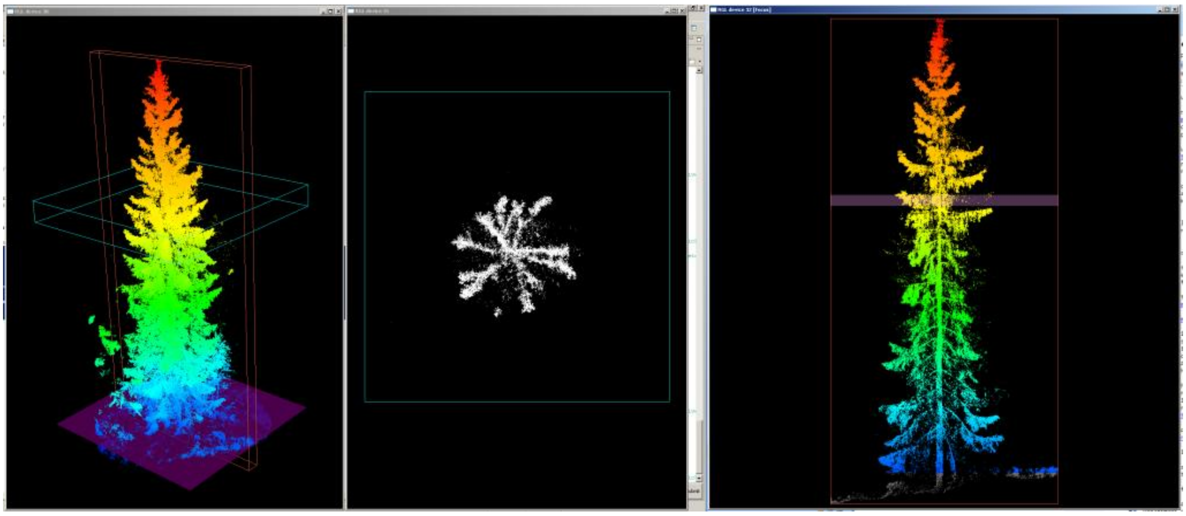

**Figure 48. A model of a tree created from laser scanned data. 3D model (left), horizontal cross section (middle), and vertical cross section (right), (Forest Inventory Research Group, 2017).**

Many LiDAR systems that are used for very high accuracy and/or high capacity, in terms of collecting a lot of measuring points, tend to be large and heavy for the purpose of mounting them on a drone platform. On the other end of the scale in terms of size, there are small, low-cost LiDAR suitable for taking series of distance measurements, but probably not good enough for creating 3D models. Such a LiDAR could be the optical distant measurement sensor from Garmin seen in Figure 49 (Garmin, 2017).


**Figure 49. Lightweight optical distant measurement sensor from Garmin (Garmin, LIDAR-Lite v3, 2017).**

This sensor is small and lightweight at approximately 22 g and just under 40 cm$^3$. It operates at a range of up to 40 m at a low power rate and with an accuracy of 2.5 cm at a distance up to 40 m. With a typical update frequency of 270 Hz it would produce a resolution of 13.5 measuring points per meter working from a DJI Phantom v4 with a top speed of 20 m/s. The LiDAR Lite v3 is available for purchase for around USD

150. This type of LiDAR has of course its limitation to more expensive one, but for small projects without high demands it might fill a position.

With the use of an airplane it is possible to apply more advanced LiDAR systems with the possibility to construct e.g. both overstory (canopy) and understory (ground) models of a forest. LiDAR have been shown to be capable of performing sub-canopy measurements. By using the last return of the beams reflection instead of the first, it is possible to detect ground level even when masked by grass, trees, rocks, or similar semi-obstructing objects. This has been used as a means of deriving terrain models in woods and other similarly obscured areas as well as estimating canopy height in the same (Moeser, Morsdorf, & Jonas, 2015). This is shown in Figure 50, where the left image (a) shows the point cloud data, and the right image (b) shows a cross section of the understory of LiDAR returns.

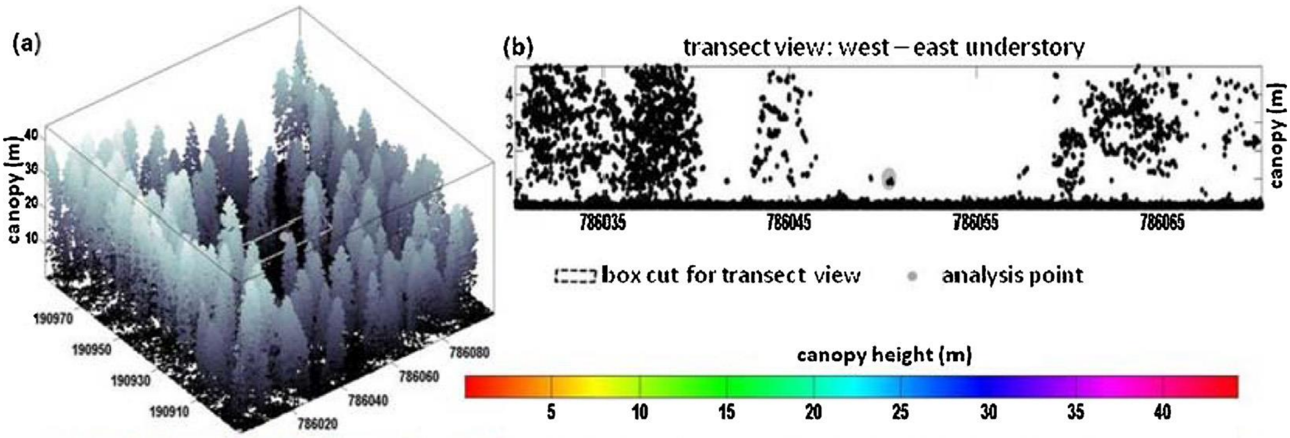


**Figure 50. Left image shows the point cloud, right image shows a cross section of the understory (Moeser, Morsdorf, & Jonas, 2015).**

The type of ground model that can be constructed from this kind of measurements is of interest when deriving a base model during snow-free seasons as the canopy will not later contribute to snow height but may well cause a premature echo in summer, thus overestimating the grounds relative height. Or as illustrated in Figure 51, reading the reflection of the virtual ground, e.g. canopy, would provide the distance $d_2$ whereas one may be able to detect the full distance d by waiting for last reflection b and using the latest reflected pulse in an interval to filter some or all semi-covering canopy. If the canopy is fully solid such an approach is not feasible but neither really relevant as a solid structure will allow for snow accumulation on top of it.

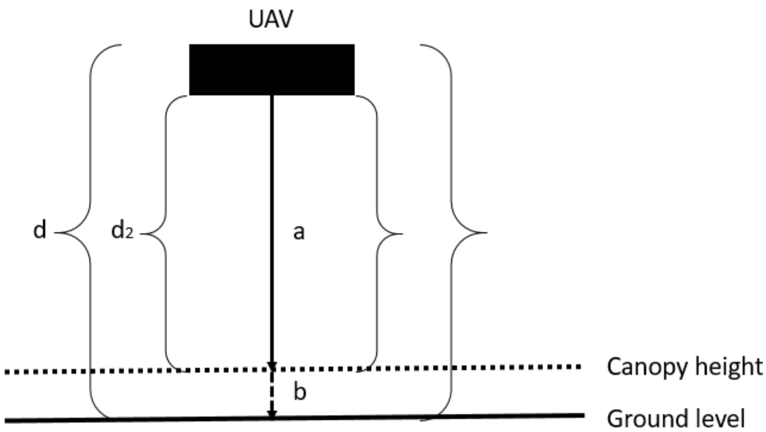


**Figure 51. Canopy false ground measurement illustration.**

Despite its advantages there are however some concerns regarding the use of LiDAR for the purpose of mapping snow layers. The primary one is due to the fact of scattering of the laser pulses on the snowy surface. Snow have a crystalline structure with a high degree of reflectivity as well as a high scattering volumetric index. Also, the water content (dryness), density etc. may well influence the measurements, especially when factoring in potentially steep terrain.

## *4.5. Ultrasound as a mean to measure snow*

Ultrasonic sensors work by emitting an ultrasonic wave and measuring the time between emission of the signal and reception of the echo reflected off the area that is being measured. Provided knowledge on the speed of sound through the medium covering the distance to the target, it is possible to determine the distance. Further analysis of the reflection strength of the echo may also provide some indication of the absorption level of the target.

Ultrasonic sensors may be of interest in measuring snow due to them having a good reflection in the interface between air and snow. However, ultrasonic waves are rather limited in range due to acoustic impedance mismatch in air. Most ultrasonic sensors of reasonable size and cost would be likely to limit the UAV to flight missions at a short distance from the target surface. Figure 52 shows the absorption rate in air as a function of temperature and for different frequencies (Vladišauskas & Jakevičius, 2004). In the figure it is seen that the use of ultrasonic sensors is favoured by colder weather and lower frequencies.

