Integrating Activities for Advanced Communities

D8.4- Report on recommendations for new sensor development

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Dissemination Level

PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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Publishable Executive Summary

There is a large number of possibilities to create new environmental research opportunities in combining drones with different types of sensors. The application of using drone platforms and sensors for environmental research is yet not very widespread and therefore there are not many standardized commercial systems that fulfils the very specific requirements for environmental research. One of the few straight forward applications today would be to apply an off-the-shelf drone with integrated camera, and to use this system for taking pictures.

This document aims at providing recommendations for new sensor development. The proposed sensors in this document are derived from opportunities and needs identified by the Arctic environmental researchers. The proposed sensors are solutions to some of the identified needs, however scientists are engaged in very diverse areas of research, which means that there is still a need for more type of sensor solutions once the application of drones within the area of environmental research starts to increase. Sometimes the need will be for a new system or process, which not necessarily includes the development of new sensors, but rather aims at combining existing sensors with new software algorithms.

Some examples or recommendations for new sensor development are:

- lightweight, sensitive and accurate sensors for measuring greenhouse gases,
- radar for measuring snow depth and snow layers,
- radar systems for earth observations of land, ice, snow, vegetation, sea,
- identifying types of vegetation with stereo camera and artificial intelligence.

This document also includes recommendations for exploiting opportunities for letting the drone perform tasks such as retrieving data from fixed deployed sensors or collecting physical samples.

Some ideas for using the drone as a tool to aid environmental researchers are:

- using the drone as a relay station to, by telecommunication, collect data from fixed sensors in remote areas,
- using hydro acoustic communication system to collect data from underwater sensors,
- track animals or fish tagged with radio transmitters and collect transmitted data,
- sensor fusion of two or more sensors to track snow change on e.g. glaciers,
- collect water samples.

All above mention ideas are elaborated on and explained in more detail in this document.

Acronyms

RPAS	Remotely Piloted Aircraft System
RFID	Radio-Frequency Identification
RTK	Real Time Kinematic
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle

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 costs 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 stations. Also, there is a large number of possibilities to create new environmental research opportunities in combining drones with different types of sensors.

This document aims at providing recommendations for new sensor development. The proposed sensors in this document are derived from opportunities and needs identified by the Arctic environmental researchers. The proposed sensors are solutions to some of the identified need, however scientists are engaged in very diverse areas of research, which means that there is still a need for more types of sensor solutions once the application of drones start to increase.

This document also includes recommendations for new systems or processes, which not necessarily includes the development of a new sensor, but rather aims at combining existing sensors with new software algorithms or exploiting opportunities for letting the drone perform tasks such as retrieving data from fixed deployed sensors or collecting physical samples.

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 in different situations 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 drone technologies and applicable types of sensors.

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. Identified drone opportunities

Overall to remember is that the research stations in the arctic and alpine regions do differ a lot from each other, both in types of terrain and environment but also in what research focus they have.

The project is named Drones in Arctic Environments, but this is in fact not one single type of environment. The environment in most cases are typically arctic with cold, snow, ice, etc, but for example on Iceland there is hot water springs, some stations have forest other do not, types of vegetation is different etc. This generates different research questions.

Group discussions during a workshop with some 50 researchers from the INTERACT community led to several conclusions on general area of interest for applications of drones and sensors. Table 1 summarizes identified needs and opportunities shared by more than 50% of all research stations. It should be mentioned that the opportunities listed are not with any type of prioritisation, but merely indications of what types of applications that could be of interest for the research stations.

Table 1. Opportunities shared by more than 50% of all participating research stations.

Opportunity	Comment
Detailed 3D mapping	Some suggested a good 3D map of the environment as a future basic property of each research station. No one really disagreed but still would not prioritise it that high on the list.
Count population	To use a lot of images and then count animals such as reindeer, birds (in air, at cliffs, nesting etc), seals etc or plants were expressed as an interest for several.
Snow coverage/layers	Measuring snow coverage was an important feature. This could be combined with 3D mapping and also give some results on snow depth. Snow density and layers of snow were only prioritised by a few.
Vegetation mapping	Vegetation mapping and to see how that progresses is of great importance for many researchers.
Temperature measurements	In air and in water (or in the ground) on different levels/altitudes.
Recurrent measurements and upscaling	Several persons mentioned the opportunity to do measurements with drones frequently and to scale up precision results collected from sensors in one single place in order to see changes.

