Artificial Intelligence (AI) Applied to Unmanned Aerial Vehicles (UAVs)

And its Impact on Humanitarian Action

May 2020

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DH Network
Digital Humanitarian Network

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This document was made possible
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Executive Summary

The drone industry is now in its golden age and its growth promises to be exponential.[1] Even though humanitarian aid workers have used this technology for a decade, the expansion of its market as well as the development of technology are pushing more and more organizations to equip themselves with this device.

Unmanned Aerial Vehicles (UAVs), also known as remotely piloted aircraft or "drones" are small aircraft that fly by remote control or autonomously.[2] This report focuses on the usage of unarmed civilian drones and UAVs. Future reports can explore the impact and development of Unmanned Underwater Vehicles and ground drones

In 2014, OCHA highlighted in its Unmanned Aerial Vehicles in Humanitarian Response policy paper[3] the different uses of drones in humanitarian action demonstrating the increasing use of this technology. Additionally, the uses of drones in humanitarian action can be summarized by six categories identified by the Swiss Foundation for Mine Action in its report Drones in Humanitarian Action (2016)[4]: Mapping; Delivery of essential products to remote or hard-to-reach locations; Search and Rescue (SAR) ; Support for damage assessment; Increased situational awareness; and Monitoring changes (such as urban and camp growth, agricultural use or the construction of roads or infrastructure). This report will shed some light on how AI powered drones are improving and modifying these uses.

Rapid adoption can be explained through a combination of the opportunities modern drones present and the ever-increasing artificial intelligence (AI)-related capacities they can leverage. On one

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1 (May 2019) ResearchandMarket The Drone Market Report 2019:Commercial Drone Market Size and Forecast (2019-2024)" Available from Research and Markets website: *https://www.researchandmarkets.com/reports/4764173/the-drone-market-report-2019-commercial-drone?utm_source=CI&utm_medium=PressRelease&utm_code=r-3bg5s&utm_campaign=1250059+-+Drone+Market+Report+2019%3a+Commercial+Drone+Market+Size+and+Forecasts+-+Market+will+Grow+from+%2414+Billion+in+2018+to+%2443+Billion+in+2024&utm_exec=cari54prd*

2 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://www.unocha.org/sites/unocha/files/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. Accessed 23 Dec 2019

3 Ibid.

4 Soesilo, D, Meier, P., Lessard-Fontaine, A., Plessis, J. D., Stuhlberger, C., & Fabbroni, V. (2016).Drones in Humanitarian Action. Retrieved from Swiss Foundation for Mine Action website: *http://drones.fsd.ch/en/drones-in-humanitarian-action/*. Accessed 25 Nov 2019.

hand, their use is simplified and empowered through autonomy. On the other hand, the improved performance in visual analytics makes it possible to rely on aerial drone imagery.

This report aims to highlight the extent to which AI increases the capabilities of drones. Thanks to the generalization of deep learning methods, drones are further capturing the environment in which they operate, allowing increasingly complex missions. This technology is also making it possible to significantly improve drone visual recognition as well as image analysis.

Since use of AI algorithms requires high computing power, its application often takes place post flight. This performance will be highlighted through three case studies:.

- Drones for Emergency Response to wildfires in Northern California (November 2018)
- Drones for Emergency Response to Cyclone Idai by UNICEF in Malawi (March 2019)
- Drones for Emergency Response to Cyclone Idai by WFP in Mozambique (March 2019)

The report also explores the potential future functionalities of drones. As advances in on-board computing power enable AI algorithms to run during flights, some experts envision further added value for the use of drones in humanitarian missions.

Although some of the issues raised by OCHA in 2014 have been addressed, this report highlights the new/exacerbated challenges identified in relation to the use of artificially intelligent drones. These operational and ethical issues are fundamental and the humanitarian community, which has well-established principles, must systematically take them into account.

This report is informed by scholarly and news articles, as well as 18 interviews with a diverse range of experts in the AI, UAV and humanitarian fields. They work in different branches of the United Nations, in academia, think tanks, non-governmental organizations, and private sector companies.

Introduction

Drones, along with satellites and mobile technology, belong to the most impactful technology for humanitarian response according to a 2019 poll undertaken by the Thomson Reuters Foundation. [5]

Mainly known for their military use, drones have gradually been developed in the civilian sphere and have become widely used in the humanitarian field. While the UN's World Food Programme (WFP) started looking into UAVs for humanitarian purposes as early as 2007 [6], their use have become widespread since the early 2010s. In 2014 the United Nations Office of Coordination of Humanitarian Affairs (UN OCHA) reflected on the use of these flying machines [7] in order to identify their potential role in humanitarian action and to inform about challenges associated with this technology. From delivering supplies in hard-to-reach areas to mapping post-disaster environments, drones are now empowered by AI technology which brings a tremendous added value in responding to disasters. [8]

The main evolutions of the drone sector are happening in both the military and civilian spaces. The global drone market is forecasted to grow from $14 billion in 2018 to over $43 billion in 2024 [9]. These figures can be explained by the democratization of this cutting-edge technology and affordable products made available to the general public. The recent increase of drone use cases in civilian sectors is partly linked to phenomenal advances in hardware, increasingly powerful batteries,

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5 Batha E, "From drones delivering children's vaccines to satellite early warning systems tracking drought, technology is revolutionising aid operations" Thomson Reuters Foundation. December 18, 2019. *http://news.trust.org/item/20191217232954-gshlg. Accessed 26 Dec, 2019*

6 Meier, P "UN World Food Program to use UAVs". iRevolution. April 9, 2008. *https://irevolutions.org/2008/04/09/un-world-food-program-to-use-uavs/*. Accessed 22 Nov 2019

7 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://www.unocha.org/sites/unocha/files/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. Accessed 23 Dec 2019

8 Batha E, "From drones delivering children's vaccines to satellite early warning systems tracking drought, technology is revolutionising aid operations" Thomson Reuters Foundation. December 18, 2019. *http://news.trust.org/item/20191217232954-gshlg*. Accessed 26 Dec, 2019

9 (May 2019) ResearchandMarket The Drone Market Report 2019:Commercial Drone Market Size and Forecast (2019-2024)" Available from Research and Markets website: *https://www.researchandmarkets.com/reports/4764173/the-drone-market-report-2019-commercial-drone?utm_source=CI&utm_medium=PressRelease&utm_code=r-3bg5s&utm_campaign=1250059+-+Drone+Market+Report+2019%3a+Commercial+Drone+Market+Size+and+Forecasts+-+Market+will+Grow+from+%2414+Billion+in+2018+to+%2443+Billion+in+2024&utm_exec=cari54prd*

increasing quality of images, and increasing capabilities of transporting ever heavier loads. Another major driver of the drone industry is the application of AI software which is empowering drones to become smarter and more autonomous.

