UAS (drone) Arctic Challenges - Next Steps

Vadim Kramar
Oulu University of Applied Sciences
Oulu, Finland
Vadim.Kramar@oamk.fi

***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].

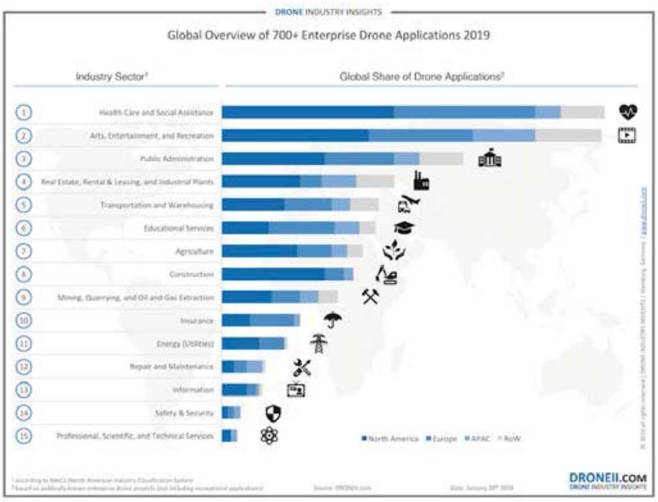

Fig. 1. UAS applications per industry sector

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.

ACKNOWLEDGEMENT

The author would like to thank members of Arctic Drone Labs innovation ecosystem [114] and international partners for supplying materials, giving constructive critics and focusing authors' attention to a range of projects and research experiments relevant to the application of UASs in the Arctic environment.

REFERENCES

[1] V. Kramar and H. Määttä, "UAV Arctic Challenges and the First Step: Printed Temperature Sensor," in *Proceedings of the 23rd Conference of FRUCT Association*, 2018, pp. 483–490.

[2] "How countries counter the drone threat - BBC News." [Online]. Available: https://www.bbc.com/news/technology-46639099. [Accessed: 22-Dec-2018].

[3] "How Much Of A Threat Do Drones Pose To Air Travel? Here's What You Should Know." [Online]. Available: https://www.forbes.com/sites/kristykiernan/2019/02/21/drones-threat-airplanes-airports/#3f77615a30c6. [Accessed: 21-Feb-2019].

[4] "DJI challenges BBC on drone danger reports - BBC News." [Online]. Available: https://www.bbc.com/news/technology-48866152. [Accessed: 19-Jul-2019].

[5] "Drone Applications Report 2019. A Cross-Industry Study of Drone Use-Cases. Drone Industry Insights," 2019.

[6] "Drone Applications Report 2019 - Drone Industry Insights," 2019. [Online]. Available: https://www.droneii.com/drone-applications-2019. [Accessed: 21-Mar-2019].

[7] "Top 100 Drone Companies to Watch in 2019 | UAV Coach." [Online]. Available: https://uavcoach.com/drone-companies/. [Accessed: 20-May-2019].

[8] V. Kramar, "Smart Living - Personal and Service Drones," in *Proceedings of the 23rd Conference of FRUCT Association*, 2018, pp. 476–482.

[9] "Oslo University Hospital will carry blood samples and vital biological material with drones (Oslo Universitetssykehus vil frakte blodprøver og livsviktig biologisk materiale med droner)." [Online]. Available: https://www.tu.no/artikler/oslo-universitetssykehus-vil-frakte-blodprover-og-livsviktig-biologisk-materiale-med-droner/441111. [Accessed: 02-Jan-2019].

[10] "Swiss Post to resume drone flights for medical services - Swiss Post," 2019. [Online]. Available: https://www.post.ch/en/about-us/media/press-releases/2019/swiss-post-to-resume-drone-flights-for-medical-services. [Accessed: 05-May-2019].

[11] "In The Air With Ziplines Medical Delivery Drones - IEEE Spectrum," 2019. [Online]. Available: https://spectrum.ieee.org/robotics/drones/in-the-air-with-ziplines-medical-delivery-drones. [Accessed: 02-May-2019].