Table 2 summarizes identified needs and opportunities shared by approximately more than 25% of all research stations.

Table 2. Opportunities shared by more than 25% of all participating research stations.

Opportunity	Comment
Collect samples: air, water, soil/mud/gravel, from trees	Drones could make non-invasive sampling possible and introduce less impact on the environment studies or possibility to access hard to reach places such as middle of a lake, mountain slopes, air 30 m up, etc. Water samples seem most interesting, air less and mud/gravel/soil (approx. 30 ml) and tree samples was only mentioned by a few, likely because it is obviously a little bit harder to achieve with a drone.
Mount or place sensors in places difficult to access for humans	There are problems today with placing sensors but also collect data from sensors placed on mountain slopes etc. Drones could be made to place the sensors but also to wirelessly receive sensor data and bring back home.
Spectral measurements	Mainly for vegetation mapping.
Radar measurements	Mainly ground radar measurements are done today but other types of radar applications were discussed, for example inspect a glacier.
Measure greenhouse gas fluxes	There are a lot of different gases that are measured today, among them CO_2.
Heat camera	
Safety, surveillance	See the scene or inspect dangerous places, look out for polar bears, send rescue material.
Marketing videos	Drones give you a good overview of the scene, the research area and more.

Table 3 summarizes identified needs and opportunities that could be of value to some research stations.

Table 3. Other opportunities mentioned.

Opportunity	Comment
Follow tagged animals or find equipment	Example with fish that have a radio tag was mentioned as well as problems with that some small equipment placed in difficult surroundings (especially in water) could be difficult to find. Example given with small optical sensors in water with a small floating device. The ice can make this entire setup to do an unwanted change of position, making it difficult to find the sensor at a later stage.
Measure water salinity	
Measure (changing) riverbed of water streams	
Laser emitting light and sensor measuring fluorescence created	
Delivery	Send or receive goods to teams out in the field

3. New sensor development

All the identified and listed opportunities in chapter 2 can be translated to needs, which further can be solved by some drone platform in combination with some sensor, sampler or other custom made solution.

The application of using drone platforms and sensors for environmental research is not very widespread and thus there are not many standardized commercial systems that fulfils the very specific requirements for environmental research. The only straight forward application would be to apply an off-the-shelf drone with integrated camera, and to use this system for taking pictures. However, most other applications would probably require some kind of customization. One opportunity that has been identified is the possibility to use a drone system to take water samples. But even this limited application is difficult to realize with a single solution since the methods for water sampling differs a lot; e.g. the amount of water in each sample, the number of samples, the water depth, lake, river, sea, etc. It is reasonable to think that standardized solutions eventually will evolve, but for now there is a need for development of new methods and new systems, including drones, sensors, data analysis and operations.

One aspect that is of interest for sensors to be used on drone platforms is that the sensors have probably already been developed for other purposes, but they need to be redesigned in order to suit the requirements set up by the drone platforms, e.g. cost, weight, size, ambient, etc. One example would be to redesign an imaging radar system carried by an aircraft to fit on a drone of moderate size. In this case it is not really a new sensor that is being developed but rather a redesign of existing ones.

Another aspect is that one or more sensors are already available, but the combination of them and/or the addition of algorithms will make it possible to produce new results not achievable by the individual sensors themselves. Again, for this case it is fusion of sensor data from existing sensors that will produce new results, not really the development of a new sensor.

This chapter will highlight some projects and ideas that includes new applications of existing sensors and some new application of how to utilize the drone for services that might facilitate the collection of samples or sensor data.

3.1. Measuring greenhouse gas

There are ways to measure greenhouse gases, but the methods and equipment normally used are bulky and often intended to be used for point measurements such as flux chambers to measure e.g. methane (CH_4). Performing mapping of emissions in agricultural landscapes or more remote and harsh areas is therefore challenging with traditional methods. Thus, there is a need to develop lightweight, sensitive and accurate sensors suitable for being mounted on e.g. a drone for mapping larger areas. When funding for future drone applications recently was made available from Sweden’s innovation agency (Vinnova) one of the rewarded contributions was related to development of a methane sensor for drone applications (University of Linköping, 2018). The project is ongoing and is scheduled to be finished June 2019.