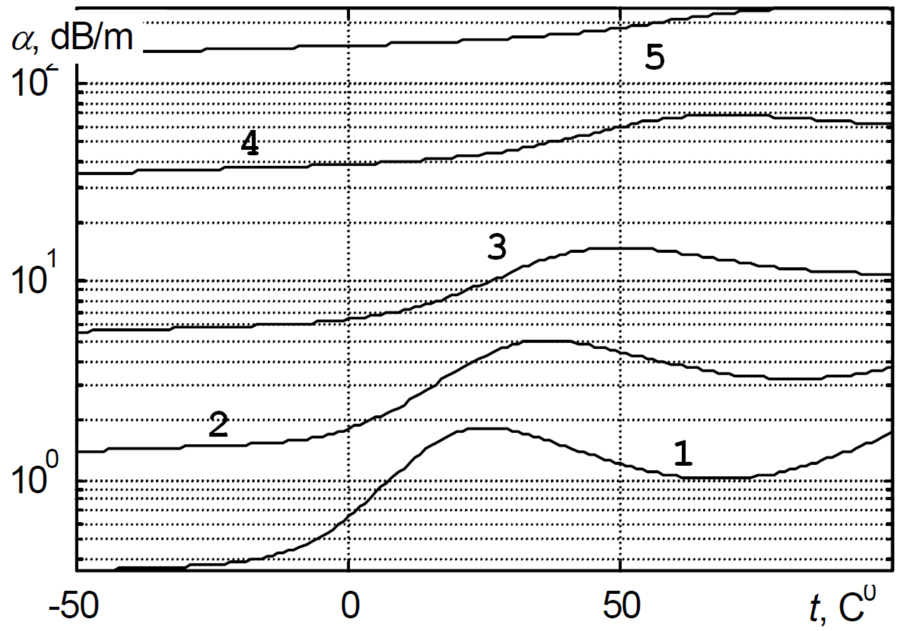


**Figure 52. Dependencies of the ultrasonic absorption coefficient versus negative and positive temperatures at pressure p=105 Pa and humidity σ=60% at frequencies; 50 kHz (1); 100 kHz (2); 200kHz (3); 500 kHz (4); 1 MHz (5) (Vladišauskas & Jakevičius, 2004).**

Ultrasonic sensors would however likely produce sufficiently accurate results provided the right operating conditions. However, such conditions are shifting during field tests and are prone to distortion from factors such as temperature, humidity, air pressure, as well as wind.

One study published the property evaluation of the reflection coefficient to its surface as a function of snow density, Figure 53 (Gudra & Najwer, 2011). Essentially, it should be feasible to measure the density of the snows top layer with ultrasonic sound as the reflection coefficient appears to drop linearly in relation to decreasing density of the snow. The graph shows almost 100% reflection at the very right side of the curve, corresponding to the approximate density of water. The linear relationship seen in the graph may open up for layer density estimation where one would, after a snowfall, measure the top layer. Using these measurements in combination with volume estimates it may be possible to create a model over time which represents the present water reserve locked up in the snow.

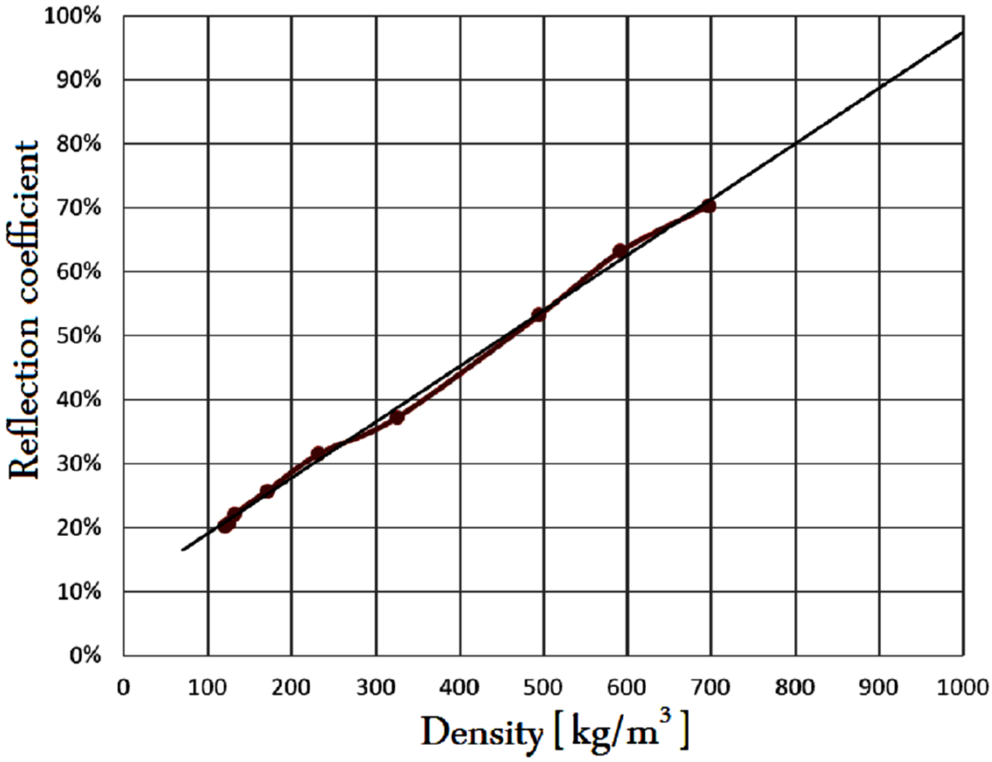


**Figure 53. Relationship between reflection coefficient and density of snow (Gudra & Najwer, 2011).**

The speed of propagation through the snow is also one parameter that could be exploited (Gudra & Najwer, 2011). However, this approach assumes a receiver being placed on the other end of the snow-layer. This could defeat the purpose of deploying data gathering by drone as it would likely entail some difficulty in finding earlier placed sensors once covered by snow.

However, the reflection coefficient correlation may be of interest as it could be used over fresh snow to estimate the density of the added layer of snow. This later has the potential of being used in the modelling of the snow structure. Measurements performed in this way will also have to be calibrated for surrounding temperature and pressure in order to ascertain the quality of measurements.

# 5. Drone projects

## 5.1. Measuring gases and temperature

Drone systems could be used to measure various atmospheric parameters at different heights, e.g. temperature, humidity, pressure, wind speed or gases such as $O_3$, $CO_2$ or $CH_4$. The use of a drone system could replace other techniques such as sending up measurement equipment with balloons. However, it should be kept in mind that it is usually not allowed to operate a drone above 120 m (400 feet). Special permissions will usually be required from national aviation authorities in order to perform drone flight missions above 120 m.

### 5.1.1. Measuring ozone

One drone system that is capable of measuring ozone and temperature at different heights is based on a quadcopter drone and a small (approx. 100 mm x 75 mm x 40 mm) lightweight (450 g) ozone monitor (2B Technologies, 2018) for monitoring ozone at up to 300 meters altitude, Figure 54.