Following increases in processing power and greater data availability, the utilization of complex AI algorithms has started to transform the way drones operate. Thanks to computer vision, UAVs are able to extract meaningful information from the images they capture leading to innovative functions such as automated mapping, object/individual recognition, motion analysis and so forth. For example, drones equipped with Vision Processing Units can be controlled to capture close-up images from specific angles and, combined with AI technology, can help detect structural damage in buildings. Neural computer chips allow deep-learning calculations and image-detection to be performed locally, without an internet connection, on drones as they fly.

Continuing rapid developments will soon find highly automated and comprehensive solutions that will increase the added value of drones. With AI adoption growing rapidly, this report aims to inform the humanitarian community of the existing and potential opportunities offered by this technology for drones as well as the challenges that will rise.

Section 1 :

AI for post-flight data analysis

Machine learning and deep learning approaches are key to process large amounts of data and perform automated tasks. Humanitarian organizations and other actors are already using AI-based data analysis applications to perform automated tasks faster and make the most of drone imagery.

A. **The AI technologies involved**

The technology that allows humanitarian actors to efficiently utilize the data collected by UAVs consists in the application of machine learning algorithms to computer vision tasks. A combination of machine learning and deep learning approaches result in greater efficiency than other image processing software solutions when a large amount of data must be processed. [10]

Machine learning for improved mapping

Mapping is the most common and popular application to date. Its use in the disaster response to the Typhoon Haiyan in 2013 in the Philippines marked the beginning of a wider utilization of drones in humanitarian action. [11]

The speed of processing aerial imagery, the resolution of imagery and the accessibility to the technology have increased significantly. This is extremely valuable in emergency response where there is an urgent need to create orthomosaic maps or actionable data in time-sensitive missions that require quick decision-making on site. It is also important that this mapping be possible offline as communication is often limited in the field. Today, there exist powerful software that can quickly

10 Schroth, L. "Drones and Artificial Intelligence", Drone Industry Insights, August 28, 2018. *https://www.droneii.com/drones-and-artificial-intelligence*. Accessed 15 Nov 2019

11 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://docs.unocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. Accessed 23 Dec 2019

process data in different formats and automatically generate orthomosaic mapping in either 2D or 3D from drone imagery. For example, in Malawi, UNICEF used Pix4D react to create 2D maps from aerial imagery in minutes. [12]

Drone imagery has been used to produce accurate two-dimensional maps, elevation models, thermal maps and three-dimensional maps. In general, the process of mapping does not need machine learning algorithms. For example, an orthomosaic map is an aerial image of an area composed from multiple images stitched together using photogrammetry. Every image has been geometrically corrected – orthorectified – so that the scale is uniform and can easily be used for measuring accurate distance. With dedicated software, aerial images from drones have been used to create orthomosaic maps for years.

However, AI and deep learning can bring further added value to the mapping process. When mapping, image classification, object detection and image segmentation are the most important computer vision tasks. Image classification is an AI capability used to classify an image or video into one or several sets of predetermined classes. For example, the computer assigns the label "cat" to an image of a cat. In mapping, this classification is used to categorize geotagged images. Object detection is the task allowing the computer to find the objects within an image. These tasks are key for mapping as it analyzes what is in a drone image, locates it, and plots it on a map.

Using deep learning models on large geographic areas can produce a map containing all the roads in the region and locate buildings. This can be particularly useful for developing countries that do not have high-quality digital maps or in areas where newer developments have been built and existing infrastructure destroyed. [13]

With deep learning methods, international organizations and private companies build AI-software that is increasingly empowering drones. Some software can now autonomously capture, processes and analyze drone data from aerial images. It then takes the integrated software only a few minutes to process aerial images as opposed to days for humans to accomplish the same task. Pix4D, a Swiss-based company, offers software that combines photogrammetry and machine learning

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12 Tautvydas Juskauskas, interview with author, November 27, 2019

13 Singh, R. "Deep Learning + GIS = Opportunity" Arc User, The Magazine for Esri Software Users. P. 10-12. (Summer 2019). Print

techniques to enable the conversion of raw image data into actionable inputs. Their algorithm is able to automatically count and locate trees, cars and other infrastructures. [14]

AI trained detection model for data analytics

Deep learning algorithms applied to computer vision tasks have improved data analytics on AI models trained to identify a specific object. AI software has automated image analysis, improving the speed and quality of image analytics and making efficient use of the large data sets collected.

The AI model must be trained to recognize the objects, to classify them and to identify, if necessary, defects. Automated detection is made possible thanks to dedicated/featured AI-algorithms. Machines can perform the same tasks as humans such as measuring objects, understanding the state of this object, its location, its flow and the application of AI is therefore relevant when a large amount of data needs to be analyzed. Machines can quickly analyze thousands of pictures, identify patterns and assemble the insights so that humans can do much more targeted decision making.

Deploying a drone and collecting data after a disaster has become increasingly easy but the challenge was how to translate this data into actionable information. "Until very recently, the recurring bottleneck, the recurring pinpoint that we saw in humanitarian drone missions was on the data analysis side" - Patrick Meier [15]

Disaster response can happen in a timely manner with AI algorithms. They allow humanitarians to quickly analyze imagery and inform decision-making rather than spend time on the laborious task of identifying damaged areas. UnleashLive, which worked with DJI in the disaster response to camp fires, has created more than 30 custom AI models. They are mostly designed for industrial purposes, but many potential use cases of custom AI models - around 20 - have been identified in the humanitarian field. Those algorithms allow automated detection of objects or anomalies with an accuracy from 80% to 95% depending on the model. This accuracy can be improved as the AI model is trained. It can be considered more accurate than humans especially in emergency contexts where stress can decrease our accuracy. However, the objective of this AI model is to give insight

14 "Machine Learning meets photogrammetry". Pix4D. September 16, 2019. *https://www.pix4d.com/blog/machine-learning-meets-photogrammetry*. Accessed Dec 23, 2019

15 Patrick Meier, interview with author, November 26, 2019

into complex situations and help humans focus on more relevant aspects. [16] However, it is important to keep in mind that every situation is different in terms of weather conditions, vegetation, building types, and other factors. Therefore, existing AI models need to be adapted for the specific area analyzed.

Developing a machine learning classifier to automatically analyze imagery often requires a long manual labelling process based on a large amount of aerial data. It required a human to outline the contents of thousands of images. Transfer learning [17] in deep learning methods and the increased availability of aerial imagery from drones and satellites make creating AI models more feasible. Currently algorithms based on less than a hundred pictures can be trained in an hour and accuracy increases with each usage.