3.2. Snow measurements

3.2.1. Measuring snow depth and layers with radar

The Norwegian research institute Norut has performed initial test to carry a ground penetrating radar on a 1,5 m wide custom made drone in order to measure snow depth and snow layers (Norut, The drone that sees through the snow, 2018). The developed system is aiming at identifying different snow layers with a resolution of 5 cm. Figure 1 shows a post-processed radar image of a measured snowpack. The yellow areas correspond to layers where more energy from the radar is being reflected and this is identified as different snow layers. The smaller image to the right shows an evaluation of the corresponding snow layers that has been manually established by digging a hole in the snowpack.

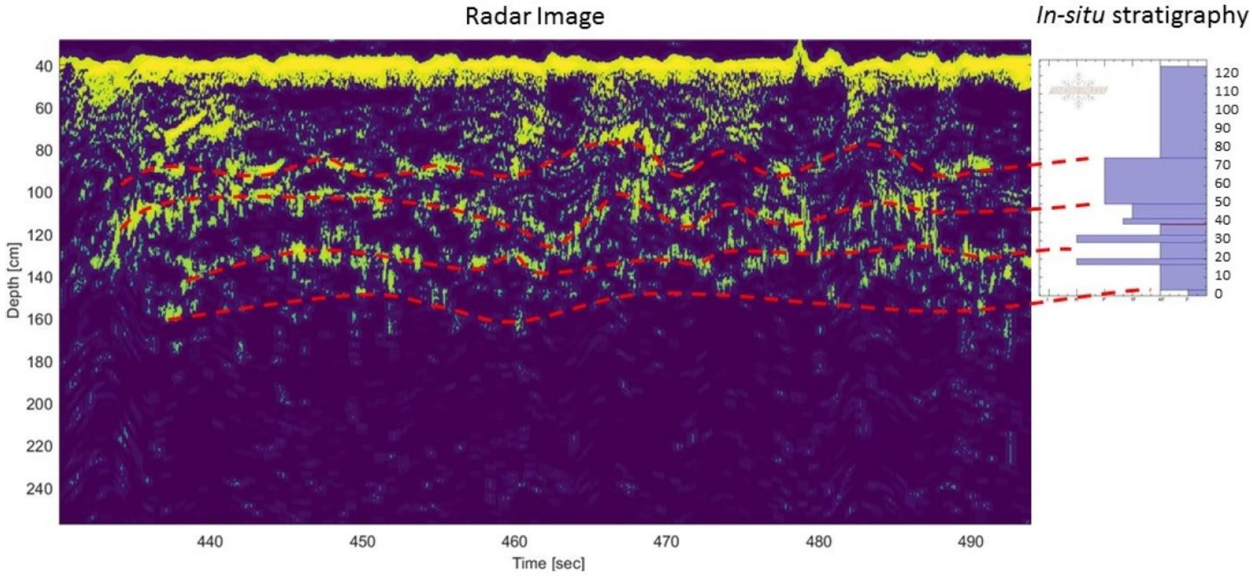

Figure 1. Backscattered energy from the radar (left image) with yellow areas indicating higher energy levels at various depths in the snow. Corresponding manually identified snow pack (right image) shows a similar layered structure (Norut, UAV-borne UWB radar for snowpack surveys, 2018).

The work done by Norut shows promising results utilizing radar as a sensor for measuring snow. It is expected that further development of radars for e.g. the automotive industry will drive the development of radars towards smaller size and better performance. Also, there is a need to develop algorithms further for faster evaluation of recorded radar data.

3.2.2. Measuring land, ice, snow, vegetation, sea with radar

A radar based method that has gained popularity is Synthetic Aperture Radar (SAR). More about the SAR technology can be found in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson). The most common platform for these SAR systems are satellites and aircraft. There are many types of SAR systems which evaluates different types of information from the backscattered radar signals. This means that different types of radars are used, and different types of post-processing algorithms are applied according to the specific application.

In an extensive tutorial on synthetic aperture radar (Moreira, o.a., 2003) there is a table that summarizes examples for applications of SAR systems 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 4.