[12] "UPS Partners With Matternet To Transport Medical Samples Via Drone Across Hospital System In Raleigh, N.C.," 2019. [Online]. Available: https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1553546776652-986. [Accessed: 05-Apr-2019].

[13] T. K. Amukele *et al.*, "Drone Transport of Chemistry and Hematology Samples over Long Distances," *Am. J. Clin. Pathol.*, vol. 148, no. 5, pp. 427–435, Nov. 2017.

[14] M. S. Y. Hii, P. Courtney, and P. G. Royall, "An Evaluation of the Delivery of Medicines Using Drones," *Drones*, vol. 3, no. 3, p. 52, Jun. 2019.

[15] T. Amukele, P. M. Ness, A. A. R. Tobian, J. Boyd, and J. Street, "Drone transportation of blood products," *Transfusion*, vol. 57, no. 3, pp. 582–588, Mar. 2017.

[16] G. Lippi and C. Mattiuzzi, "Biological samples transportation by drones: ready for prime time?," *Ann. Transl. Med.*, vol. 4, no. 5, pp. 92–92, Mar. 2016.

[17] E. Ackerman and E. Strickland, "Medical delivery drones take flight in east Africa," *IEEE Spectrum*, vol. 55, no. 1. Institute of Electrical and Electronics Engineers Inc., pp. 34–35, 01-Jan-2018.

[18] S. J. Kim, G. J. Lim, J. Cho, and M. J. Côté, "Drone-Aided Healthcare Services for Patients with Chronic Diseases in Rural Areas," *J. Intell. Robot. Syst. Theory Appl.*, vol. 88, no. 1, pp. 163–180, Oct. 2017.

[19] J. E. Scott and C. H. Scott, "Models for Drone Delivery of Medications and Other Healthcare Items," *Int. J. Healthc. Inf. Syst. Informatics*, vol. 13, no. 3, pp. 20–34, Apr. 2018.

[20] J. C. Rosser, V. Vignesh, B. A. Terwilliger, and B. C. Parker, "Surgical and Medical Applications of Drones: A Comprehensive Review," *JSLS J. Soc. Laparoendosc. Surg.*, vol. 22, no. 3, 2018.

[21] European Commission, *Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems*, no. March 2019. European Comission, 2019, p. C/2019/1821.

[22] European Commission, *Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft*, no. May 2019. European Comission, 2019, p. C/2019/3824.

[23] T. K. Amukele, L. J. Sokoll, D. Pepper, D. P. Howard, and J. Street, "Can unmanned aerial systems (Drones) be used for the routine transport of chemistry, hematology, and coagulation laboratory specimens?," *PLoS One*, vol. 10, no. 7, pp. 1–15, 2015.

[24] "Fly with a legend | GRIFF Aviation." [Online]. Available: http://griffaviation.com/. [Accessed: 21-Aug-2019].

[25] "NATILUS." [Online]. Available: http://www.natilus.co/. [Accessed: 21-Aug-2019].

[26] "Autonomous Systems – Northrop Grumman." [Online]. Available: https://www.northropgrumman.com/Capabilities/AutonomousSystems/Pages/default.aspx?utm_source=PrintAd&utm_medium=Redirect&utm_campaign=AutonomousSystems_Redirect#Technology. [Accessed: 21-Aug-2018].

[27] F. Nex and F. Remondino, "UAV for 3D mapping applications: A review," *Appl. Geomatics*, vol. 6, no. 1, pp. 1–15, 2014.

[28] S. Manfreda *et al.*, "On the use of unmanned aerial systems for environmental monitoring," *Remote Sens.*, vol. 10, no. 4, 2018.

[29] A. Al-Kaff, D. Martín, F. García, A. de la Escalera, and J. María Armingol, "Survey of computer vision algorithms and applications for unmanned aerial vehicles," *Expert Syst. Appl.*, vol. 92, pp. 447–463, 2018.