Many AI model needs are met by consulting companies hired to develop a custom AI model responding to the specific needs of the client. But the best person to train the model is the expert who needs the model. [18] In 2019, the 26 Flying Labs co-created and facilitated by WeRobotics chose to use the online AI platform developed by Picterra. This Swiss-based startup provides a platform where users can easily use AI to analyze imagery from drones or satellites. This solution helps disaster management organizations and responders quickly translate aerial imagery into actionable data. Users can create their own model from a few sets of images in an hour.

To enable the quick elaboration of custom detectors, Picterra has used transfer learning methods to train a classifier. The users use a global model trained by Picterra. This platform has made extensive use of imagery coming from different sources among which its broad community of users to train algorithms. Transfer learning has enabled the use of these algorithms for the training of new tasks which would require less training data. You can train the model to detect any type of object that is relevant to you.

The platform is user-friendly and the user can easily and rapidly train a model to detect any type of object. There is no need to create many data points for training to come up with a sufficiently

16 Hanno Blankenstein, interview with author, November 27, 2019

17 Transfer learning is the improvement of learning in a new task through the transfer of knowledge from a related task that has already been learned

18 Frank de Morsier, interview with author, December 6, 2019

accurate classifier. The more the platform is used, the more efficient the models become. Most models have an accuracy over 80% and the Picterra team aggregates those custom detectors to improve the overall performance of the AI model. In this sense, the quality of the model has significantly improved in a year. The accuracy of the model also depends on how the user trains the model. So there is an indirect community aspect where the creation of a detector by a user strengthens the platform's capabilities: the detection model learns from everyone and gets better and better.[19] This community aspect could be reinforced in the future by enabling users to share the model they have created or by allowing users to work in collaboration on the same model.

"We would like campaigns where several people collaborate and set up detectors that make sense to the citizens"

- Frank de Morsier

The custom detector is now flexible enough to address with a good rate of accuracy very diverse use cases. This has been possible thanks to their 5000 users - 200 weekly users - creating more than 200 good quality models[20] that can detect roads, vehicles, buildings, trees and plants, damaged roofs and other objects. There is no limit on what the AI can detect, if you can see it, AI can learn to detect it.[21]

Once a model is trained it can be exported as a Docker container and run offline at the edge. Therefore, this solution has largely democratized access to AI solutions.[22] However, to train a detector, an internet connection is needed which can be challenging in a post-disaster environment.

19 Rebetez, J. "One year of Custom Detector", October 30, 2019. *https://medium.com/picterra/one-year-of-custom-detector-df867f9515ed*. Accessed 25 Nov 2019

20 Frank de Morsier, personal communication with author, April 20, 2020

21 Frank de Morsier, interview with author, December 6, 2019

22 Patrick Meier, interview with author, November 26, 2019

B. Impact on humanitarian action

In emergency response

Automated detection can be essential for humanitarians in disaster response and disaster risk management.

Mapping can reduce the time of damage assessment after a disaster and therefore improve the quality and speed of the response. Drones are often considered as a good tool for obtaining a rapid and precise evaluation of the damage. Drones are often faster than humans especially in difficult to reach areas, and they can quickly assess the situation and relay the live data; by getting to the damage site first, UAVs can provide valuable data and better ensure the safety of first responders; it can access areas that are not accessible otherwise by flying under clouds and get closer to the affected area ; drones are small and equipped with various cameras allowing an accurate analysis of the endangered area.

With drones, humanitarians are able to collect high resolution data in a short time. The challenge is the time needed to analyze this data and turn it into information for the decision making process. This is when machine learning complements the usage of drones. [23] After a disaster such as a hurricane, a flood, an earthquake or a wildfire, AI models applied to drone imagery can provide quick and accurate damage assessment and result in being fundamental to identify the areas to be prioritized. After a disaster occurs, every second saved in assessing the damage and obtaining accurate and actionable information can largely improve the response.

Drones Integrated in Disaster Emergency Response Plans

"We are seeing departments starting UAV programs all over the world. Up until last year, it was about how I can start a UAV program and today it is about how I can scale up this program, how can I increase it from thirty drones to a hundred drones. This has a tremendous impact not only on what is being done but also on how technology scale up." - Romeo Durscher [24]

In the US, local authorities and first responder teams have been interested in the use of UAVs for

23 Marco Codastefano, interview with author, December 17, 2019

24 Romeo Durscher, interview with author, November 19, 2019

decades. The first use of UAVs in disaster response dates back to 2005 after Hurricane Katrina where drones were used to determine the flood crest of the Pearl River in Louisiana and Mississippi. [25]

Their use has significantly increased, and they are now used by first responders all over the country to respond to a wide range of disasters such as floods, hurricanes, typhoons or campfires.

The undeniable increase in their use [26] is primarily due to their proven utility and massive investments by government agencies to integrate UAVs into their response protocols and to encourage innovation. Therefore, the budgets dedicated to UAVs in disaster response have increased allowing first responders to partner with innovative private companies which have developed AI models for drones used in disaster response.

For example, aerial application software has been used in recovery efforts in several hurricane emergency responses. Late 2016, after Hurricane Matthew caused widespread devastation in Florida, their AI software was used on aerial imagery to automatically detect broken power lines. The time to restore communication after the disaster was halved. Their services were also used after Hurricane Irma in September 2017 and Hurricane Florence a year later. [27]

Case Study 1:
Drones for Emergency Response to wildfires in Northern California (November 2018)

An impressive large scale drone emergency response happened in late 2018 when drones were used to map damage in northern California after a devastating wildfire. The fire started on November 8 and burned more than 153,000 acres (620 square kilometers), destroying thousands of structures and killing more than 80 people. DJI, world largest manufacturer of commercial and consumer drones,

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25 Murphy,R. (May 2019) The Use of Small Unmanned Aerial Systems For Emergency Management of Flooding. Retrieved from US Department of Transportation website: *https://www.fhwa.dot.gov/uas/resources/hif19019.pdf.* Accessed 7 Nov 2019

26 Murphy,R. (May 2019) The Use of Small Unmanned Aerial Systems For Emergency Management of Flooding. Retrieved from US Department of Transportation website: *https://www.fhwa.dot.gov/uas/resources/hif19019.pdf.* Accessed 7 Nov 2019

27 Joe Sullivan, interview with author, November 14, 2019

partnered with County Sheriff's Offices, local police, local fire departments and other private companies to map 17,000 acres (70 square kilometers) in two days. This map aimed to have a precise overview of the damage, giving a sense of its extent and helping residents with insurance claims, city planners and recovery crews. It was also used by SAR teams to spot potential missing persons.