Table 4. 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

There are several ongoing trials that are aiming at applying the different SAR techniques to drone platforms. The driver for this is the possibilities to obtain better data quality over specific locations of interest, where satellites or aircraft platforms might not be available or too expensive to utilize. Therefore, the use of SAR systems on drone platforms would be either as a complement to available satellite data, or for new applications where the access to satellite data not is an option.

From satellites the SAR data from the Sentinel-1 satellite run by the European Space Agency (ESA) can be used for monitoring e.g. Arctic sea-ice extent (Alaska Satellite Facility, 2018). In regard to airborne SAR-systems the NASA Jet Propulsion Laboratory runs it UAVSAR project to study e.g. vegetation and ice (Jet Propulsion Laboratory, 2018). As seen there are a lot of examples on applications on SAR-system in relation to earth observations and environmental research. The main platforms for now has been on satellites and aircraft, but the applications for drones are coming as the technology matures and evolves.

3.3. Identifying vegetation with stereo camera and artificial intelligence

A stereo camera has two lenses, which gives it the capability to accurately make distance measurements and also the ability to capture 3D images. 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. A possible application for the Arctic environmental research could be to train such a system in order to identify different kinds of plants or to count animal populations.

An ongoing research collaboration is using a stereo vision system with built-in artificial intelligence (Unibap, 2017) mounted on a wheeled robot in order to identify the wanted crops in a famer's field and then mechanically remove the remaining unwanted weeds. The robotic mobile platform is shown in Figure 2 (Robotdalen, 2017). The stereo vision system is the blueish cylinder that serves as the robot's eyes.

For Arctic environmental research this type of vision system could be integrated on a flying drone platform instead of a wheeled robot. Before embarking on a mission, the vision system has to be trained through machine learning in order to be able to detect and identify the specific plant or animal that it should look for. This training of the system occurs mainly in a lab environment. The reliability for correct identification can be more than 95% after proper training of the system, which is sufficient for many industrial applications.

Figure 2. Intelligent Vision System (Unibap, 2017) on a wheeled robot (Robotdalen, 2017) developed to be used in the agriculture area to identify and mechanically remove unwanted weeds from the wanted crops.

3.4. Drones as a tool to collect sensor data

One opportunity that has been identified is to use a drone to collect data from sensors that have been placed at any location for a particular reason. These locations could be in remote areas where access is difficult or dangerous. For these cases it might be possible to use some type of drone to collect the sensor data. Typical examples are either to place and/or pick up a specific sensor in such a remote location. It can also be to continuously and repeatedly, over a period of time, access and retrieve small sensors in isolated places. Typical sensors may be cheap and passive RFID (radio-frequency identification) tags or low powered radio transmitters with limited range, which when the drone is nearby, will deliver data from the site.

3.4.1. Collect data in very remote areas

Wireless communication networks with base stations can be set up in order to enabled radio communication between sensors and a central receiving station. There are numerous examples of techniques to do this depending on the type of application, but for sensor networks with low demands of capacity and large areas to cover, it is preferable to use equipment that requires low energy but still are capable of transmitting data over large distances.

One fundamental restriction for radio communication over large distances is the curvature or the surface of the earth which restricts the so-called radio horizon, i.e. how far a transmitter can “see” a receiver. Due to the curvature the maximum distance between to communication entities is proportional to the square root of the height above ground of the antennas for the transmitter and/or receiver. This means that the higher the antenna is located, the longer is the possible communication distance. Another fundamental restriction for long-distance communication is the risk of location of objects that shadows the radio path between the transmitter and receiver, i.e. mountains, hills or forests.

In the Arctic region, there are not many well established radio communication networks that could carry information between sensors. Therefore, distances between any applied sensors equipped with radio transmitters and the receiving research station might be very long or there might be interfering obstacles along the path. One way to overcome this problem could be to use a drone as a relay station, as described in Figure 3. The drone in the right image would be equipped with a transceiver, that could receive and re-transmit the broadcasting from the sensor to the receiving research station. Given that the drone might operate at heights up to 120 m (400 feet) and that the radio horizon is proportional to the square root of the height of the radio antenna means that this type of solutions could drastically increase the possibility for successful transmission of data.
The opportunity to read sensors or equipment that is positioned in a remote area, without any direct access, is also described as a specific request in chapter 2, Table 2.

