UAS (drone) Arctic Challenges - Next Steps

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Abstract—**This paper develops further the overview of technical and operational challenges associated with Unmanned Aerial Systems (UAS) operations in the Arctic. Essentially, many weather-relevant challenges are similar in other climate zones. Due to the lack of research on the Arctic particularities, the overview of included references to generic UAS challenges and considerations. Both collections of challenges, technological and operational, are revised and updated. For most of the listed challenges, the appropriate researches are introduced as entry points to the more specific research areas relevant to the given challenges.**

I. INTRODUCTION

The presented work continues and develops further the earlier-published [1] overview of technical and operational challenges associated with Unmanned Aerial Systems (UAS) operations in the Arctic.

During the past year, even more frequently public discussions were caused by UAS-relevant activities around the world [2]. Some of the UAS applications or rather actions shanked safety and security paradigms [3] and some even hit the newsmakers [4].
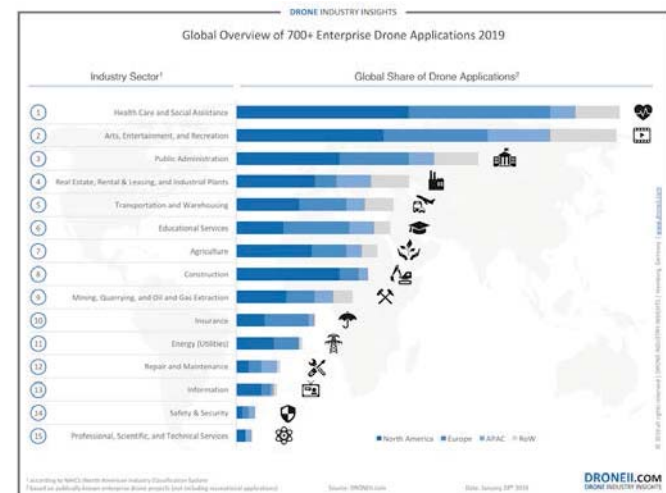

Fig. 1. UAS applications per industry sector

Nevertheless, outside of the military domain, many of UAS applications took places with relevance to observation, inspection, monitoring, surveying, mapping, mining, construction, agriculture, energy and utilities and logistics. According to Drone Applications Report 2019 by Drone Industry Insights, energy and public administration are the industrial sectors that use drones the most, while about one-third of researched drone missions were for the purpose of inspection [5]. UAS applications ratio in fifteen industry sectors is shown in Fig. 1 [6].

UAV Coach pointed to more than one hundred companies and organisations to watch in 2019 [7]. The list was categorised into ten categories, which are: Hardware Companies, Drone Industry News, Flight Operation Management, Data-Processing Tools, Marketplaces and Databases, Funders, Drone Delivery, Drone Racing, Drone Conferences, Training and Education. While all the other categories seem essentially relevant to UAS technologies, missions, and general UAS domain activities, drone delivery and drone racing are separated and highlighted as important application domains.

According to Drone Industry Insights [5] [6], the biggest application areas for drones are Health Care and Social Assistance and Art, Entertainment, and Recreation industries. Even though there was not observed a significant breakthrough towards personal assistive and service UASs in a form they had been described earlier [8], several cases of drone-based medical supply and bio-medical delivery have been observed [9],[10],[11],[12]. Because of additional requirements for transportation of high-value cargo [13],[14],[15],[16],[17],[14],[18],[19],[20] coping with the environmental conditions is of a high importance for UAS-based transportation.

Safety and security are essentially among the most primary considerations regarding application of drones. For example, in Europe, several aspects are highlighted and addressed in recently-adopted regulations, such as Commission Delegated Regulation (EU) 2019/94512 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems [21] and Commission Implementing Regulation (EU) 2019/94713 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft [22]. Weather conditions and performance of the unmanned aircraft are the important factors affecting safe and secure UAS missions.

Tough aviation-grade requirements for robust and weather-resilient UASs bring importance of research [23] on the Arctic challenges and UAS technologies matching the requirements under any environmental conditions. The UAS technologies suitable for operations in the Arctic conditions will cover margins of safety that surpass criteria for similar operations in other climate zones.