As the use of drones is not fully integrated in disaster response, the UAV response team obtained the necessary authorizations to go to the site 6 days after the incident.[28] 30 mapping missions were identified and 518 flights were performed by 16 UAV teams to capture over 70,000 images. Processing 500GB of data into actionable insights posed a challenge. Therefore the data was physically driven at the Drone Deploy headquarters office in San Francisco. In one night the 70,000 images became 75 maps.[29]

Where the AI technology proved to be valuable was in the automatic detection of damaged structures. The application of Unleash Live's AI algorithm methodology enabled them to turn the data into actionable insights on the damage to structures and vehicles.[30]

To achieve this large-scale data analytics mission, Unleash Live trained an algorithm to automatically count and give the location and size of affected structures, intact structures and burnt vehicles. In partnership with DJI, Unleash Live trained a custom AI algorithm at the beginning of 2018 for two weeks on high resolution datasets uploaded by various police and emergency services.[31] To train and improve the accuracy of the model, they used imagery datasets from other wildfires in California, Portugal and Greece. The AI model was deployed for two weeks and while used, the algorithm learned and improved to an accuracy of 80% to 90%.[32]

The AI algorithm applied on the imagery from the drone rapidly processes data and automatically detects, counts and evaluates the state of a structure or vehicle: (*see next page*)

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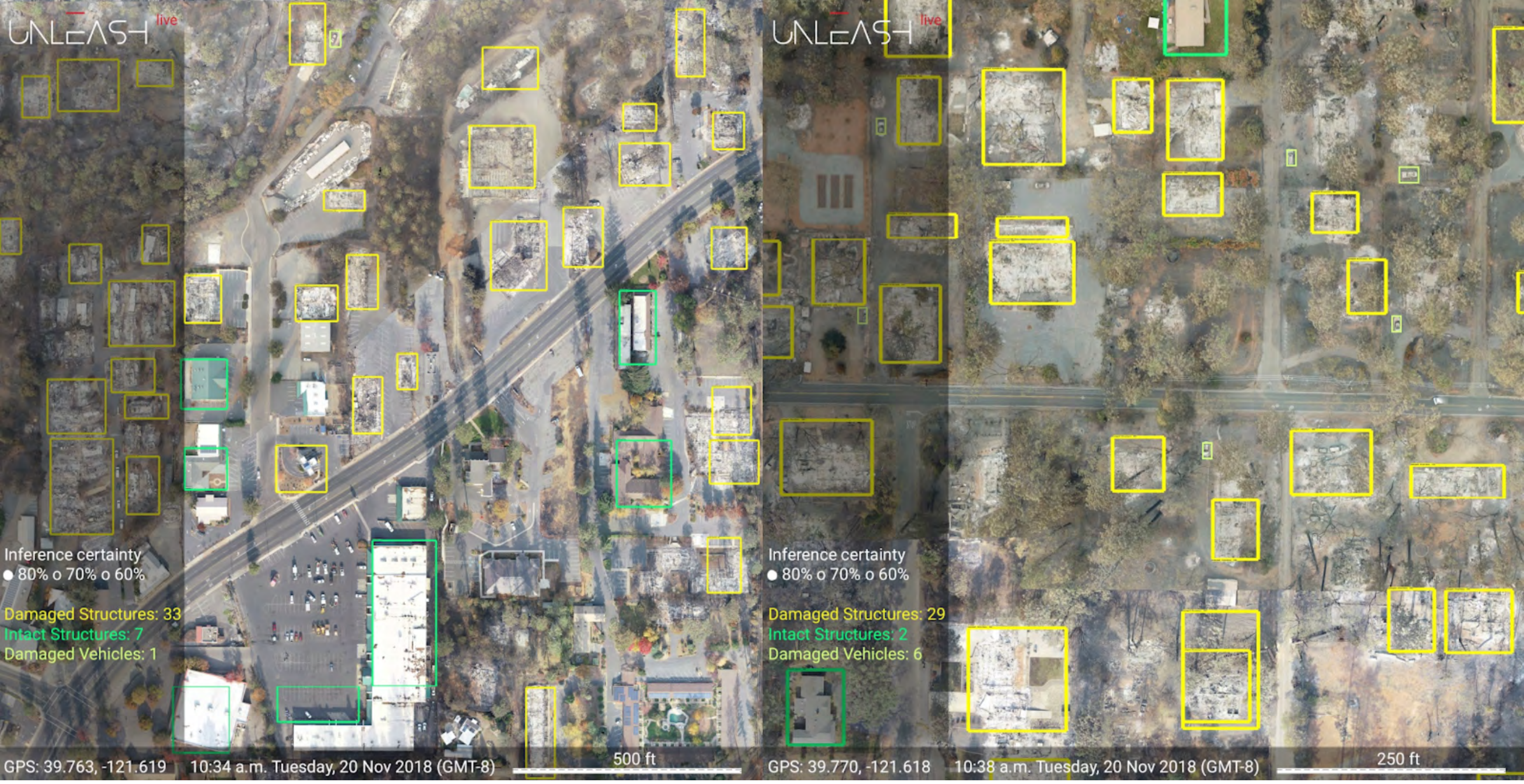
28 Durscher, R "Camp Fire - 17,000 Acres Mapped by Drones", LinkedIn, November 24, 2018 *https://www.linkedin.com/pulse/camp-fire-17000-acres-mapped-romeo-durscher/*. Accessed 22 Nov 2019.

29 Ibid.

30 "Instant Intelligence - turning raw data into actionable insights fast", Unleash Live November 27, 2018 *https://medium.com/unleash-live-blog/instant-intelligence-turning-raw-data-into-actionable-insights-fast-615f1ac96de9*. Accessed 22 Nov 2019.

31 Ibid.

32 Hanno Blankenstein, interview with author, November 27, 2019



Source : Unleash Live

DJI highlighted the challenges of this kind of large-scale mapping mission: relevant division of the flying areas was difficult to establish; the post-disaster environment where teams were operating was difficult; a large number of flights and considerable power were needed; and the management of a large amount of data which requires powerful processing capabilities.

Responses to Cyclone Idai

Case study 2:

Drones for Emergency Response to Cyclone Idai by UNICEF in Malawi (March 2019)

The government of Malawi launched, along with UNICEF, a drone corridor in 2017 at Kasungu Aerodrome in central Malawi [33] to test the innovative opportunities offered by the use of drones in the humanitarian and development sectors. This drone corridor of a 40km radius is part of UNICEF's larger drone program which explores the use of this technology to deliver supplies, bring connectivity to hard-to-reach communities and to collect aerial imagery for better disaster response and preparedness.

33 Drones corridors are also located in Akmola and Almaty, Kazakhstan and Freetown, Sierra Leone. Those drone testing corridors bring together various actors from public and private sector as well as academia.