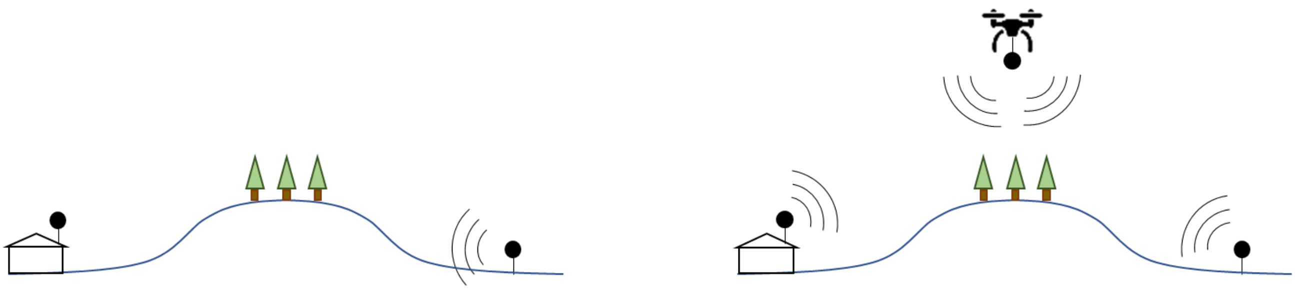

Figure 3. Using drones as a mean of overcoming radio communication challenges such as large distances or obstacles.

There are similar opportunities to collect data and use a drone as a relay for acquiring data on remote sensors carried by animals. Sensors placed on animals are often limited in size and performance and at the same time their pattern of movement can be unpredictable. A drone might be a solution to extend the range for retrieving information from these sensors. It has been identified at least one example of a specific request for this type of service during this work package.

3.4.2. Collect data from underwater sensors

One location of sensors can be under water. If a sensor is placed under water it will be difficult to communicate with it wirelessly, since radio waves are heavily attenuated by water. The problem statement would be the following: acquire data from sensors immersed in water.

One solution to this problem can be to use hydro acoustic communication systems to transmit data from a sensor to a drone. A very coarse description of an application of a hydro acoustic communication system solution is visualised in Figure 4. The idea is to have a communication base station on a drone with a capability to immerse an antenna into the water. In the water there are one or many sensors that have collected data. When the base station starts communicating with the sensor, the sensor will send its data to the base station.

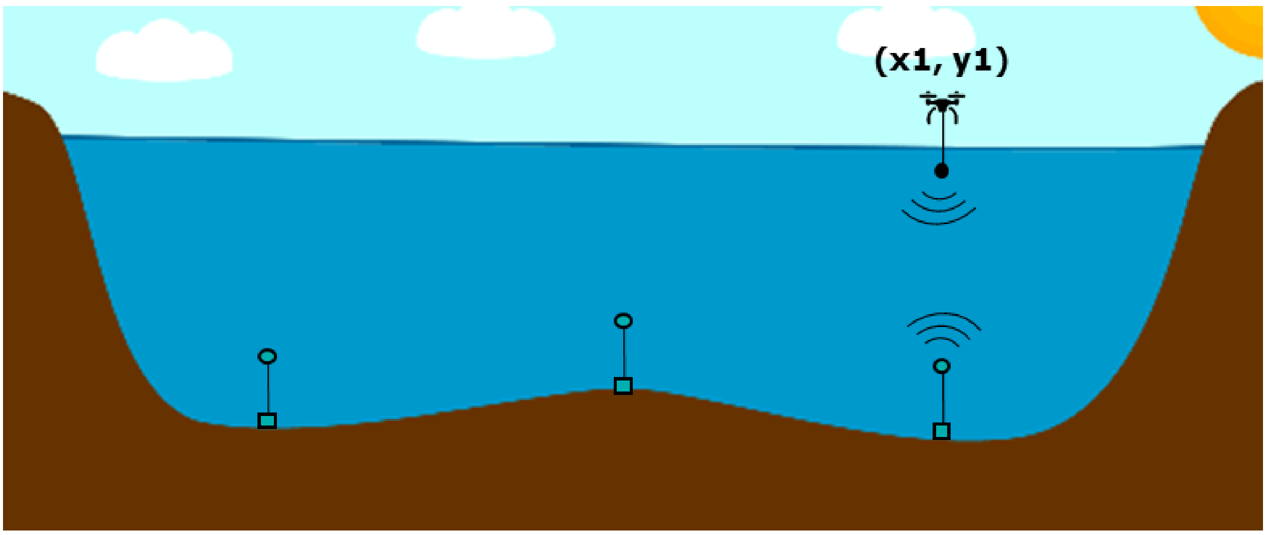

Figure 4. An overview of how a drone based hydro acoustic communication systems could be used to extract data from underwater sensors.