The earlier presented terminology [1] requires some clarification. According to [21], the following definitions are proposed:

"(1) 'unmanned aircraft' ('UA') means any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board;

(2) 'equipment to control unmanned aircraft remotely' means any instrument, equipment, mechanism, apparatus, appurtenance, software or accessory that is necessary for the safe operation of a UA other than a part and which is not carried on board that UA;

(3) 'unmanned aircraft system' ('UAS') means an unmanned aircraft and the equipment to control it remotely;

(4) 'unmanned aircraft system operator' ('UAS operator') means any legal or natural person operating or intending to operate one or more UAS".

Therefore, in the scope of the research, the following acronyms will be used: UAS, UA, UAS operator. The following acronyms and terms will be used interchangeably: UA, Unmanned Aerial Vehicle (UAV) and drone. With respect to those, definition of UAV as "lightweight aircraft" is not appropriate since some of UAVs or UAs are heavy-duty drones that are able to carry payload of thirty or more kilograms, e.g. GRIFF [24], and some are such heavy as aircrafts, e.g. NATILUS [25] or Northrop Grumman MQ-4C Triton [26].

The rest of this paper has the following structure. Overview of technical challenges is presented in Section II and overview of operational challenges are presented and Section III. Concluding remarks are given in Section VI.

II. TECHNOLOGICAL CHALLENGES

Technological challenges, or technical how they have been referred to earlier [1], are those that may be addressed, and their impact reduced or eliminated with the development of technologies, improved design or functionality of UAS, more sophisticated construction materials or application of additional technological means or artefacts. Some of the technical challenges may also be considered as operational challenges since they are relevant to the weather conditions and may be affected by human actions (e.g. cancelling or rescheduling UAS mission) [1]. The overview of the technical challenges presented in alphabetical order is following below.

AI data post-processing is widely used whenever volumes of data, requirements for processing speed, other demands or processing-specific requirements do not match with the ability of processing by humans. One of the typical AI application areas for data post-processing is 3D mapping [27] and other photogrammetry tasks [28]. Although with current development of drone computing capacity it is possible to build 3D models of the environment as a part of operational AI e.g. for navigation purposes [29]. A great number of applications relevant to monitoring, mapping and observation UAS require data post-processing, e.g. in forestry [30].

AI operational could help UA with processing vast volumes of operational data to achieve higher operational efficiency. For example, autonomous and assisted flight control systems may use machine vision, data fusion, machine perception, and AI-enhanced communications and data security to perform flights within set ethical principles and interact with UAs operator through adaptive multimodal interfaces. With the help of operational AI in the future, it will be possible to carry out fully autonomous missions [31], also life-critical [32]. Ethical considerations with respect to AI are relevant to operational challenges [33].

Assistive and mission-specific sensors is a huge area of technological development that progresses along with non-specific to UAS sensor development. The UA sensor technologies [34] may include a range of cameras [35], [36], deployment, integration with IoT services [37], utilise data fusion [38] and be implemented as multi-UA setup [39], which may also be organised as UA swarms [40]. Sensor accuracy may be crucial in some application areas [41].

Battery technologies are important regardless of UAS power sources. Even aviation gasoline-powered UA may have battery-powered ignition and computing boards. These challenges [42] are addressed from both ends, by developing more sophisticated battery technology [43],[44] and by optimising the energy expenditure [45], [46]. The battery technology challenges are relevant to weather physics challenges [47].

Body materials, main construction and moving parts may serve a multi-purpose, generic UAS, or be designed for a specific application or even a very specific mission. Different classifications of UAS exist [48],[49]. In Europe, one of the proposed classification for small UAs under 25 kg is by Maximum Take-off Mass (MTOM) [21], while light UAs up to 150 kg and large UAs more than 150 kg are not classified further. Depending on the construction type, different design challenges appear [48]. One of the earlier researches suggests that fixed-wing light-weight UA would be suitable for a wide range of operational environments including maritime, mountains and arctic environments [47],[50].