[30] C. Torresan *et al.*, "Forestry applications of UAVs in Europe: a review," *Int. J. Remote Sens.*, vol. 38, no. 8–10, pp. 2427–2447, 2017.

[31] A. Faust, I. Palunko, P. Cruz, R. Fierro, and L. Tapia, "Automated aerial suspended cargo delivery through reinforcement learning," *Artif. Intell.*, vol. 247, pp. 381–398, 2017.

[32] C. Sampedro, A. Rodriguez-Ramos, H. Bavle, A. Carrio, P. de la Puente, and P. Campoy, "A Fully-Autonomous Aerial Robot for Search and Rescue Applications in Indoor Environments using Learning-Based Techniques," *J. Intell. Robot. Syst. Theory Appl.*, pp. 1–27, 2018.

[33] R. C. Arkin, "Ethics and Autonomous Systems: Perils and Promises," *Proc. IEEE*, vol. 104, no. 10, pp. 1779–1781, 2016.

[34] G. Pajares, "Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs)," *Photogramm. Eng. Remote Sensing*, vol. 81, no. 4, pp. 281–329, 2015.

[35] N. Mohd Noor, A. Abdullah, and M. Hashim, "Remote sensing UAV/drones and its applications for urban areas: A review," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 169, no. 1, 2018.

[36] J. Linchant, J. Lisein, J. Semeki, P. Lejeune, and C. Vermeulen, "Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges," *Mamm. Rev.*, vol. 45, no. 4, pp. 239–252, 2015.

[37] N. Hossein Motlagh, T. Taleb, and O. Arouk, "Low-Altitude Unmanned Aerial Vehicles-Based Internet of Things Services: Comprehensive Survey and Future Perspectives," *IEEE Internet Things J.*, vol. 3, no. 6, pp. 899–922, 2016.

[38] T. Sankey, J. Donager, J. McVay, and J. B. Sankey, "UAV lidar and hyperspectral fusion for forest monitoring in the southwestern USA," *Remote Sens. Environ.*, vol. 195, pp. 30–43, 2017.

[39] E. Yanmaz, S. Yahyanejad, B. Rinner, H. Hellwagner, and C. Bettstetter, "Drone networks: Communications, coordination, and sensing," *Ad Hoc Networks*, vol. 68, pp. 1–15, 2018.

[40] A. Bürkle, F. Segor, and M. Kollmann, "Towards autonomous micro UAV swarms," *J. Intell. Robot. Syst. Theory Appl.*, vol. 61, no. 1–4, pp. 339–353, 2011.

[41] T. Villa, "An Overview of Small Unmanned Aerial Vehicles for Air Quality Measurements: Present Applications and Future Prospectives," *Sensors*, vol. 16, no. 7, p. 1072, 2016.

[42] M. Ader and D. Axelsson, "Drones in arctic environments," Stockholm, 2017.

[43] N. A. Khofiyah, W. Sutopo, and B. D. A. Nugroho, "Technical feasibility battery lithium to support unmanned aerial vehicle (UAV): A technical review," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 2019, no. MAR, pp. 3591–3601, 2019.

[44] X. Dou *et al.*, "Hard carbons for sodium-ion batteries: Structure, analysis, sustainability, and electrochemistry," *Mater. Today*, vol. 23, no. March, pp.