In March 2019, a flood followed by typhoon Idai caused catastrophic damage in Malawi, Zimbabwe and Mozambique impacting over 700,000 people. UNICEF was involved in the emergency response in Malawi as part of the inter-agency assessment group in partnership with the Red Cross and the Malawi Department of Disaster Management Affairs. Three people were in charge of mapping the damage of the areas affected by floods and heavy rains in Nsanje District. They focused on the most affected areas to provide other teams with aerial data. In five days, they were able to fly their drones in 10 different areas giving them valuable insight on the damage. They were able to collect high resolution imagery in those areas as well as map seven locations representing eight square kilometers. Drones allowed the ground team to see from an aerial perspective and have a better understanding of the extent of the flood and the impact it had on the communities. [34]

They used a particular photogrammetry software provided by Pix4D that allowed them to process the drone imagery in about 12 minutes and quickly see the damage and the extent of flooding. This software proved essential, as it is able to process aerial imagery in a timely-manner and can be used offline.

The use of AI and machine learning algorithms enabled rapid analysis – it can analyze a map of one square kilometer in approximately five minutes – from aerial data. To automatically identify households, flooded areas and other data points, the inter-agency assessment team partnered with Globhe, a company that developed AI object detection algorithms and was in charge of the analysis and feature extraction of the images. The team was able to provide valuable recommendations for community and settlement planning.

The analysis was done offline, processed maps were uploaded into the cloud for further processing.[35] These maps and further data analytics enabled ground teams to quickly see occupants still at risk, roads and farmland covered by water, and fallen and collapsed structures. However, they discovered that there is a need to improve the algorithms to detect fallen grass thatched roofs, which made up a considerable amount of affected structures. [36]

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34 Juskauskas, T. "Flying a drone in Malawi: My first emergency deployment". Unicef. April 10, 2019. *https://blogs.unicef.org/blog/flying-drone-malawi-my-first-emergency-deployment/*. Accessed 27 Now 2019.

35 Tautvydas Juskauskas, interview with author, November 27, 2019

36 Chipukunya, L, Kunje, W & Juskauskas T. (March 2019). Floods in Nsanje District 2019. Accessed Dec 2, 2019

Case study 3:

Drones for Emergency Response to Cyclone Idai by WFP in Mozambique (March 2019)

The two previous cases highlighted interventions where the use of machine learning works in a complex workflow with many different actors involved. WFP has decided to invest in creating their own offline AI application for rapid damage assessment. The Technology Emergency Preparedness and Response Branch of WFP, responsible for coordinating and managing WFP's Information Technology response to emergencies, has been developing a UAV program since 2017. [37]

When an emergency strikes, humanitarians are often offline and unable to share data. According to Marco Codastefano of WFP, "the emergency environment is an extreme environment from a machine learning point of view." Therefore, they have developed DEEP (Digital Engine for Emergency Photo-analysis), a deep learning application designed to automate the learning analysis and processing of high resolution images and ultimately help speed up response time during emergencies. DEEP works offline and does not require supercomputing power. Data is transformed into information by three machine learning models: a building segmentation model [38]; an unsupervised model [39]; and a damage assessment model. [40]

DEEP detects every building in a map to understand population density distribution and estimate the surface area of damaged buildings. This type of analysis, when done manually, is generally completed in another stage of the emergency response since it usually takes weeks. But with automated AI analysis, the damage assessment can be executed in the first 72 hours of a disaster, providing key information to support decision making and resource allocation. It takes only 10 minutes (per drone flight) to complete a damage assessment (with a 15% margin of error).

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37 Marco Codastefano, interview with author, December 17, 2019

38 The building segmentation model used is UNet. The goal of semantic image segmentation is to label each pixel of an image with a corresponding class of what is being represented.

39 The unsupervised model used is K-mean. Unlike supervised model, Algorithms work on their own to discover and present the interesting structure in the data. To learn more *https://machinelearningmastery.com/supervised-and-unsupervised-machine-learning-algorithms/*

40 VGG16 is an image classification model, in DEEP workflow it works classifying the shape of the buildings detected by the combination of UNeT and K-mean in damage.

DEEP is modular as it can be programmed to detect any item with the right data, i.e., standing water, roads and bridges. Users only have to change the dataset and the machine learning algorithm will understand the patterns to detect the selected structure.

DEEP was trained in Mozambique following Cyclone Idai in April 2019 after mapping the city of Beira and its surroundings. The team on the ground operated 154 flights (18 minutes per flight) with 16 drones collecting 60,000 images and mapped about 50 square kilometers. [41]

At the time, DEEP was not trained for the data collected after Cyclone Idai and the Mozambique context. To train the algorithm, they had a one-week workshop gathering university students and people from the Mozambique government to manually label damaged and undamaged buildings within their collected imagery. The accuracy of the resulting model reached a rate of 89-90%.

In the unfortunate case of another cyclone, first responders in Mozambique will be able to fly a drone, collect the data, compile an orthomosaic and run it through the DEEP program.

"[Local authorities] will be able to inform the government with a very good level of confidence (90% of accuracy) of how many buildings had been destroyed, where those buildings are and which areas are the most affected.... This will shorten the time you need to make important decisions and life saving decisions."

- Sophia Rosa

Although the algorithm is ready, it needs to be trained for a specific context. Once developed, these models can be retained and shared. In 2020 WFP plans to create a global catalog of trained models covering a range of environments such as the Bahamas or Nepal.[42]

"Machine learning applications need to be rooted in emergency response contexts, and respond to the challenges of connectivity and computing power. And complementing drone data gathering with machine learning analysis capacity, like DEEP, is essential to improve the information value chain and decision-making in disaster response"

- Marco Codastefano

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41 Sophia Rosa, interview with author, December 12, 2019

42 Marco Codastefano, interview with author, December 17, 2019

In disaster risk reduction

The use of AI to analyze drone images is not exclusive to the response phase. Many experts also value the use of drones for preparedness.

For example, data analytics was used to improve flood modelling and vulnerability mapping in the Malawi response effort. Predictive flood modelling is a critical subject that UNICEF Malawi is working on. There is a need to inform the public and the government on the most vulnerable areas, especially in Southern Malawi where floods are a recurrent phenomenon. AI algorithms applied to drone imagery could map the infrastructure, households, settlements or crops, determine which are most vulnerable, and predict who and what could be affected in case of a flood.[43] UNICEF's project combines the imagery analysis with ground based data, digital elevation models, historical data on the rains and other variables.

"Knowing when, at what scale and how a flood would occur would enable much better emergency preparedness and early action including location of the internally displaced people, evacuation plan, and repositioning of supplies. We hope that this flood modelling will be the backbone of our emergency response and preparedness."