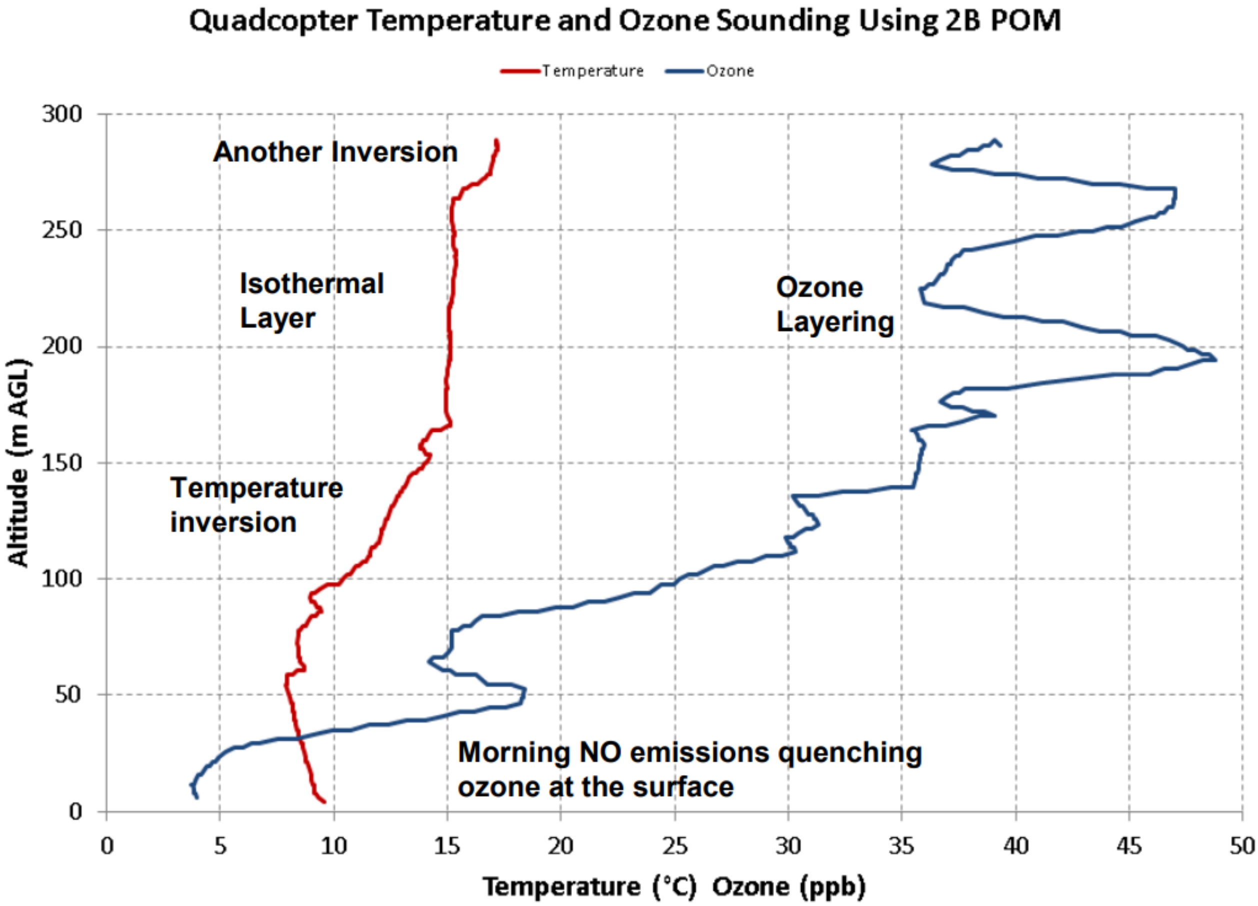


**Figure 54. Ozone sampling at different heights using a quadcopter and an ozone monitor (T&B Systems).**

### 5.1.2. Measuring methane

There is an increasing interest for measuring greenhouse gases (GHG). One such gas is methane. EU has recently launched new satellites within the Copernicus program to aid in monitoring GHG. The satellite Sentinel-5P is being operative during 2018 and will provide an average methane value with the resolution of 7 km x 7 km, the averaged value is taken from the ground surface to the top of the atmosphere. This type of data is very useful on a global scale for identifying larger areas with different concentrations of methane. However, for more precise measurements other methods would be preferred.

A highly sensitive methane sensor spun-off from the NASA Mars Rover project has been further developed by SeekOps (SeekOps Inc, 2017). The detector can easily be integrated with SeekOps own drone platform. Applications of the system is typically for detection of methane leakage at industrial sites, but it is expected that this system also could be useful for environmental research. An image of the system is shown in Figure 55. The orange tube in the front is the highly compact and sensitive methane detector.

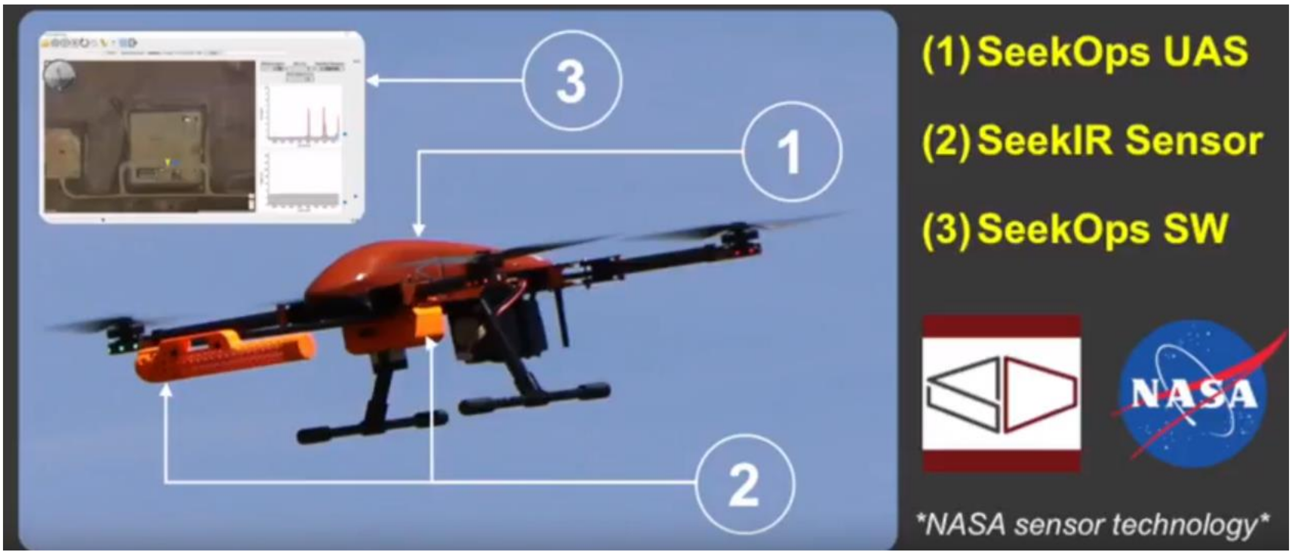


**Figure 55. SeekOps drone system with an integrated methane detector (SeekOps Inc, 2017).**

## *5.2. Photography*

Aerial photos can be used to analyze a variety of things on the ground. One application can be to count animal populations. Such a method would consist of capturing aerial photos, stitching them together and then perform automated image analysis to count individual animals.

One example of this method to register population has been developed in New Zeeland with the purpose of counting penguins (Manaaki Whenua Landcare Research, 2017). Photos of a penguin colony has been taken from a helicopter and these photos have been merged and aligned to a single image to be analyzed (Figure 56, left image). Then a software (Figure 56, right image) has been developed to automatically count the number of black dots in the image, where each black dot represents a nesting penguin. This software renders the total number of 3392 penguins, whereas the estimated correct number of penguins is 3405.

This way of counting large populations is an alternative way to performing land-based calculations, where it might be easy to lose count if a large population is to be counted.

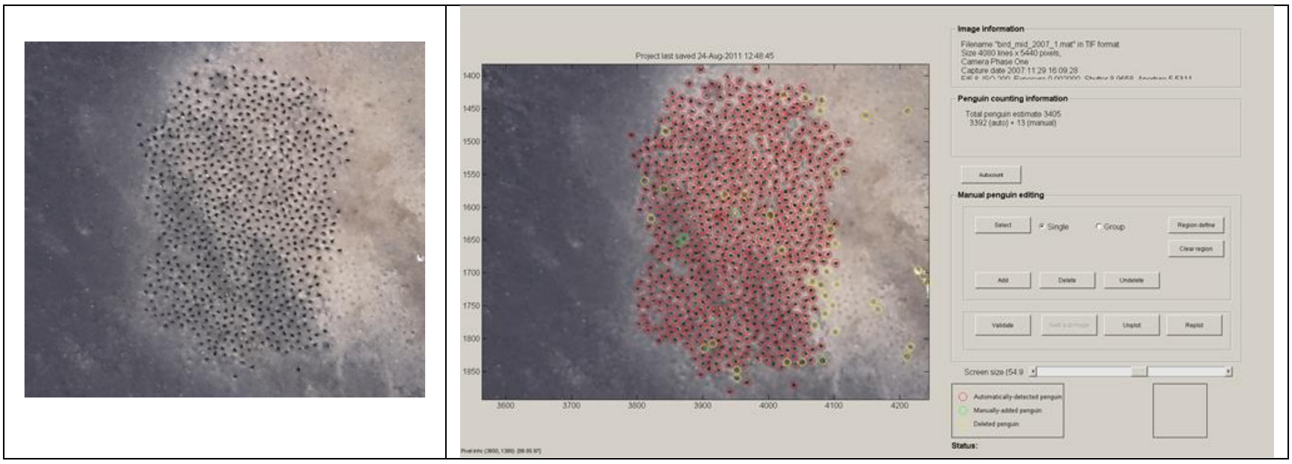


**Figure 56. Application of using aerial photography and image analysis to count a penguin population in New Zeeland (Manaaki Whenua Landcare Research, 2017).**

## *5.3. Normalized Difference Vegetation Index*

There are ways to measure the amount of vegetation in a specific area. One method to do this is called Normalized Difference Vegetation Index (NDVI). NDVI quantifies the vegetation in an area by measuring the difference between reflected near-infrared (NIR) light and reflected red light. The resulting normalized index is a value between -1 and +1, where very green areas are close to +1 and -1 is likely to be water. The index is calculated using the following expression:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Vegetation that is growing well contains more chlorophyll and will reflect more near-infrared light as well as green light. Less healthy vegetation will reflect less near-infrared light. This is illustrated in Figure 57 which shows examples on the index for vegetation that strongly reflects NIR (left) and vegetation which absorbs more NIR (right).