This type of hydro acoustic communication system has been developed by the Swedish research institute RI.SE (Platt, 2017) under the EU Seventh Framework programme. The application is for keeping track of fish as well as fish health monitoring with the aquaculture industry (Seafood Security, 2018). For this case a 15 mm capsule with sensors and a communication device has been developed. The small size of the sensor makes it possible to place it inside a fish. This type of capsule could be redesigned for different purposes and be located either statically immersed in water, or dynamically within certain boundaries. The communication distance for such a device is typically 25 m in water. The cost for a base station is in the order of €1000 and each capsule might cost €10 if produced in some quantity.

Another solution has been evaluated that relies on UHF radio waves at approximately 400 MHz to transfer signals from fish tagged with radio transmitters to a receiver station mounted along a riverside (Huusko, o.a., 2017). The aim is to follow salmons as they travel along rivers. At certain locations receiver stations are mounted in order to collect data from the pods inside the salmons. One challenge with this solution is that it is sometimes difficult, due to the terrain or local geographic situation, to access the riverside to be

able to assemble or position the receiver station. One idea that has surged is attach the receiver station to drones for easier access but also to have the possibility to follow the fish along parts of the journey along the river.
Any future project for this would very much simplify, streamline and improve the collection of data during a project.

3.4.3. Snow change tracking aid using sensor fusion

The Arctic is subject to rapid climate change that can be difficult to track. Environmental researchers in the polar regions are analysing the glacier dynamics by monitoring and gathering data through field work. From a previous master thesis work conducted within the INTERACT project (Ader & Axelsson, 2017), researchers expressed a desire in facilitating the current field work part of their daily work. Daniela Attalla and Alexandra Tang, two master thesis students at the Royal Institute of Technology in Stockholm, have therefore worked on a proof of concept aimed at making the in-situ work more efficient (Attalla & Tang, 2018). The goal has been to suggest, develop and evaluate a concept in which researchers in the Arctic benefit from incorporating drones in their snow ablation research.

An alternative way to measure ablation stakes with the help of a sensor fusion system mounted on a drone is presented. Ablation stakes are stakes placed in a grid over glaciers, below the snow and ice surface, during the winter and then measured during the summer to keep track of the amount of snow that has melted throughout the mass balance year. Each measurement is therefore given by physically going to these stakes, which can be dangerous since the terrain can be difficult. Researchers have moreover expressed an interest in getting more data through more frequent measurements. This is not possible with the current methods due to time constraints. The accuracy achieved today is at the decimetre level.

The proposed solution is estimating the height of the ablation stakes using a forward-faced LiDAR and a downward-faced ultrasonic sensor. The stake height is interpreted as the highest ultrasonic distance while the forward-faced sensor system is detecting an object, see Figure 5. The prerequisite is that the pilot manoeuvres the drone such that it hovers around the stake top within a distance of 3 metres from the stake.