87–104, 2019.
[45] K. Dorling, J. Heinrichs, G. G. Messier, and S. Magierowski, "Vehicle Routing Problems for Drone Delivery," *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 47, no. 1, pp. 70–85, Jan. 2017.
[46] W. C. Chiang, Y. Li, J. Shang, and T. L. Urban, "Impact of drone delivery on sustainability and cost: Realizing the UAV potential through vehicle routing optimization," *Appl. Energy*, vol. 242, no. February, pp. 1164–1175, 2019.
[47] M. Funaki and N. Hirasawa, "Outline of a small unmanned aerial vehicle (Ant-Plane) designed for Antarctic research," *Polar Sci.*, vol. 2, no. 2, pp. 129–142, 2008.
[48] M. Hassanalian and A. Abdelkefi, "Classifications, applications, and design challenges of drones: A review," *Prog. Aerosp. Sci.*, vol. 91, no. April, pp. 99–131, 2017.
[49] H. Shakhatreh *et al.*, "Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges," *IEEE Access*, vol. 7, pp. 48572–48634, 2019.
[50] T. J. Mueller, "Aerodynamic Measurements at Low Reynolds Numbers for Fixed Wing Micro-Air Vehicles," *Mech. Eng.*, p. 33, 1999.
[51] W. D. Ivancic, R. J. Kerczewski, R. W. Murawski, K. Matheou, and A. N. Downey, "Flying drones beyond visual line of sight using 4g LTE: Issues and concerns," *Integr. Commun. Navig. Surveill. Conf. ICNS*, vol. 2019-April, pp. 1–13, 2019.
[52] N. Bloise *et al.*, "A Survey of Unmanned Aircraft System Technologies to enable Safe Operations in Urban Areas," *2019 Int. Conf. Unmanned Aircr. Syst.*, pp. 433–442, 2019.
[53] A. La Cour-Harbo, "Quantifying risk of ground impact fatalities of power line inspection BVLOS flight with small unmanned aircraft," *2017 Int. Conf. Unmanned Aircr. Syst. ICUAS 2017*, pp. 1352–1360, 2017.
[54] G. Beverley, "BVLoS and blockchain - Why distributed ledgers may be the key to unlocking widespread BVLoS operations," 2019.
[55] M. Johnson *et al.*, "Flight test evaluation of an unmanned aircraft system traffic management (UTM) concept for multiple beyond-visual-line-of-sight operations," *12th USA/Europe Air Traffic Manag. R D Semin.*, no. July, 2017.
[56] L. Gupta, R. Jain, and G. Vaszkun, "Survey of Important Issues in UAV Communication Networks," *IEEE Commun. Surv. Tutorials*, vol. 18, no. 2, pp. 1123–1152, 2016.
[57] M. Erdelj, E. Natalizio, K. R. Chowdhury, and I. F. Akyildiz, "Help from the Sky: Leveraging UAVs for Disaster Management," *IEEE Pervasive Comput.*, vol. 16, no. 1, pp. 24–32, 2017.
[58] D. Axisa and T. P. DeFelice, "Modern and prospective technologies for weather modification activities: A look at integrating unmanned aircraft systems," *Atmos. Res.*, vol. 178–179, pp. 114–124, 2016.
[59] W. Xu *et al.*, "Internet of vehicles in big data era," *IEEE/CAA J. Autom. Sin.*, vol. 5, no. 1, pp. 19–35, 2018.
[60] F. Zhou, Y. Wu, R. Q. Hu, and Y. Qian, "Computation rate maximization in UAV-Enabled wireless-powered mobile-edge computing systems," *IEEE J. Sel. Areas Commun.*, vol. 36, no. 9, pp. 1927–1941, 2018.
[61] J. Y. C. Chen, M. J. Barnes, and M. Harper-Sciarini, "Supervisory control of multiple robots: Human-performance issues and user-interface design," *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.*, vol. 41, no. 4, pp. 435–454, 2011.