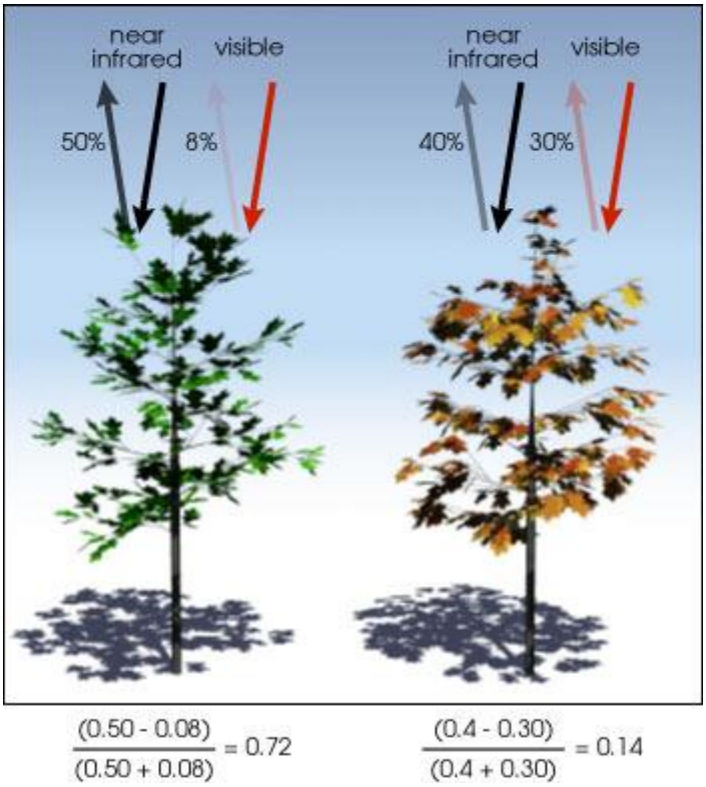


**Figure 57. Examples demonstrating different NDVI for differently growing vegetation (GISGeography, 2018).**

Common applications for measuring NDVI is within agriculture and forest industry.

Measurements are most often done through the use of satellites, but there are more and more applications for using drones equipped with one or more camera to perform the measurements. One advantage of using drones for these measurements is increased resolution for the measurement points.

Typically two cameras are used for NDVI; one to measure NIR, and one to measure red light. However, in order to decrease cost for the measuring system, a standard camera modified slightly and equipped with specific filters can be used for measuring both NIR and red light. One example of the result of measuring NDVI for such a drone system is shown in Figure 58. The left image shows the index resulting from satellite data, whereas the right image shows the results from using a drone system. The higher resolution in the right image clearly shows one advantage of using a drone system.

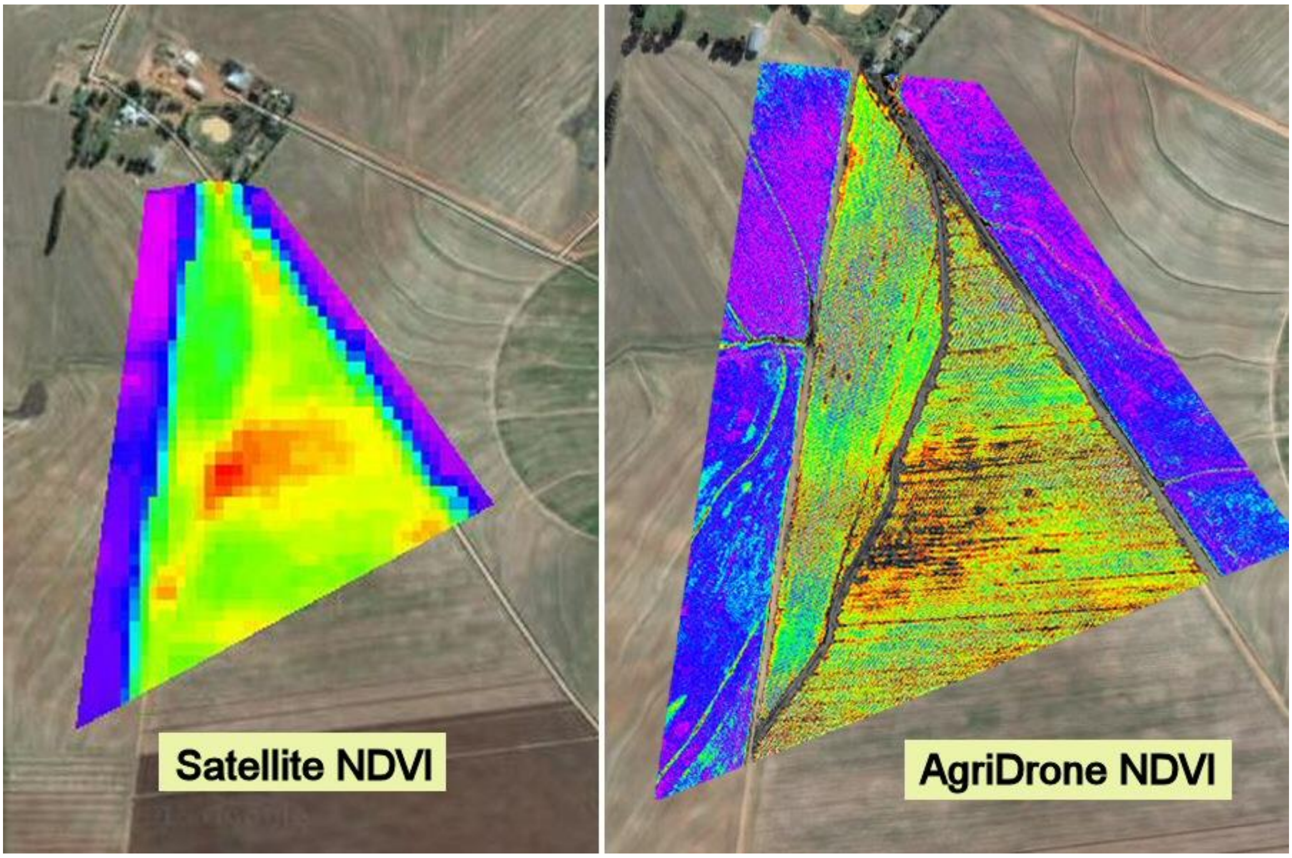


**Figure 58. Satellite NDVI compared to NDVI from a drone system (AgriDrone, 2017).**

An estimated cost for this type of system is approximately USD 5000, but this of course depends heavily on the requirements for flight time and correctness in calculated indices.

In section 3.7.9 the eBee SQ drone is described. This is one drone system that can be used for this purpose of measuring NDVI.

## 5.4. Infrared cameras on drones

Infrared (IR) cameras can be useful for detecting heat anomalies in an environment. Typical applications are finding missing persons in the forest or detecting heat leakage in facilities. An IR-camera mounted on a drone platform makes it easy to fly over any area of interest in the search for warmer spots. For environmental research this could e.g., include detecting birds or mammals, or identifying heat gradients.

FLIR Systems is one of the world's largest supplier of thermal imaging cameras. They offer a series of IR-camera systems that can be integrated with drones (FLIR Systems, 2017).

In order to facilitate the adoption of the use of IR-cameras on drones, the drone manufacturer DJI offers integrated solutions with different drone platforms and an IR-camera from FLIR (DJI, 2017). Figure 59 shows the DJI M600 with approximate flight time of 35 minutes with the integrated IR-camera from FLIR.

**Figure 59. M600 from drone manufacturer DJI and the integrated IR-camera from FLIR (DJI, 2017).**

## *5.5. Photogrammetry*

### 5.5.1. Extracting information from photos through photogrammetry

Photogrammetry is a way to make measurements from photographs. The technique can be used to create topographic maps and 3D models of objects by taking multiple overlapping photographs and deriving measurements from them, Figure 60. The position of the camera for each image is used to estimate the coordinates of the pixels in the original image. This technique is also known as structure from motion (SfM).

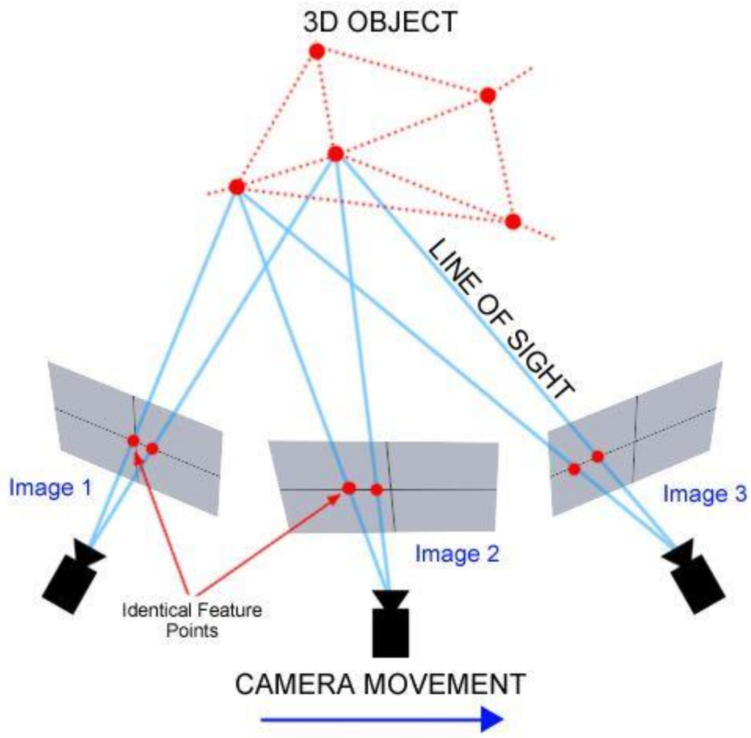


**Figure 60. The concept of making 3D models by photogrammetry (Mason, 2017).**

Structure from Motion (SfM) photogrammetry is performed by employing algorithms that combines and analyses the apparent difference in shape that the shifts in perspective provides. By keeping track of the cameras position for each picture it is possible to identify tie-points which are recognizable features that may be matched inter-pictorially.