Beyond Visual Line of Sight (BVLoS) missions bring certain technology challenges [51],[52],[53],[54], also in case of multiple UAs missions [55] and correlate with operational challenges.

Communications expose a broad range of challenges [49],[56] associated with poor quality of communication channels, absence or out-of-reach of required communication infrastructure, and insufficiency of communication parameters. Certain methods aimed at improving the communications as a part of disaster management [57] may be utilised for other UAS applications in areas with poor communication infrastructure.

Computing capacity is always a compromise in autonomous systems [58] with limited capacity power sources, a wide range of sensors, intensive communications and demand for energy-hungry data processing [48], e.g. big data processing [59]. Edge computing may bring certain benefits to UAS computational architectures [60].

Control interfaces may help eliminate human limitations and assist in decision-making processes [61]. Human-robot interactions have been researched well before UAS era [62].

Similar principles apply, may be enhanced with assistive technologies [63]. More specific control interface requirements may come from the UAS application domain, e.g. infrastructure inspection [64], civil engineering [65].

Dust and solid particles clouds may damage UA sensors and therefore additional protection may be needed [66]. In addition to the earlier published description of these challenges [1], it is good to mention that UAS are used to research distribution of ultrafine particles in the air and air quality [41],[67].

Extreme light conditions are always challenging for optical sensors. The machine vision technologies may be enhanced [34],[68],[69].

Freezing rain is one of the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74],[75].

Heavy and gusty wind is one of the weather dynamics challenges [42],[70] that may be addressed with technology advances [76],[77].

Heavy clouds are among the weather physics challenges [70] that may be addressed with advances in navigation and communications technologies [49].

Ice fog is one of the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74],[75].

Infrastructure requirements may be addressed temporally with mission-specific infrastructure set that may be deployed for the UAS mission [78].

Just-in-time/dynamic data supply has crucial importance for data-critical missions and autonomous of assisted navigation [42],[49] and relevant to UTM technologies.

Low temperatures are among the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74].

Low-carbon operations are relevant to optimising the energy expenditure [45], [46] and the use of renewable energy sources [79],[80],[81].

Navigation systems may be addressed with technology advances [29],[32],[48],[65],[82],[83] and enhanced with geofencing technologies combined with satellite remote sensing [84].

The *payload* is a combination of different technological design and mission-specific factors [85][86].

Power source: modern power technologies such as solar [80] or fuel cell [87] may be supplemented with energy scavenging technologies [79].

Rain and fog are among the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74],[75].

Rapid temperature changes are among the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74].

Safety is one of the key technological challenges [88],[89]. Variety safety-relevant aspects are investigated and addressed [52].

Security is another key technology consideration that may be addressed in a variety of ways [49],[90].

Snow is one of the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74].

Technical malfunctioning may be very diverse [49],[53], in all varieties from power source failures through computing or communication malfunctions and to UAS operator control interface crash.

Temperature crossing 0°C is one of the weather physics challenges [70] that may be addressed with technology advances [71],[72],[73],[74].

Time constraints are affected by take-off and landing time and speed of UAS. The main associated challenges are relevant to battery technologies, payload and fuel type. When UASs are utilised in life-critical applications, time constraints are among the crucial factor of the mission success [91], [92], [93], [94].

UAS Traffic Management (UTM) systems [55], [95], [96] lift up a bunch of technological challenges relevant to communications, computing capacity, control interfaces, infrastructure requirements, just-in-time/dynamic data supply, safety, security, technical malfunctioning and time constraints [97].

Vertical Take-off and Landing (VTOL) with the current technology development allows reaching very challenging cases e.g. take off from docking stations [98] or landing on moving platform [99].

Weight of UAS and auxiliary equipment may be positively affected by novel constructive materials such as carbon nanotubes [71].

III. OPERATIONAL CHALLENGES

Operational challenges are those that may be addressed with human actions, predictive or corrective. Some problems or risks brought by the operational challenges may be reduced or excluded by access for information content and proper awareness. Some operational challenges (e.g. legislative or weather-related) are not possible to overcome and therefore they must be taken into consideration at planning and operational phases [1]. The overview of operational challenges presented in alphabetical order is following below.