- Tautvydas Juskauskas

Other use cases of AI applied to drone imagery for disaster risk reduction include detection of landmines[44] in Bosnia-Herzegovina, Afghanistan or Iran[45], identification and mapping of non-timber trees in Brazil[46] and mosquito eradication in urban ponds in India.[47]

43 Tautvydas Juskauskas, interview with author, November 27, 2019

44 Hanno Blankenstein, interview with author, November 27, 2019

45 "10 Countries With the Most Landmines". Listverse. June 13, 2014. *https://listverse.com/2008/08/11/10-countries-with-the-most-landmines/*. Accessed Dec 17, 2019

46 "UNICEF Innovation Fund welcomes six drone startups to help solve global challenges". UNICEF. December 6, 2019. *https://www.unicef.org/innovation/venturefund/dronescohort*. Accessed Dec 9 2019.

47 Dash, S. "AI is helping drones kill mosquitoes in Hyderabad."Business insider. December 17, 2019.*https://www.businessinsider.in/tech/news/marut-drones-uses-artificial-intelligence-to-kill-mosquitoes-in-hyderabad-telangana/articleshow/72435585.cms*. Accessed Dec 18 2019.

Improving satellite imagery

Satellite imagery and drone imagery can be difficult to obtain. Satellite imagery is often unavailable for humanitarians on the grounds - as there is no internet connection - or cloud cover inhibits its capture. In the case of overcast skies, optical satellite imagery is ineffective and radar satellite imagery does not allow identification of damaged structures. [48] Drones are not always available for immediate use and local capacity for drone mapping is often limited. For effective use of drones in emergency mapping, the drones need to be in the country and first responders should have the equipment. [49]

"Drones have the speed and agility and resolution to get in a post disaster environment very quickly and that means training AI models in a very rapid way to be useful in a specific situation."

- Robert Kirkpatrick

With state-of-the-art equipment, drones can provide high resolution imagery and enable the creation of precise maps responding to many humanitarian needs. Drones can even take pictures in three angles allowing for 3D rendering of buildings and geographical elements.

However, drones only covered small distances as their battery is limited and because drones fly over the same areas to provide a sufficient overlap of images for mapping and therefore a higher resolution map needed to apply machine learning algorithms. [50] So considering their speed and time of flight, drones usually cover no more than 1.5 square kilometer per flight. [51] Furthermore, the larger the surface area and the higher the resolution, the longer it takes to collect and process data. However, within the humanitarian community, many missions focus on assessment and monitoring of large areas, such as: identifying and monitoring displaced populations, their movements and

48 Sophia Rosa, interview with author, December 12, 2019

49 Soesilo, D, Meier, P., Lessard-Fontaine, A., Plessis, J. D., Stuhlberger, C., & Fabbroni, V. (2016). Drones in Humanitarian Action » Drones in Humanitarian Action. Retrieved from Swiss Foundation for Mine Action website: *http://drones.fsd.ch/en/drones-in-humanitarian-action/*. Accessed 25 Nov 2019.

50 Tautvydas Juskauskas, interview with author, November 27, 2019

51 Sophia Rosa, interview with author, December 12, 2019

temporary settlements; conducting large-scale evaluations of an affected region or evaluate remote and hard-to-reach areas; or monitor logistics convoys in real time. [52]

By contrast, satellite imagery is often used because it covers larger areas, there is no need for flight permission nor for a team on the ground. Today the market of satellite imagery is developing to become more affordable. Some companies are working to make satellite images more accessible and customizable, i.e., to buy only the pixels customers are interested in and not a whole satellite image. [53] When very high-resolution imaging is not required, satellites can provide images at a much lower cost than drones. [54]

Satellite images often provide the resolution needed for various AI algorithms, but to increase the level of detail of an analysis - from identifying damaged building to identifying the degree of damage -an even higher resolution is required. [55] Thus, Picterra - among others - is working on solutions that would use machine learning algorithms to predict high resolution imagery with low resolution satellite imagery based on drone imagery. They are developing a neural network model that could learn what elements are in a pixel based on high resolution images from drones. By using this machine learning algorithm on low resolution satellite imagery, they can predict higher resolution satellite imagery and generate more precise information. [56] In case of large scale disaster, drones can fly over enough of an area to sample the post-disaster imagery and use this imagery as a data set for training the algorithm which would take lower resolution satellite imagery and increase its resolution for larger damage assessment and to identify specific features. [57]

Developments in machine learning algorithms have greatly improved computer vision tasks and have improved the speed of mapping missions in the humanitarian world. The democratization of

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52 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://docs.un-ocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. Accessed 23 Dec 2019

53 Frank de Morsier, interview with author, December 6, 2019

54 Soesilo, D, Meier, P., Lessard-Fontaine, A., Plessis, J. D., Stuhlberger, C., & Fabbroni, V. (2016). Drones in Humanitarian Action » Drones in Humanitarian Action. Retrieved from Swiss Foundation for Mine Action website: *http://drones.fsd.ch/en/drones-in-humanitarian-action/*. Accessed 25 Nov 2019.

55 Nathaniel Raymond, interview with author, December 4, 2019

56 Frank de Morsier, interview with author, December 6, 2019

57 Robert Kirkpatrick, interview with author, December 6, 2019

this technology is made possible by private companies but also by the development of internal tools for humanitarian organizations allows humanitarians to easily use this technology and improve their disaster response. The constant increase in the access to UAVs and satellite images and the constant research in the field of machine learning and image analysis show that many opportunities are still to come.

Section 2:

AI during flight

UAVs are able to capture a very large volume of data in a very short time. The challenge is to capitalize on this data. Although many cloud-based and software-based post-flight AI services exist, the full potential of drones is reached when data is acquired and analyzed instantly during a flight.

A. **AI during live drone footage**

There are many applications of computer vision algorithms that can be used on aerial images post-flight. But, it is now possible to have AI algorithms analyze data in real time thanks to radio, mobile and satellite communication technologies.

Live AI for situation monitoring

The use of drones to obtain real-time information, such as live streamed video, presents additional opportunities for situation monitoring.

In Australia, the University of Technology Sydney and the Ripper Group – an Australian drone company - have developed the SharkSpotter. It combines AI, drones and computing power to identify and alert lifesavers of sharks near swimmers. The AI system receives streaming imagery from the drone camera, identifies all objects in the scene and classifies them into one of 16 categories: sharks, whales, dolphins, rays, different types of boats, surfers, and swimmers. If a shark is detected, SharkSpotter provides both a visual indication on the computer screen and an audible alert to the operator.[58] Rescuers are warned of the danger and can intervene.