The photogrammetric approach to constructing digital models is done by collecting a set of photographs of an area and computing a point cloud based on the differences in the photographs. Wherever there is an overlap in the photographs, a range of different software are available for identifying tie-points. Based on these tie-points, the collected images and their metadata, a point cloud can be constructed. From the constructed point-cloud a mesh can be created by different means of interpolation between the points. The methodology is thoroughly described in a report for SfM Photogrammetry (Eltner, o.a., 2017) and this methodology is outlined in Figure 61.

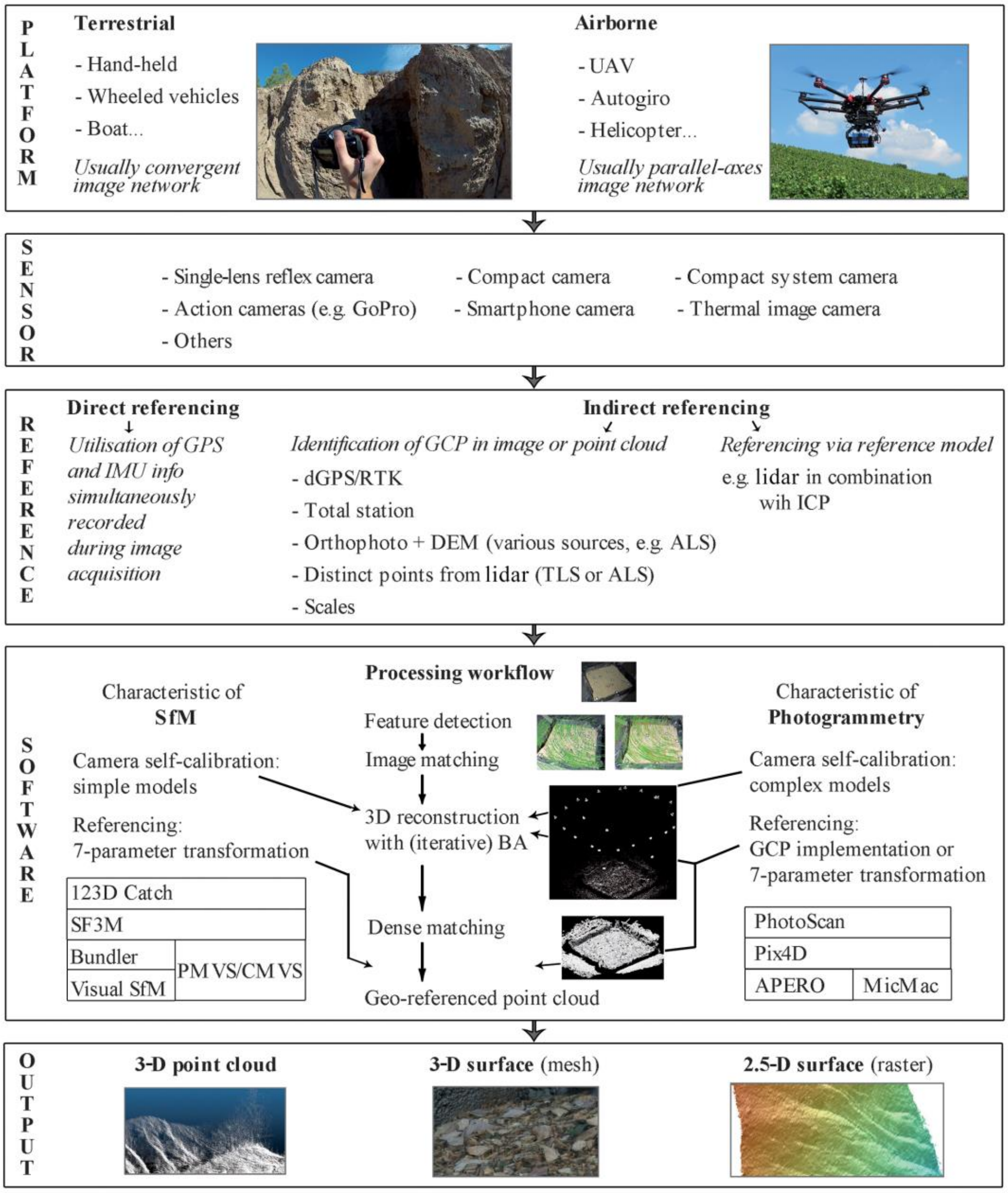


**Figure 61. Schematic illustration of versatility of SfM photogrammetry (Eltner, o.a., 2017).**

There are a lot of available software for this purpose. A few popular ones are named Agisoft Photoscan and Pix4D together with many others. Both Agisoft Photoscan and Pix4D are available in a freeware version with limited functionality. This means that they can be used to do mapping missions and render 3D models with pictures taken although some functionality like volume measurement and export features will be locked. However, they can still easily do impressing data processing of a project for free and add the extra features by a periodically subscription whenever needed. The software can be downloaded for free and installed on a computer for personal use.

Pix4D will also offer a useful and intuitive app for Android and iOS mobile units. This will, together with a drone and its remote control, assist to set up a fully automatic flight mission for a project. Within an hour or so it is possible, with no further experience of the software and little experience of drones, to collect a set of pictures that can be used for post processing by Pix4D software installed on a computer. A few hours more will be needed to learn to get going with the software and to start producing the first 3D pictures.

A special case is stereo photogrammetry that can be used as a robust and accurate measurement technique of static and dynamic objects.

There is a Wikipedia page (Comparison of photogrammetry software, u.d.) that will list a comparison of a number of software for photogrammetry.

### 5.5.2. Photogrammetry from drones

In practice, photogrammetry can be widely applied from a range of platforms including handheld cameras, aircrafts, drones and satellites. This platform versatility is mainly due to the fact that regardless of the relative resolution, the same algorithms may be employed. The resolution (point density) drops with altitude in relation to the camera angle and pixel size as any given pixel correlates to a certain point on the measured target. Both resolution and accuracy of photogrammetry at centimeter level is not only feasible but has been repeatedly demonstrated while employed on drone platforms.

Metadata must contain locational and situational data in order for the images to be properly mapped and compared. In the context of flight-photographs from a drone it is most commonly mapped in GNSS coordinates calibrated in an xyz-coordinate-grid by the aid of straight motion measurements derived from either an IMU or accelerometer. Through the IMU or a gyro it is also important to collect the angular situation of the drone in relation to the ground i.e. in-flight terms; "roll, pitch and yaw".

Apart from the movement and precision of the drone and the metadata, the accuracy of this method is mainly dependent on photogrammetric factors and the structure of the area it is mapping. The quality is expected to be greater in areas where there are clearly visible reference points that are distinguishable from their immediate surroundings with regards to color, tilt, height, brightness etc. Despite the pixelated format of an individual photograph it is possible to achieve nuances of quality better than pixel-resolution level provided a large number and good distribution of the photographs (Eltner, o.a., 2017).

### 5.5.3. Ground Control Points

One very important thing to remember when applying photogrammetry from drones is to use ground control points (GCPs). This applies for all land surveying projects where a precise map is desired.

For other projects, like where just a nice picture from the sky is needed, the GCPs not are much of importance.

GCPs are physically marked locations with a fixed position and their already (precisely) determined coordinates. The marked location will be clearly displayed in the aerial photo and can be georeferenced to the map or project that is being produced. This will increase the accuracy for the project in all three dimensions (X, Y and Z).

The GCPs needs a precise GNSS receiver, for example an GNSS-RTK equipment to determine the exact position where the GCPs are located. Sometimes specific GCP markings are used, sometimes a fixed and clearly visible object in the terrain may be used.

The use of GCP in combination with photogrammetry and drones may seem trivial but recommendations are that proper training courses are taken before the start of any scientific mission. This will avoid beginners' mistakes that may develop to fatal errors in the end.