[62] M. A. Goodrich and A. C. Schultz, "Human-robot interaction: A survey," *Found. Trends Human-Computer Interact.*, vol. 1, no. 3, pp. 203–275, 2007.
[63] T. Dierks and S. Jagannathan, "Output feedback control of a quadrotor UAV using neural networks," *IEEE Trans. Neural Networks*, vol. 21, no. 1, pp. 50–66, 2010.
[64] K. Máthé and L. Buşoniu, "Vision and control for UAVs: A survey of general methods and of inexpensive platforms for infrastructure inspection," *Sensors (Switzerland)*, vol. 15, no. 7, pp. 14887–14916, 2015.
[65] P. Liu *et al.*, "A review of rotorcraft unmanned aerial vehicle (UAV) developments and applications in civil engineering," *Smart Struct. Syst.*, vol. 13, no. 6, pp. 1065–1094, 2014.
[66] J. Rüdiger *et al.*, "Implementation of electrochemical, optical and denuder-based sensors and sampling techniques on UAV for volcanic gas measurements: Examples from Masaya, Turrialba and Stromboli volcanoes," *Atmos. Meas. Tech.*, vol. 11, no. 4, pp. 2441–2457, 2018.
[67] B. Altstädter *et al.*, "ALADINA - An unmanned research aircraft for observing vertical and horizontal distributions of ultrafine particles within the atmospheric boundary layer," *Atmos. Meas. Tech.*, vol. 8, no. 4, pp. 1627–1639, 2015.
[68] N. Franceschini, "Small brains, smart machines: From fly vision to robot vision and back again," *Proc. IEEE*, vol. 102, no. 5, pp. 751–781, 2014.
[69] R. Gade and T. B. Moeslund, "Thermal cameras and applications: A survey," *Mach. Vis. Appl.*, vol. 25, no. 1, pp. 245–262, 2014.
[70] I. Gultepe *et al.*, "A Review of High Impact Weather for Aviation Meteorology," *Pure Appl. Geophys.*, vol. 176, no. 5, pp. 1869–1921, 2019.
[71] O. Gohardani, M. C. Elola, and C. Elizetxea, "Potential and prospective implementation of carbon nanotubes on next generation aircraft and space vehicles: A review of current and expected applications in aerospace sciences," *Prog. Aerosp. Sci.*, vol. 70, pp. 42–68, 2014.
[72] A. Cristofaro, T. A. Johansen, and A. P. Aguiar, "Icing detection and identification for unmanned aerial vehicles: Multiple model adaptive estimation," *2015 Eur. Control Conf. ECC 2015*, pp. 1651–1656, 2015.
[73] K. L. Sørensen, A. S. Helland, and T. A. Johansen, "Carbon nanomaterial-based wing temperature control system for in-flight anti-icing and de-icing of unmanned aerial vehicles," *IEEE Aerosp. Conf. Proc.*, vol. 2015-June, pp. 1–6, 2015.
[74] C. P. Lawson, "Electrically powered ice protection systems for MALE UAVs - Requirements and integration challenges," in *ICAS-Secretariat - 25th Congress of the International Council of the Aeronautical Sciences 2006*, 2006, vol. 6, pp. 3565–3573.
[75] Y. Liu, L. Li, H. Li, and H. Hu, "An experimental study of surface wettability effects on dynamic ice accretion process over an UAS propeller model," *Aerosp. Sci. Technol.*, vol. 73, pp. 164–172, 2018.
[76] A. A. N. M. Tafreshi, I. Shafieenejad, "Open-Loop and Closed-Loop Optimal Guidance Policy for Samarai Aerial Vehicle with Novel Algorithm to Consider Wind Effects," *Int. J. Eng. Techincal Res.*, vol. 2, no. 12, pp. 185–191, 2014.