58 Sharma, N & Blumenstein, M. "SharkSpotter combines AI and drone technology to spot sharks and aid swimmers on Australian beaches" The Conversation. September 27, 2018. *https://theconversation.com/sharkspotter-combines-ai-and-drone-technology-to-spot-sharks-and-aid-swimmers-on-australian-beaches-92667*. Accessed 24 Dec 2019

In South Africa, the SPOT system, built by researchers from the University of Southern California's Center for Artificial Intelligence in Society and piloted by the organization Air Shepherd, automates the process of detecting poachers in infrared video feeds. Drones fly over the protected park and a video stream is sent via radio waves to a computer station. An AI trained model will automatically identify a poacher's whereabouts. [59]

Live AI for real time damage assessment

The Verizon 5G First Responder Lab aims to build solutions enabled by 5G technology for first responder communities. Leveraging a 5G network, Aerial Application is working to send data directly from a flying drone to the cloud. Drones could then map or provide actionable data in near real-time.[60] In late 2019, Verizon announced its commitment to be the first 5G network to connect one million drone flights. [61]

"In the future this will be amazing to have a real-time damage assessment to respond immediately." - said Marco Codastefano from WFP. This was implemented in China in response to a forest fire in early April 2019. Drones were deployed in the affected zone of Sichuan Province where footage was transmitted to responders over 5G networks. They were able to parse the video with AI computer vision algorithms to assess the crisis situation and concentrate rescue efforts. [62]

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59 Chui, M, Harryson, M, Manyika, J, R obertsm R, Chung, R, van Heteren, A & Nel, P. (2018) Notes from the AI Frontier: Applying AI for Social Good. Retrieved from McKinsey Global Insitute website: *https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Artificial%20Intelligence/Applying%20artificial%20intelligence%20for%20social%20good/MGI-Applying-AI-for-social-good-Discussion-paper-Dec-2018.ashx* (see p. 24). Accessed 17 Dec 2019.

60 Joe Sullivan, interview with author, November 14, 2019

61 Leake, F. "Verizon 5G claims it will be the first to power one million drone flights". 5G radar. December 31, 2019.*https://www.5gradar.com/news/verizon-5g-claims-it-will-be-first-to-power-one-million-drone-flights*. Accessed Jan 2 2020.

62 "World's Largest Mobile Network Taps NVIDIA EGX for 5G, Mobile Edge Computing". AIthority. December 20, 2019. *https://www.aithority.com/internet-of-things/5g-technology/worlds-largest-mobile-network-taps-nvidia-egx-for-5g-mobile-edge-computing/*. Accessed Dec 26 2019

B. **AI onboard**

Edge computing makes AI analysis onboard drones possible. Devices equipped with processors and sensors can process data locally as it is captured. Drones then do not need to be centrally connected in order to process data and canmake decisions independently. Computer vision algorithms help drones make an immediate decision - like avoid a tree - or send signals when an anomaly or event triggers a need for additional attention.

This embedded AI has enabled the development of detect-and-avoid systems and the "Follow Me" function. When mixed with other technological advances one can see many future opportunities.

Onboard AI for autonomous flight

Today, most of the UAVs used in humanitarian response are partly autonomous as flight parameters can be set: over what area to fly, at what altitude and what overlap you want for the images collected.[63] Most civilian drones are self-flying, which is the drone's ability to perform maneuvers without a human at the controls. This can be considered different from autonomy which is the drone's ability to decide on performing self-flying tasks without human inputs. [64]

In general, human inputs are not necessary in guiding the drone during its flight as the area to survey is pre-programmed. However, drones need to fly in visual line of sight so the drone pilot can ensure that the device does not collide with something present in its environment. This is particularly fundamental when you operate in a post-disaster environment where unpredictable damage could have occurred or when you fly in proximity to other drones or aircraft. [65]

AI companies like Nvidia have developed small AI computers with the necessary power to run AI algorithms and multiple neural networks to process data from high resolution imagery. This is an entry-level option to add advanced AI to embedded products. [66] Similarly, Intel has designed a new vision processing unit that could be used to execute pre-trained neural network algorithms

63 Romeo Durscher, interview with author, November 19, 2019

64 Feist, J. "Autonomous drone vs self-flying drones, what's the difference?". December 2019. *https://dronerush.com/autonomous-drone-vs-self-flying-drones-10653/*. Accessed 26 Dec 2019

65 Romeo Durscher, interview with author, November 19, 2019

66 See Nvidia website : *https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/*

for computer vision applications. [67] The AI chip market is growing quickly and edge computing is expected to be the driver of the market growth in the near future. [68]

With these advances, AI can enable autonomous flight. Such flight is a complex robotic task requiring perception and execution in a constantly changing environment. [69] A system is autonomous if it can perceive, analyse, communicate, plan, make decisions and act, in order to achieve objectives assigned by a human or by another system with which the system communicates. [70] The system must have sensors to perceive its environment but it also needs to have actuators to act on this environment. Image classification and object recognition are fundamental as they enable avoidance system implementation in a complex environment: image classification is used to guide the drone's directional navigation while object detection is used to circumvent obstacles such as trees.

Onboard AI is needed to make moment-to-moment decisions about how to respond to the data perceived by sensors. An autonomous system must be able to take into account the uncertainties and changes in its environment. Its level of autonomy is linked to its ability to analyse the data acquired by its sensors, as well as its short-, medium- and long-term planning/decision-making capabilities. [71]

The use of artificial intelligence in drones provides more autonomy. The December 2019 Drone Racing League welcomed AI piloted drones for the first time to compete with human pilots. According to expert estimates, computer-powered drones are likely to surpass humans in 2023.[72]

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67 Woodie, A "Intel Debuts New VPU Chip at AI Summit". Datanami. November 12, 2019. *https://www.datanami.com/2019/11/12/intel-debuts-new-vpu-chip-at-ai-summit/*. Accessed Nov 13, 2019

68 Joshi, S. Artificial Intelligence (AI) Chip Market is Expected to Witness Significant Revenue Growth Through 2019-2027". Info Street Wire December 24, 2019. *https://infostreetwire.com/2019/12/24/artificial-intelligence-ai-chip-market-is-expected-to-witness-significant-revenue-growth-through-2019-2027/1022650/* Accessed Dec 24, 2019.

69 Feist, J. "NVIDIA Jetson and Redtail drone – the future of autonomous UAVs". DroneRush. September 20, 2017. *http://dronerush.com/nvidia-jetson-redtail-drone-10506/*. Accessed Dec 24 2019

70 Hui-Min Huang (2008) Autonomy Levels for Unmanned Systems (ALFUS) Framework - Volume I : Terminology. Dans Special Publication 1011-I-2.0, Nationnal Institute of Standards and Technology (NIST)

71 Sotiropoulos T (2018) Test aléatoire de la navigation de robots dans des mondes virtuels [archive] (Doctoral dissertation, Université de Toulouse, Université Toulouse III-Paul Sabatier).