## *5.6. Drone applications with photogrammetry*

### 5.6.1. Digital Surface Model of a coal mine

Using a fixed wing drone, a coal mine in the US was mapped by the company West Coast Placer (West Coast Miners, 2017). The digital surface model (DSM) achieved an accuracy of 30 cm, Figure 62. All image data was collected in just one day. The image resolution was 4 cm per pixel, i.e. each pixel represented a 4 cm by 4 cm piece of the real world. The height is color coded and the maximum height difference is around 250 m. The total covered area is approximately 1 km by 1 km.

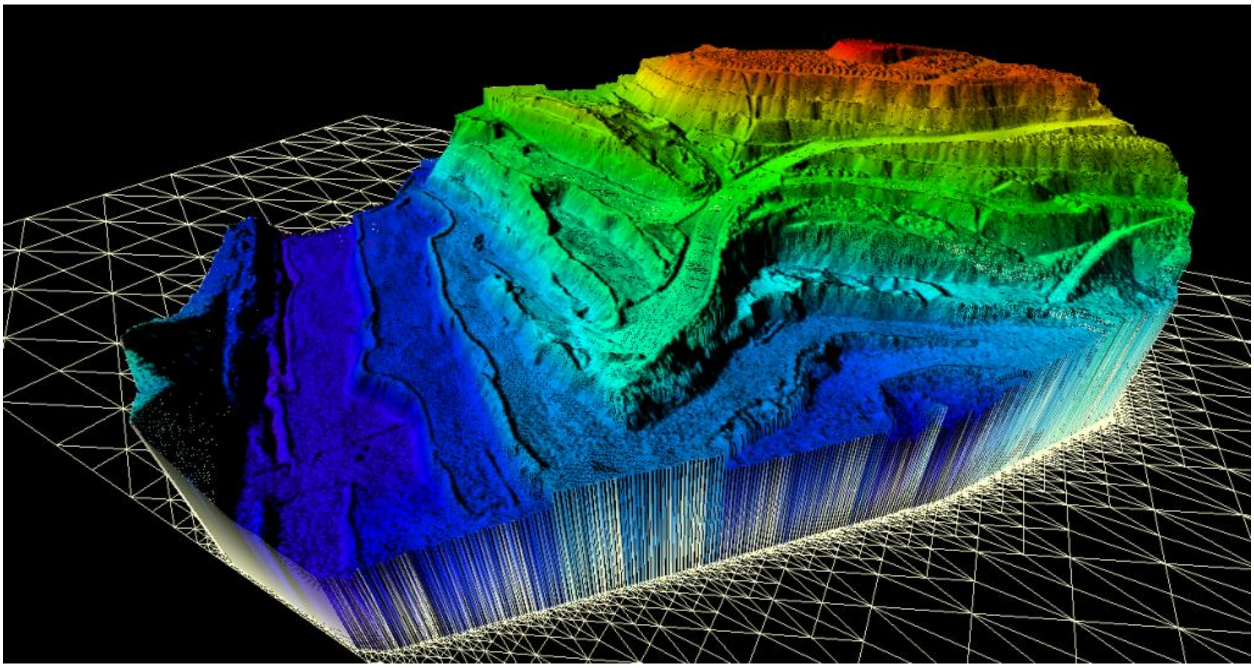

**Figure 62. Digital Surface Model of a coal mine (West Coast Miners, 2017).**

### 5.6.2. Measuring snow depth

Using Ascending Technologies Falcon 8 octocopter equipped with a customized Sony NEX-7 camera (Bühler, Adams, Bösch, & Stoffel, 2017) it was possible to achieve a 25 cm vertical accuracy of a snow height with thickness ranging from 0 to 2 m. The study was based on seasonal measurements where a reference digital model was taken during the summer. Then an overlay generated by photos of the snow-covered ground could be examined. Verification was performed by manual measurements. Photos from this can be seen in Figure 63.

The system weighs 2.3 kg (incl. camera).

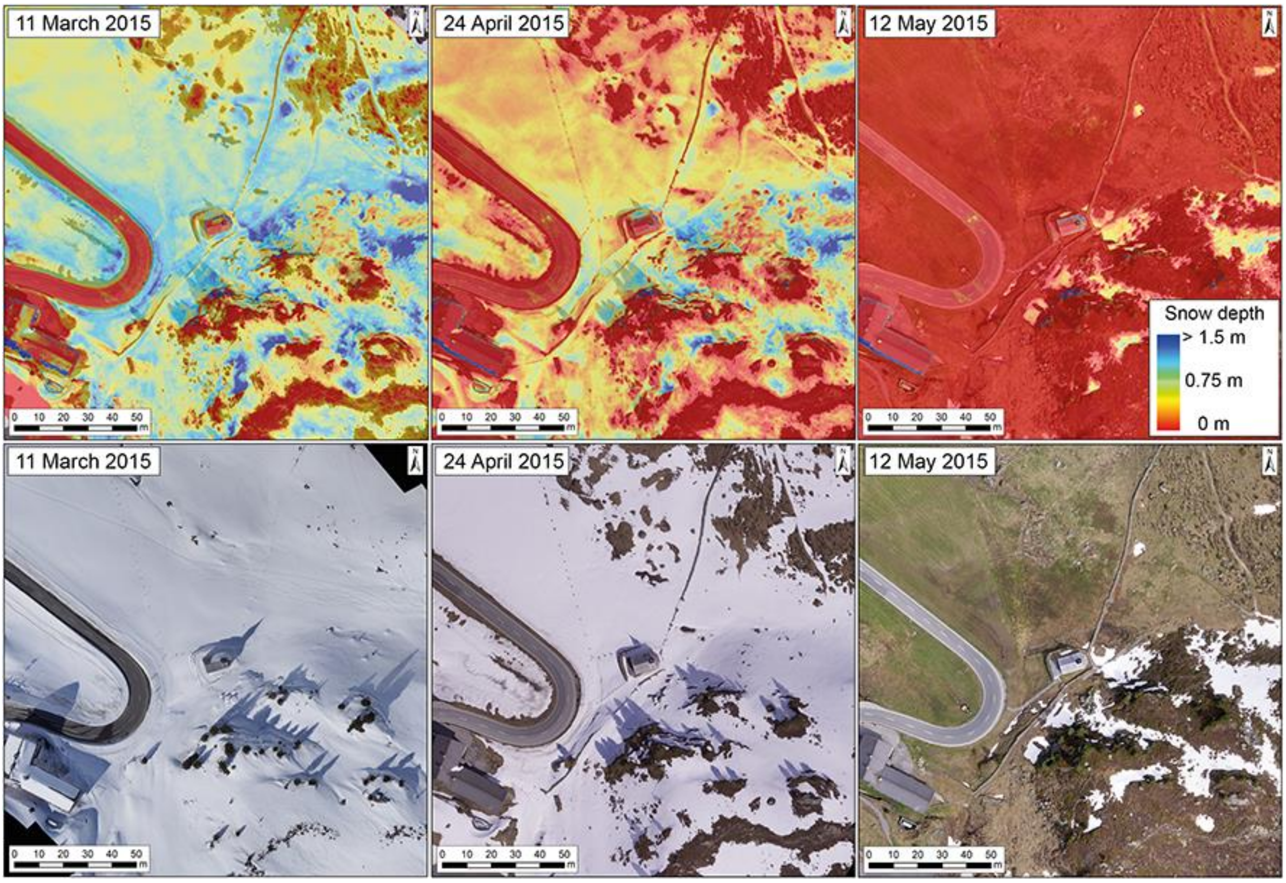


**Figure 63. Snow layer maps (top) and corresponding orthophotos (bottom).**

A concern regarding photogrammetry in the event of mapping snow-layers would be the smoother, visually homogenous and bright nature of snow. This may prove difficult for the software to detect any good or even usable tie-points to begin building the structure. Should this be the case, there may however still be an interest in using the method for building the ground-layer during snow-free periods in the regions where such weather can be anticipated.

## *5.7. Radar*

### 5.7.1. Snow depth measurements

Some fundamental issues remain for snow-penetrating radar. Snow, essentially being water in solid form, retains the highly absorbent characteristics of water with some dependence on how densely it is packed, as well as the liquid water content, determined by the relative air-content of the packed snow.

A frequency-modulated continuous-wave (FMCW) radar can be used to measure distance to the top layer of snow. An 80 GHz FMCW radar was shown to achieve high levels of accuracy with errors <1 cm at 2.6 m reference height (Ayhan, Pauli, Scherr, Göttel, & Bhutani, 2017). The price of the radar module is stated to be at about 100 Euro when ordered in large quantities. Thus, it is a low-cost and accurate means of measuring distance between drone and snow/ground. However, it does not have the capability of layer mapping as other, more powerful radars would have.

### 5.7.2. Synthetic Aperture Radar

One very interesting application of the radar is to us it to create two- or three-dimensional images of objects. The real interest lies in the possibility to create these types of images regardless of weather conditions since the radar signal is neither obstructed by clouds, nor affected by darkness. These facts have motivated the development of the techniques for Synthetic Aperture Radar (SAR) systems.