[77] H. Huang, G. M. Hoffmann, S. L. Waslander, and C. J. Tomlin, "Aerodynamics and control of autonomous quadrotor helicopters in aggressive maneuvering," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 3277–3282, 2009.
[78] A. Zolich, T. A. Johansen, K. Cisek, and K. Klausen, "Unmanned aerial system architecture for maritime missions. design & hardware description," *2015 Work. Res. Educ. Dev. Unmanned Aer. Syst. RED-UAS 2015*, pp. 342–350, 2016.
[79] J. P. Thomas, M. A. Qidwai, and J. C. Kellogg, "Energy scavenging for small-scale unmanned systems," *J. Power Sources*, vol. 159, no. 2, pp. 1494–1509, 2006.
[80] H. Runge, M. Hepperle, and N. Zealand, "A Solar-Powered HALE-UAV for Arctic Research," 2007, no. September, pp. 3329–3334.
[81] M. F. McCabe *et al.*, "The future of Earth observation in hydrology," *Hydrol. Earth Syst. Sci.*, vol. 21, no. 7, pp. 3879–3914, 2017.
[82] Z. Liu, Y. Zhang, X. Yu, and C. Yuan, "Unmanned surface vehicles: An overview of developments and challenges," *Annual Reviews in Control*, vol. 41. Elsevier Ltd, pp. 71–93, 2016.
[83] A. Imdoukh, A. Shaker, A. Al-Toukhy, D. Kablaoui, and M. El-Abd, "Semi-autonomous indoor firefighting UAV," in *2017 18th International Conference on Advanced Robotics, ICAR 2017*, 2017.
[84] J. C. Padró, F. J. Muñoz, J. Planas, and X. Pons, "Comparison of four UAV georeferencing methods for environmental monitoring purposes focusing on the combined use with airborne and satellite remote sensing platforms," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 75, no. July 2018, pp. 130–140, 2019.
[85] S. R. Herwitz *et al.*, "Imaging from an unmanned aerial vehicle: Agricultural surveillance and decision support," *Comput. Electron. Agric.*, vol. 44, no. 1, pp. 49–61, 2004.
[86] G. S. Hadi, R. Varianto, B. R. Trilaksono, and A. Budiyono, "Autonomous UAV System Development for Payload Dropping Mission," *J. Instrumentation, Autom. Syst.*, vol. 1, no. 2, pp. 72–77, 2015.
[87] T. H. Bradley, B. A. Moffitt, D. N. Mavris, and D. E. Parekh, "Development and experimental characterization of a fuel cell powered aircraft," *J. Power Sources*, vol. 171, no. 2, pp. 793–801, 2007.
[88] Y. Cho, "Lost in Debate: The Safety of Domestic Unmanned Aircraft Systems," *J. Strateg. Secur.*, vol. 7, no. 4, pp. 38–56, 2014.
[89] D. Sullivan-Nightengale, "Unmanned Aerial Systems: Risks & Opportunities in the Workplace," *Prof. Saf.*, vol. 60, no. 3, pp. 34–42, 2015.
[90] B. Rao, A. G. Gopi, and R. Maione, "The societal impact of commercial drones," *Technol. Soc.*, vol. 45, pp. 83–90, May 2016.
[91] A. Claesson *et al.*, "Unmanned aerial vehicles (drones) in out-of-hospital-cardiac-arrest," *Scand. J. Trauma. Resusc. Emerg. Med.*, vol. 24, no. 1, pp. 1–9, 2016.
[92] A. Pulver, R. Wei, and C. Mann, "Locating AED Enabled Medical Drones to Enhance Cardiac Arrest Response Times," *Prehospital Emerg. Care*, vol. 20, no. 3, pp. 378–389, May 2016.
[93] A. Claesson *et al.*, "Defibrillation before EMS arrival in western Sweden," *Am. J. Emerg. Med.*, vol. 35, no. 8, pp. 1043–1048, 2017.
[94] J. Sanfridsson *et al.*, "Drone delivery of an automated external defibrillator