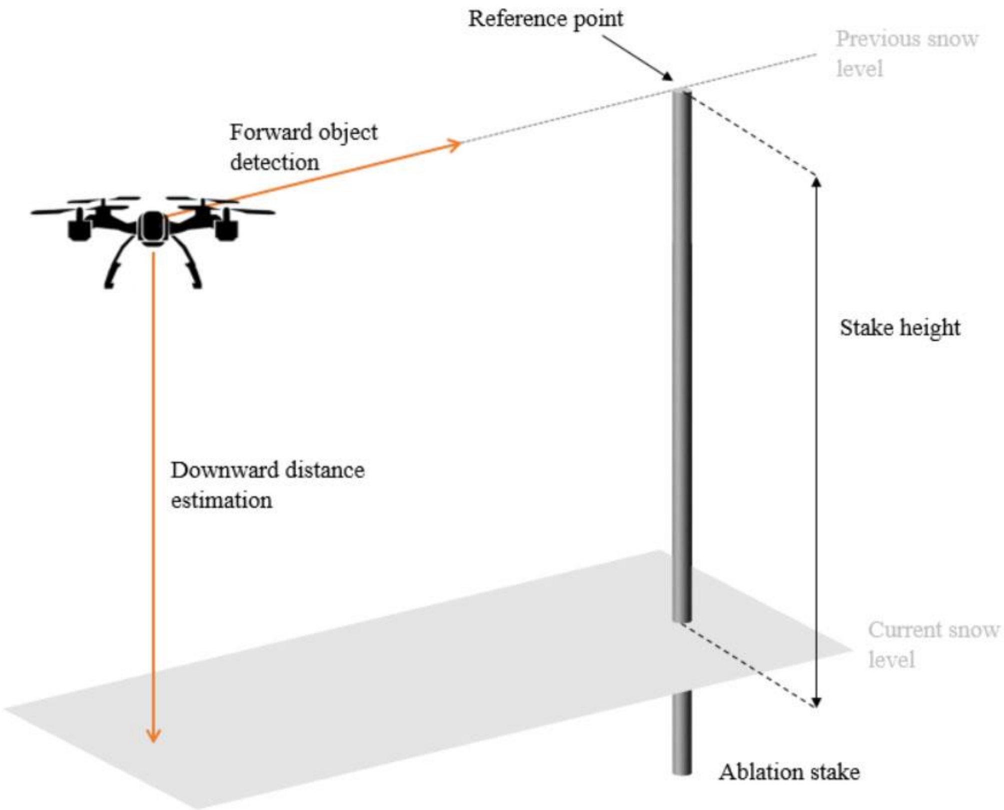

Figure 5. Illustration of the developed concept for measuring the height of ablation stakes.

Three tests were conducted to evaluate the suggested concept. The first test aimed at evaluating the forward-faced subsystem's ability to detect ablation stakes within a certain area from the sensor. The second aimed at evaluation the downward-faced subsystem's accuracy in estimating the distance to snow surfaces. The third test was designed as an initial integration test in which both subsystems were combined and tested on a handheld prototype in order to estimate the height of the stakes. All tests were performed in an indoor environment. The final prototype can be seen mounted underneath a drone in Figure 6. The total weight of the measurement system is 320 grams.

Figure 6. The final prototype mounted underneath a drone.

The results indicate that the stake height estimation using the proposed concept is a potential solution for the researchers if the tilt of the drone during measurements are compensated for. The fact that the forward-faced LiDAR tilted when the test prototype was subject to tilt introduced errors in the resulting measured distance from the prototype to the ground surface. These errors were caused since the top of the stake was considered being at a lower or higher distance than the position of the prototype relative to the stake. Consequently, the stake height was estimated with an error of more than two decimetres during the integration tests. This issue could be fixed by mounting the LiDAR on a 3-axis gimbal, which will stabilize any movements in all three dimensions.

Furthermore, in order to conclude on the accuracy of the system with certainty, tests in which the sensor fusion system is mounted on an actual drone need to be conducted. These tests should also be performed in the concept's intended environment.

3.5. Water sampling

Gathering water samples manually is time consuming, uncomfortable because of rough weather, potentially dangerous and is limited to the reach of people and/or boat. With an automatic water sampling drone, lakes and water in harsh areas could be reached, which would expand the data gathering possibilities and improve the knowledge of the water in those areas (Olsson, 2018). Sofia Olsson is a master student at the Royal Institute of Technology in Stockholm that has elaborated on a proof of concept aimed at using a drone to collect water samples. The purpose of her thesis is to study the current water sampling process carried out by researchers within the INTERACT network with a mechatronic perspective to investigate how to improve the process.

The water sampling process can vary depending on the purpose of the water study, but the generalized user case begins with the researchers rowing their boat to a specific position in an open lake. The most commonly used water sampler is a Ruttner sampler, which is a hollow cylinder, open in both ends to let water flush through it while sinking. This is an important step to avoid contamination from earlier samples. When the Ruttner sampler is at the desired depth, a weight called the messenger that can slide along the wire is dropped by the researcher to trigger a closing mechanism in the sampler which captures the water sample inside. The wire is manually marked to know at which depth the sampler is. The captured water sample is then used to rinse a laboratory bottle 1-2 times, before being transferred into the laboratory bottle. The rinsing step is important to avoid contamination from earlier samples. The sample temperature, depth, date and time are then protocolled before the next sample is taken.