The SAR system origins from military applications and the application for surveillance from high altitudes. There are today many satellite-based SAR systems, as well as airborne ones.

The basic idea with SAR systems is to have a moving radar that continuously saves all the backscattered radar signals as the radar moves along a certain path, Figure 64. The analogy is that all the positions along the flight path can be seen as individual elements along a very large antenna array aperture. This artificially large aperture is a prerequisite in order to obtain high image resolution.

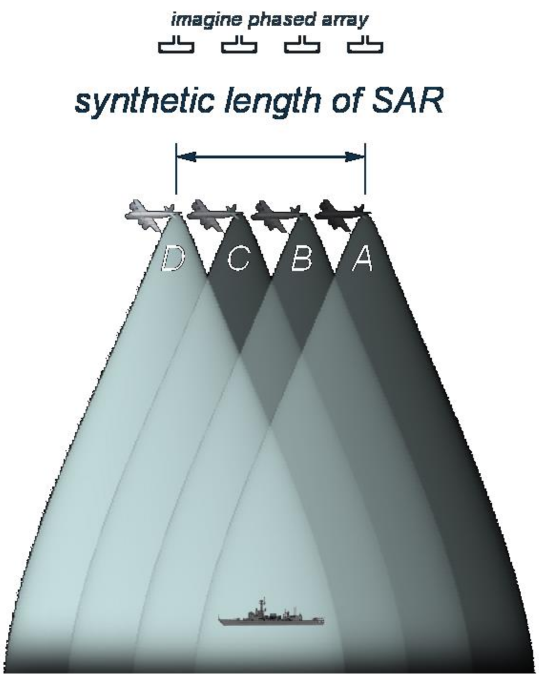


**Figure 64. Illustration of the principle of the synthetic aperture (Wolff, 2017)**

During the collection of data from the backscattered radar signals, highly computational and advanced computer algorithms are used to assemble the radar data from different positions into images of the ground structures or objects that have been reached by the radar signals. Thus, in order to produce images from radar signals, there is a need for three building blocks; a radar, a moving platform and advanced algorithms for postprocessing of the collected data.

SAR imagery is seen to be very useful for environmental researchers. In an extensive tutorial on synthetic aperture radar (Moreira, o.a., 2003) there is a table that summarizes examples for applications of SAR imagery when there is a need for all-weather, day-and-night high-resolution information about climate variables that are of great concern for environmental research. Some of these applications are reprinted and listed in Table 1.

**Table 1. Examples of application of SAR imagery for environmental research purpose.**

| Area of application | Climate variable |
|---|---|
| Land | Surface imagery, soil type, land cover, lake levels, landslides, erosion, flooding, soil moisture, permafrost, wetlands |
| Vegetation | Vegetation type, forest biomass, forest height, forest profile, crop height |
| Ocean | Sea state, ocean currents, wind speed, oil spill, ship monitoring |
| Sea ice | Sea-ice cover, sea-ice type, sea-ice thickness, iceberg cover and movement |
| Snow and land ice | Snow cover, ice and glacier cover, snow water equivalent, glacier motion |

A high-performance SAR system is expensive and normally has to be mounted on an aircraft or a satellite. There is however work being done on developing cheaper and smaller systems that can be operated on drone platforms.
One droned based SAR system is being developed in cooperation between the University of Calgary and Nanjing University of Aeronautics and Astronautics, Figure 65. The SAR unit (left image) is an X-band radar (8-12 GHz) that weighs approximately 5 kg and will produce images with a resolution of 0.1-0.5 m. Due to the heavy radar the flight time is limited as for now. The SAR unit mounted on the drone platform and the corresponding side looking antenna is shown in the right image.

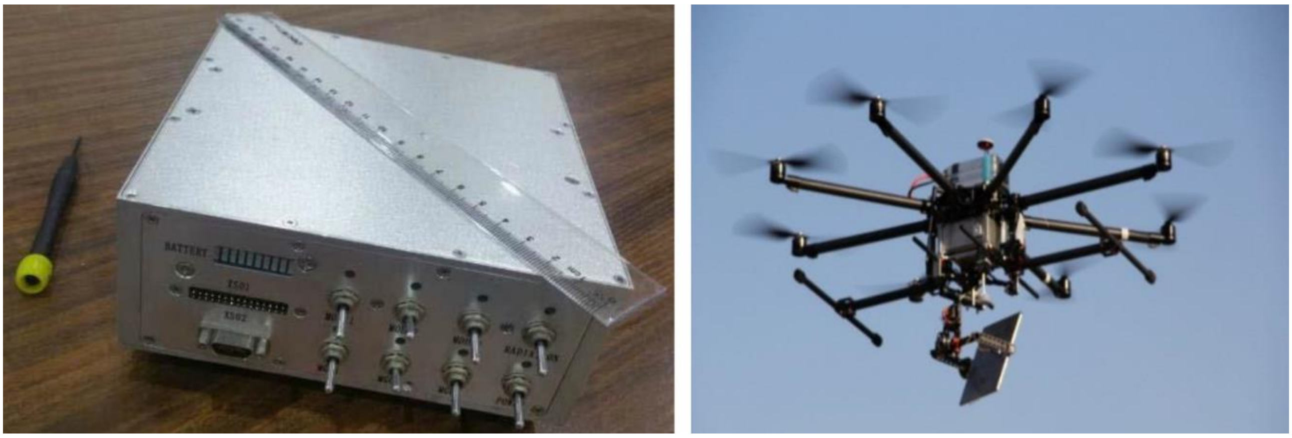

**Figure 65. SAR on drone for Arctic surveillance.**

One intended application for this system is sea ice classification. However, for developing reasons the first applications have been to produce images. One such result is demonstrated in Figure 66, where the left image shows a regular photo image and the right image shows the corresponding image assembled by the SAR system.

**Figure 66. Comparison of an optical image (left) and a SAR image constructed from a drone system (right).**

## *5.8. LiDAR sensor on an octocopter*

The Austrian laser scanning company Riegl has developed an airborne integrated system comprising a drone and a LiDAR sensor, Figure 67. Total payload (sensor and power supply) is 16 kg. Maximum flight time with this payload is 30 minutes. The size of the drone is 1220 mm x 810 mm x 540 mm (Riegl, 2017). The LiDAR sensor can measure up to 350 000 points per second. Measurement accuracy is 10 mm.

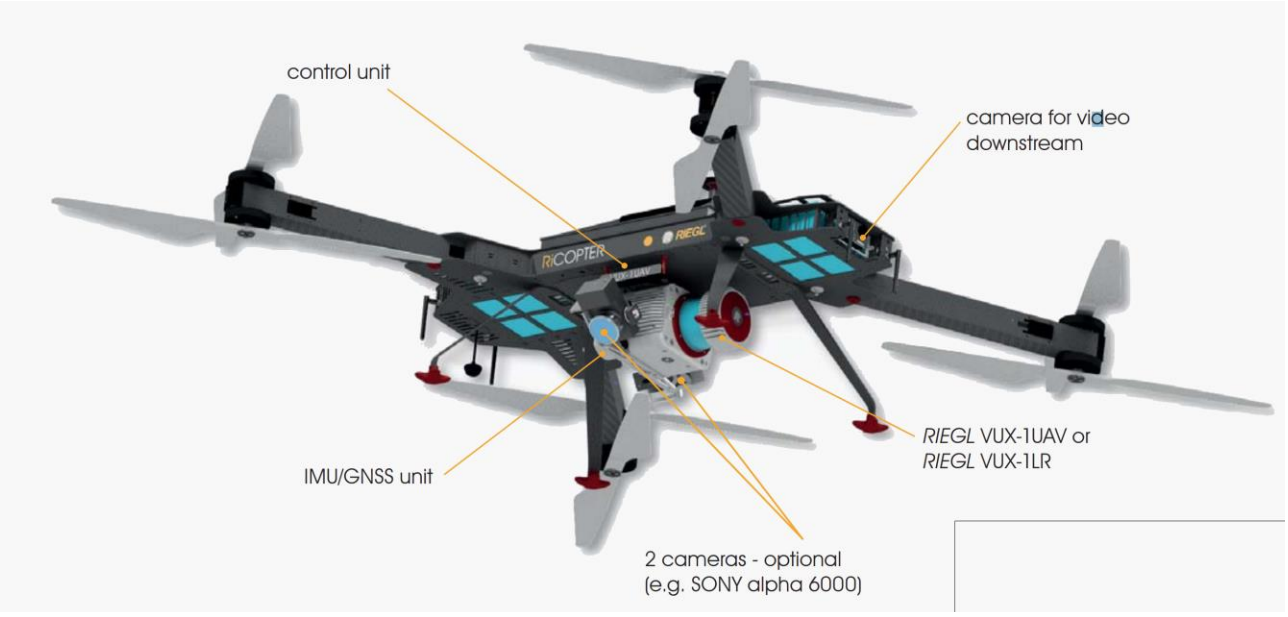


**Figure 67. The RiCOPTER from Riegl is a commercial off the shelf system with a UAV ready to be incorporated in any Riegl LiDAR system (Riegl, 2017).**

As opposed to a Terrestrial LiDAR System (TLS), a drone with a LiDAR system can be used to perform airborne laser scanning. This is of course advantageous for such applications as large industries, forests, construction sites, mines or any remote area. Figure 68 shows two such examples; power line (left) and forest (right) (Riegl, 2017).