AI operational challenges are relevant to limitations of AI-enhanced automation and assistance and those ethical dilemmas that sometimes are not even possible to be resolved by humans [33].

Best practices that are technology-driven have already been researched for several application domains [28],[30],[36],[57],[81],[100]. They paid attention to some of the operational aspects too. But more systematic research on operational best practices is needed as well as dissemination research results outside the research community.

BVLOS may require the authorisation of the mission, UAS certification and a subject of UTM systems. The recently published UAS regulations in Europe categorise such missions as specific or certified category[21], [22]. The rigid guidelines restricting BVLOS UAS missions in different countries may need to be revised or clarified [101].

Control interfaces may help eliminate human limitations such as slow reaction compared to a real-time control system, inability to pay attention to several objects under control [102], and the like.

Coordination with professional operations may be performed, for example for search and rescue and backcountry medical response [103] under conditions of technical readiness of UA, qualified operator, compliance with policies and regulations and whenever needed – interoperability with or integration into the professional information system.

Emotional aspects affect the UAS operator, the supporting team and the other actors of UAS missions including the object of the mission, e.g. the victim to whom the life-critical UAS mission is aimed [94]. The personal quality of UAS operators and their experience help them withstand the influencing factors. Inter-communications and support for decision making may also be helpful to all the actors of the mission even in case of automated missions [94].

Ethics and privacy considerations are already in the focus of legislative regulations in different countries but still to be researched further [101].

Extreme light conditions may not affect UA backed up with a multi-sensor vision. But the UAS operator and the supporting team may require auxiliary light sources or direct sunlight protection. It is recommended to consult with weather forecast [70].

Following guidelines and professional codes of practice is a high goal but achieving that may still take quite a time [104].

Formal procedures e.g. for operation and maintenance [34] may provide more streamline experiences with smaller probability for errors. As well as guidelines and professional codes [104], those procedures may still not be formalised in the nearest time. Even though some effort towards formalisation has already been taken [22].

Freezing rain is one of the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Geographical irregularities may prevent communications between the UAS operator and UA. It is recommended to be aware of local geographical irregularities and prepared for corrective actions.

Heavy and gusty wind is one of the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Heavy clouds are among the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Human factors may not be predicted by their negative impact may be reduced with classical approaches for human-robot interactions [62] and preventive awareness [61].

Human responses, public and personal, may vary significantly and it is recommended to be aware of possible negative responses to save the drone mission or cancel it [90],[105].

Human rights should not be violated by any of the UAS missions but the general public has a lot of concerns conditioned by sometimes unethical applications of drones [106].

Ice fog is one of the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Infrastructure requirements may not be achievable in certain geographical areas or might be too high due to the demand for specific UAS missions e.g. duration of expedition [107]. The first type of cases may require engaging additional technological solutions, e.g. non-GPS navigation, or deployment of additional equipment, e.g. portable base-station. The other type of cases may require achieving compromises between the desired infrastructure specification and available, and therefore a more thorough mission planning. For this type of cases, it is recommended to conduct cost-benefit analysis to evaluate effectiveness of UAS applications [101].

Insufficient qualification of UAS operator may not be a reason for mission failure but may bring high risk, therefore for some specific missions the official certification of operators is required [21].

Just-in-time/dynamic data supply is not the challenge itself. The challenge is when the communication channel has been compromised, and the expected data exchange has fallen [42]. This kind of cases may be addressed with negative scenario planning.

Lack of supply may appear during the ling-time expedition [42],[107] and can be prevented by careful planning and availability of reserve equipment.

Laws, policies and regulations to be considered are not only those that relevant to generic applications of UASs but also mission-specific, e.g. health or medical applications [101].

Low temperatures are among the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Navigation systems may be impacted by heavy clouds (satellite) or extreme light conditions (visual sensor-based). Missions performed during the day time in cloud-free conditions are recommended [108]. Other impact factors presented earlier [1] and those that are specified by mission requirements may demand more sophisticated UA technologies utilising multi-sensor non-satellite positioning.