Two problems are identified in the current work process. The first problem is that the user needs to trigger the closing mechanism of the sampler manually. The second problem is that the rinsing step of the laboratory bottle requires extra water sample, that is only used for rinsing. From the survey, the minimum required water sample volume is 500 ml. The conclusion is that a water sampler that has full remote and automatic function and is designed to avoid the rinsing step of the laboratory bottle is needed for remote water sampling using a drone.

With inspiration from the current water samplers, which are hollow cylinders, open in both ends, the solution was to integrate the laboratory bottle into the sampling equipment directly. A laboratory bottle, threaded in both ends was designed, Figure 7. The idea is that the integrated laboratory bottle will rinse automatically when sinking through the water column. This will maximize the volume of useable water sample, as no water sample will be used to rinse the laboratory bottle at the shore. The threaded ends of the laboratory bottle led to the idea of designing different valves that are screwed onto the ends of the laboratory bottle. Two different concepts were further developed.

Figure 7. A picture demonstrating the designed laboratory bottle threaded in both ends.

The first concept is called the Cake unit, Figure 8 (left image). The Cake unit is a mechatronic unit consisting of a microcontroller to handle in- and outgoing signals. A pressure sensor is used to measure and save the current water depth and water temperature. When at the desired depth, the microcontroller outputs a signal to a servo to close the valve. The valve consists of two discs on top of each other, with complementing cut-outs. When the servo rotates to a specific angle, the cut-outs of the discs can align to let water through or misalign in order to block the water. The Cake unit is attached to the laboratory bottle using the threads. The advantages of the unit is that it is automatic, it saves the data automatically and the data is very accurate. The disadvantages is that it is relatively complex, it needs batteries and it is relatively heavy.

Figure 8. Two developed concepts for the water sampler: the Cake unit (left) and the Wheel unit (right).

The second concept is called the Wheel unit, Figure 8 (right image). The Wheel unit is a mechanical valve consisting of acrylic plastic. It consists of a disc that can slide along a rod to let water in from one direction and block water from the other direction. The advantages of the Wheel unit is that it is automatic, simple and lightweight.

The developed sampling equipment consists of the double-threaded laboratory bottle with a valve unit on each end. As the valve units can open and close independently from each other, unlike the closing mechanisms of today's water samplers, different valve designs can be combined. The independence of the valves also allows the product to be modular, as the height of the laboratory bottle decides the volume capacity of the sampling equipment.

Prototypes were evaluated through their ability to gather water samples at specific depths. The conclusion is that when sinking to 5 m, the design of the prototypes tends to block the flushing water, and the water sample at 5 m is therefore unreliable. However, it is not necessarily the design of the prototypes that is the problem. Reconstructing the prototypes with smaller tolerances and better machines, that were not available for use in this thesis, would probably give a better result. The constructed prototypes can successfully gather surface samples.

Figure 9. Gathering samples of water during test of the prototype.

Water samples were gathered using the drone to evaluate the full test system, Figure 9. The following observations were made:

- It is possible to gather water samples with the drone.
- The water sampler needs to be very robust during take-off and landing as it is dragged along the ground.
- The closing mechanism of the water sampler needs to be very robust as the water sampler can be dropped roughly on the ground at landing.
- The suspended load is oscillating which makes the drone harder to control.

Other interesting problem areas were defined through the interviews and survey. The first is to investigate how several water samples can be gathered at the same time, for example throughout the water column. The other problem area is how to gather larger water samples, as 75% of the researchers participating in the survey needs a volume of 1 litre or more. These two problems were not focused on in the thesis because of the drones' weight constraint of 1 kg.

3.6. Data management

A final remark on development in this document is the concern for managing all the collected data from the drone missions. This is something that should be taken into account already from the early phases of planning for introducing a drone capability for research purposes.

There is a need to invest in some form of data management infrastructure. This could preferably be some shared infrastructure for the entire INTERACT community (as discussed in INTERACT WP4). Such a system would then serve as a common point for data storage.

Some requirements for this system is to collect data, structure data, store data, relate it to other data, analyse the data, present the data, share the data, comment the data, etc.

The system should preferably also be fully automated and capable of handling the expected large amounts of data.

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