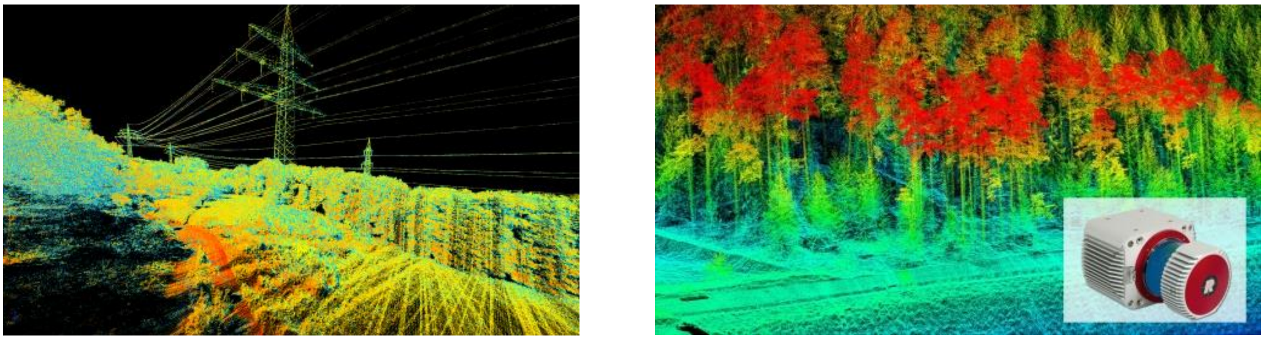

**Figure 68. Results from airborne LiDAR missions, showing the resulting post processed 3D models of a power line (left) and a forest (right), (Riegl, 2017).**

Laser scanning together with traditional photogrammetry will be an ultimate way to do land surveying. Photogrammetry is good for surveying sites without any obstacles for example trees, but when the area is full of obstacles like leaves from trees, laser surveying becomes the best. The laser will reach the ground beneath the leaves and branches and can send the information back to the LiDAR sensor. The laser will also be reliable in low light or even non-existing light conditions, where a traditional camera won't deliver any results at all.

# 6. References

2B Technologies. (2018, 08 21). *Personal Ozone Monitor*. Retrieved from https://twobtech.com/pom-personal-ozone-monitor.html

Acreo. (2016). *Intelligent Vehicles Symposium 2016.* IEEE.

Ader, M., & Axelsson, D. (2017). *Drones in arctic environments.* Stockholm: KTH.

AgriDrone. (2017, 10 5). Retrieved from http://agridrone.co/

Ayhan, S., Pauli, M., Scherr, S., Göttel, B., & Bhutani, A. (2017). Millimeter-Wave Radar Sensor for Snow Height Measurements. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 55, NO. 2,* , 854-861.

Beisswenger, A. e. (n.d.). *Issues and Testing of Non-Glycol Aircraft Ground Deicing Fluids.*

Bosch. (2017, 11 27). *Bosch Sensortec*. Retrieved from https://www.bosch-sensortec.com/bst/products/all_products/bmp280

Bühler, Y., Adams, M., Bösch, R., & Stoffel, A. (2017, 11 28). *Mapping snow depth in alpine terrain with unmanned aerial.* Retrieved from https://www.the-cryosphere.net/10/1075/2016/tc-10-1075-2016.pdf

*Comparison of photogrammetry software*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software

DJI. (2017, 12 09). *Zenmouse XT.* Retrieved from https://www.dji.com/zenmuse-xt

*Drone racing*. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Drone_racing

Edition Truth. (2017, 12 12). *Terrestrial Laser Scanning Market Estimated to Experience a Hike in Growth by 2023*. Retrieved from http://www.editiontruth.com/terrestrial-laser-scanning-market-estimated-experience-hike-growth-2023/

Eltner, A., Kaiser, A., Castillo, C., Rock, G., Neugirg, F., & Abellán, A. (2017, 11 28). *Image-based surface reconstruction in geomorphometry.* Retrieved from https://www.earth-surf-dynam.net/4/359/2016/esurf-4-359-2016.pdf

FLIR Systems. (2017, 11 27). Retrieved from http://www.flir.co.uk/suas/content/?id=70733

Forest Inventory Research Group. (2017, 12 12). *Estimating forest biomass components by airborne and terrestrial laser scanning*. Retrieved from http://www.forestinventory.no/?p=935

Garmin. (2017, 12 22). *LIDAR-Lite v3*. Retrieved from https://buy.garmin.com/en-US/US/p/557294

GISGeography. (2018, 02 24). *What is NDVI (Normalized Difference Vegetation Index)*. Retrieved from https://gisgeography.com/ndvi-normalized-difference-vegetation-index/

Gudra, T., & Najwer, L. (2011). Ultrasonic Investigation of Snow and Ice Parameters. *ACTA PHYSICA POLONICA A, vol 120 (4)*, 625-629.

Gustafsson, T., & Bendz, E. (2018). *D8.5 Guidelines for drone useage in arctic environments.* Interact.

Gustafsson, T., Bendz, E., Tang, A., Attalla, D., Olsson, S., & Ericsson, T. (2018). *D8.4 - Report on recommendations for new sensor development.* Interact.

*Gyro developments*. (n.d.). Retrieved from http://www.oceannavigator.com/January-February-2003/Gyro-developments/.

*IATA Dangerous Goods Regulations*. (n.d.). Retrieved from https://www.iata.org/whatwedo/cargo/dgr/Documents/passenger-lithium-battery.pdf

International Met Systems. (2017, 11 27). Retrieved from http://www.intermetsystems.com/products/iMet-XF-UAV-Sensor

Manaaki Whenua Landcare Research. (2017, 10 10). *DISTRIBUTION AND ABUNDANCE*. Retrieved from Manaaki Whenua Landcare Research: https://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/birds/penguins/adelie-research/methods/distribution-and-abundance

Mason, A. (2017, 11 28). *Making 3D Models from Photogrammetry*. Retrieved from https://thehaskinssociety.wildapricot.org/photogrammetry

Moeser, D., Morsdorf, F., & Jonas, T. (2015). Novel forest structure metrics from airborne LiDAR data for improved snow interception estimation. *Agricultural and Forest Meteorology*, 40-49.

Moreira, A., Prats-Iraola, P., Younis, M., Krieger, G., Hajnsek, I., & Papathanassiou, P. K. (2003). A Tutorial on Synthetic Aperture Radar. *IEEE Geoscience and Remote Sensing Magazine* , 6-43.

Olofsson, J. (2017, 04 06). Hur arbetet går till vid Abisko forskningsstation. Stockholm.

Riegl. (2017, 12 12). *RiCopter with RIEGL VUX-SYS integrated .* Retrieved from http://www.riegl.com/uploads/tx_pxpriegldownloads/RiCOPTER_Brochure_2017-09-12.pdf

SeekOps Inc. (2017, 11 7). *Drone Methane Leak Detection Demonstration.* Retrieved from https://www.youtube.com/watch?v=EHrL2W4yexw

Sørensen, L. (2016). *Autonomous Icing Protection Solution for Small Unmanned Aircraft. Doctoral thesis.* Trondheim: Norwegian University of Science and Technology. Retrieved from http://folk.ntnu.no/torarnj/Kim_thesis_12_09_2016.pdf

T&B Systems. (n.d.). *Use of Small Unmanned Aerial Vehicles for Air Quality and Meteorological Measurements.* Retrieved from 2014 National Ambient Air Monitoring Conference: https://www3.epa.gov/ttnamti1/files/2014conference/wedngambaxter.pdf

*The Trippy, High-Speed World of Drone Racing*. (2018). Retrieved from The New Yorker: https://www.newyorker.com/magazine/2018/02/05/the-trippy-high-speed-world-of-drone-racing

Unibap. (2017, 11 28). Retrieved from https://unibap.com/product/intelligent-vision-system/

West Coast Miners. (2017, 11 29). *Drone Mapping of a Coal Mine.* Retrieved from http://www.westcoastplacer.com/drone-mapping-of-a-coal-mine/

Wingtra. (2018). Retrieved from https://wingtra.com/drone/

Vladišauskas, A., & Jakevičius, L. (2004). Absorption of ultrasonic waves in air. *ISSN 1392-2114 ULTRAGARSAS, Nr.1(50).* , 46-49.

Wolff, C. (2017, 8 31). *Radartutorial.eu.* Retrieved from Radar Basics: http://www.radartutorial.eu/20.airborne/ab07.en.html