The *payload* of the UA should be known at the planning stage and it is not recommended to exceed the maximum value. That may cause mission failure and safety treat. Many concerns the general public has about the nature of the payload [90].

Planning and following the plan is essential unless there is a strong need to change to the backup plan or to act proactively [109].

Communications may not cause problems when possible problems are known and appropriate solutions are planned in advance [56]. In case of unexpected occurrence in the field of operations, the corrective actions may be quite challenging [39].

Power source shortage may appear during the ling-time expedition along with a shortage of other supply [42],[107] and mitigation actions are similar.

Processes-relevant challenges [34], [90],[104] are typically known in advance and may be considered during the planning phase.

Rain and fog are among the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Rapid temperature changes are among the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

The *security breach* is one of the serious challenges that may lead to lost data and/or control of UA and make the mission compromised, e.g. the flight may be rerouted [101]. Properly addressed security challenges may help to reduce the risk of the security breach.

Short flight time of UA may be affected negatively by extreme weather conditions and therefore relevant to the availability of supply [42],[105].

Snow is one of the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Technical malfunctioning may not be resolvable during the mission [101], while the negative impact may be reduced by a fast and correct response of the UAS operator. It is possible to assume that conducting the drone mission within the range of technical specification of the UAS would not cause the additional risk of technical malfunctioning. When the corresponding safety and technological challenges are properly addressed, the negative impact of technical malfunctioning may be reduced or entirely eliminated e.g. by redundant functionality. When the UA is not able to return to the departure point, the search missions may be more effective if the UAS operator and supporting team are prepared in advance and backed up with positioning technologies. That kind of cases may occur when e.g. in a result of technical malfunctioning the UA parachute is engaged, or the UA is blown out of operating range by the wind.

Temperature crossing 0°C is one of the weather-related challenges that can impact the success of a drone mission [101]. It is recommended to consult with the weather forecast [70].

Time constraints are an important consideration in rapidly changing weather conditions since those may simply make impossible the planned mission. Life-critical missions require pro-active planning and fast reaction to fast-changing situation. For example, optimal placement of UASs to cover the operation area, optimal routing and help with decision-making may significantly help to cope with time constraints [91], [92],[93],[94].

UTM associated challenges may appear when dynamically updated due to newly discovered circumstances routing may affect UAS mission dramatically. Then the involvement of the entire support team may be needed for rapid decision making [110].

VTOL may require launching pad or base or can be performed from docking station [98].

Weight of UAS and auxiliary equipment is not only important when the UAS operator and the supporting team moves to a remotely located areas to deploy the temporal home base. Those are also important to consider in UAS-based delivery applications where the weight of the cargo is not fixed. That is to be aware that the weight of cargo would not exceed the available payload. For some of the specific UAS missions, it is recommended to conduct cost-benefit analysis to evaluate effectiveness of UAS applications [101].

Wild animals may be disturbed by UASs and expose a wide range of emotions from internal stress to angriness [111], [112] that may result in their attack [113]. It is recommended to get acquainted with the presence of wildlife in the area of UAS mission and minimise the possible negative impact [111], [112].

VI. CONCLUSION

All the technical and operational challenges presented in this paper are typical to applications of UAS in the Arctic and in other climate zones. Because there is a lack of research about UAS challenges in the Arctic, some of the most challenging non-military UAS application areas have been considered, such as medical and life-critical applications.

Several clarifications and corrections to the previously published research are introduced. Particularly, those are about the definition of UAS, rather technological but not technical nature of challenges, the weight of UAS and auxiliary equipment, and regarding both collections of challenges.

The overview of the Arctic challenges included references to generic UAS challenges and considerations. When the weather is ugly, the severe Arctic climate exacerbates many of the listed challenges. More research is needed to investigate the Arctic challenges and their particularities further. Every technological challenge may be addressed in a variety of ways. Those are worthy of dedicated researches, and many are already ongoing.

Coping with operational challenges is in line with UAS and supportive infrastructure technology development, acquiring and sharing experiences, gathering and processing operational data, educating UAS operators and raising public awareness. Supportive regulations and positive perception of general public may contribute to this too.

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