- A mixed method simulation study of bystander experience," *Scand. J. Trauma. Resusc. Emerg. Med.*, vol. 27, no. 1, pp. 1–9, 2019.

[95] P. Kopardekar, J. Rios, T. Prevot, M. Johnson, J. Jung, and J. E. Robinson, "Unmanned aircraft system traffic management (UTM) concept of operations," in *16th AIAA Aviation Technology, Integration, and Operations Conference*, 2016.

[96] E. Ancel, F. M. Capristan, J. V. Foster, and R. C. Condottax, "Real-time risk assessment framework for unmanned aircraft system (UAS) traffic management (UTM)," in *17th AIAA Aviation Technology, Integration, and Operations Conference, 2017*, 2017.

[97] B. Hedblom, "Addressing the low-altitude airspace integration challenge: USS or UTM core?," *ICNS 2018 - Integr. Commun. Navig. Surveill. Conf.*, pp. 1–17, 2018.

[98] F. Cocchioni *et al.*, "Unmanned ground and aerial vehicles in extended range indoor and outdoor missions," *2014 Int. Conf. Unmanned Aircr. Syst. ICUAS 2014 - Conf. Proc.*, pp. 374–382, 2014.

[99] B. Herissé, T. Hamel, R. Mahony, and F. X. Russotto, "Landing a VTOL unmanned aerial vehicle on a moving platform using optical flow," *IEEE Trans. Robot.*, vol. 28, no. 1, pp. 77–89, 2012.

[100] J. M. Harris, J. A. Nelson, G. Rieucau, and W. P. Broussard, "Use of Drones in Fishery Science," *Trans. Am. Fish. Soc.*, pp. 1–11, 2019.

[101] K. Bhatt, A. Pourmand, and N. Sikka, "Targeted Applications of Unmanned Aerial Vehicles (Drones) in Telemedicine," *Telemed. e-Health*, vol. 24, no. 11, pp. 833–838, 2018.

[102] M. L. Cummings and P. J. Mitchell, "Predicting controller capacity in supervisory control of multiple UAVs," *IEEE Trans. Syst. Man, Cybern. Part ASystems Humans*, vol. 38, no. 2, pp. 451–460, 2008.

[103] D. G. Clark, J. D. Ford, and T. Tabish, "What role can unmanned aerial vehicles play in emergency response in the Arctic: A case study from Canada," *PLoS One*, vol. 13, no. 12, pp. 1–16, 2018.

[104] M. T. Tierney, "Ethics on the Fly: Toward a Drone-Specific Code of Conduct for Law Enforcement," no. March, 2016.

[105] F. Schenkelberg, "How reliable does a delivery drone have to be?," in *Proceedings - Annual Reliability and Maintainability Symposium*, 2016, vol. 2016-April.

[106] R. Berkowitz, "Drones and the question of the human," *Ethics and International Affairs*, vol. 28, no. 2. Cambridge University Press, pp. 159–169, 2014.

[107] K. M. Fornace, C. J. Drakeley, T. William, F. Espino, and J. Cox, "Mapping infectious disease landscapes: Unmanned aerial vehicles and epidemiology," *Trends Parasitol.*, vol. 30, no. 11, pp. 514–519, 2014.

[108] M. Funaki *et al.*, "Small unmanned aerial vehicles for aeromagnetic surveys and their flights in the South Shetland Islands, Antarctica," *Polar Sci.*, vol. 8, no. 4, pp. 342–356, 2014.

[109] A. Thibbotuwawa, P. Nielsen, G. Bocewicz, and Z. Banaszak, "UAVs Fleet Mission Planning Subject to Weather Fore-Cast and Energy Consumption Constraints," in *Advances in Intelligent Systems and Computing*, 2020, vol. 920, pp. 104–114.

[110] V. Battiste, A. Q. V. Dao, T. Z. Strybel, A. Boudreau, and Y. K. Wong, "Function Allocation Strategies for the Unmanned Aircraft System Traffic Management (UTM) System, and Their Impact on Skills and Training Requirements for UTM Operators," *IFAC-PapersOnLine*, vol. 49, no. 19, pp. 42–47, 2016.

[111] "'Inspirational' bear video reveals dark side of filming animals with drones." [Online]. Available: https://www.nationalgeographic.com/animals/2018/11/drone-brown-bear-video-russia-wildlife-harrassment-news/. [Accessed: 21-Nov-2019].

[112] M. Mulero-Pázmány, S. Jenni-Eiermann, N. Strebel, T. Sattler, J. J. Negro, and Z. Tablado, "Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review," *PLoS One*, vol. 12, no. 6, Jun. 2017.

[113] "Wild Animal Attacks on Drones Videos – Drones UAV Report." [Online]. Available: http://dronesuavreport.com/2018/08/04/wild-animal-attacks-on-drones-videos/. [Accessed: 20-Dec-2019].

[114] "Arctic Drone Labs - Finnish Drone Expertise." [Online]. Available: https://www.arcticdronelabs.com/. [Accessed: 05-Jun-2018].