72 Shankland, S. "Drone-racing human pilot defeats AI - at least this year". CNET. December 9, 2019. *https://www.cnet.com/news/drone-racing-human-pilot-defeats-ai-at-least-this-year/* Accessed Dec 26 2019

Indeed, onboard computers will get more powerful, new algorithms will improve flight paths programing and image processing so that decision-making processes will get faster. Also, drones are able to use sensors that humans don't have, such as an accelerometer, to become more precise. [73]

Today the most streamlined civilian UAVs, in terms of on-board artificial intelligence, are the drones that have the "Follow Me" function. These UAVs are capable of recognizing a person or an object and tracking it. For example, Skydio's intelligent drones are used by sportsmen and women who want to be followed and filmed during their prowess. Such abilities could be useful during humanitarian missions for things such as advocacy, remote support, extra sensors (e.g. heat sensors in search and rescue) and security.

The function of avoidance, that enables the drone to operate in a complex environment is still not 100% reliable. The safety and operating guidelines of Skydio 2 allow the company to deny coverage if the drone is flown "over people"; "around thin branches, telephone and power lines, rope, netting, wires, chain link fencing"; and "around windows or mirrors". This raises concerns about what their AI technology can and cannot avoid. When flying in daylight and good weather conditions, the system is highly capable of following an individual and circumventing obstacles. [74] But, such conditions are not always guaranteed in a humanitarian operation.

Legislation and the concerns over crashing are two common issues preventing autonomous flight.. In most cases, legislation dictates that people can only fly drones if they are in visual line of sight for safety reasons. However, in November 2019, the first beyond visual line of sight (BVLOS) drone operation using only onboard detect-and-avoid systems was authorized by the US Federal Aviation Administration (FAA). [75] The drone used Iris Automation's detect-and-avoid system to complete more than 150 miles of power line inspections. This special authorization paves the way for more autonomous drone operations and demonstrates the trust put in the existing AI avoidance systems.

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73 Swearingen, J. "AI is Flying Drones". The New York Times. March 26, 2019. *https://www.nytimes.com/2019/03/26/technology/alphapilot-ai-drone-racing.html*. Accessed Dec 26, 2019.

74 Hollister, S & Pavic, V. "Skydio 2 Review: a drone that flies itself". The Verge. December 11, 2019. *https://www.theverge.com/2019/12/11/21009994/skydio-2-review-self-flying-autonomous-drone-camera-crash-proof-price*. Accessed Dec 26, 2019.

75 Garrett-Glaser, B. "Energy Inspects 150 Miles of Power Lines with True BVLOS Drone Flights". November 13,2019. *https://www.aviationtoday.com/2019/11/13/evergy-inspects-150-miles-power-lines-true-bvlos-drone-flights/*. Accessed 15 Nov, 2019.

Many experts from drone companies believe that BVLOS flights will rise during the next decade enabling many use cases of civilian UAVs.

BVLOS can improve the safety of various workers. For first responders, a drone equipped with a high-quality avoidance system can be sent to hard-to-reach areas and map an ideal path for travel / delivery. It can also retrieve videos and images from areas that are far to reach or are insecure.

To be useful, drones need to fly far, fast and BVLOS. They need a detect-and-avoid system when they can't rely on external guidance systems like GPS. [76] At the moment, the main challenge preventing BVLOS flights is the need for seamless coverage, real-time high throughput data transmission, command and control, identification, and regulation. [77]

Onboard AI for feature detection

Integrating an AI model for feature detection into a drone represents a valuable opportunity for the humanitarian sector. For example, it could be useful to download a custom detector, such as one created on the Picterra platform, to enable instant detection. For such a feature, computer calculation power needs are high.

The industrial sectors are developing more and more intelligent drones. However, this technology is far from being democratized to all sectors. Companies producing UAVs or UAV dedicated software will target specific industry sectors, often where the market is attractive and the potential profits high such as the construction and warehouse-related industries. In construction, drones are used for inspection tasks. In warehouses, drones are used to navigate through the building and automatically do inventory checks.

Customized models have also been created specifically for disaster response. In 2018, DJI created an AI model trained to identify burnt buildings and vehicles. During its flight, the drone collects information and reports before it lands. Such an ability provides an immediate assessment of the degree and size of damages. [78]

76 Ibid.

77 Tardif, A. "Deniz Kalaslioglu, Co-Founder & CTO of Soar Robotics – Interview Series". January 2, 2020. *https://www.unite.ai/deniz-kalaslioglu-co-founder-cto-of-soar-robotics-interview-series/*. Accessed Jan 3 2020.

78 Romeo Durscher, interview with author, November 19, 2019

Leveraging edge computing and having an AI model onboard is valuable as the drone can transmit results to the ground controller. In a Search and Rescue (SAR) mission, you can train an AI model to look for a body, an arm or even a leg under debris and integrate this model into a drone. In the event of a disaster, first responders would send a drone into a damaged area to look for stranded survivors. If the cameras on the drone "sees" a shape that matches, it would instantly report sightings of potential missing people with a certain level of confidence.[79] As drones get better at object recognition, humanitarians can send drones over damaged areas to get a more detailed physical damage analysis. They could identify how many people are alive in a building, where they are and whether they are stuck.[80] Drones could focus on the search and first responders could focus on the rescue thereby saving precious time.[81]

79 Patrick Meier, interview with author, November 26, 2019

80 Daniel Gilman, interview with author, November 20, 2019

81 Sophia Rosa, interview with author, December 12, 2019

Section 3 :

The potential future of humanitarian drone missions

Artificial Intelligence of Things (AIoT)

AIoT is the combination of AI and IoT (the Internet of Things). AI has always relied on large data sets to develop efficient algorithms. IoT [82] could feed live data to AI to build more complex algorithms and apply "reason" to real-time data. AI could be used to transform IoT data into useful information for improved decision making processes. Meaning, AIoT is mutually beneficial for both technologies.

During a mission, if a drone applies machine learning algorithms to all the data collected by its various sensors, it could make moment-to-moment decisions about how to respond to its environment. For example, in response to a wildfire, drones could be sent to drop fire retardant. Based on the conditions and datasets captured by their IoT-enabled sensors, they could autonomously decide on the best place to drop the substance. These conditions would include the wind direction and speed; current temperature; and the percentage of fire contained. [83]

Combining the data from the drone sensors and the data from the IoT, drones could gain valuable situational awareness for independent decision making. A future scenario of a humanitarian drone missions could involve drones that see through buildings, determine how many residents are in a partly collapsed building, and with other data inputs, such as information from social media posts, construction types, and health information on residents, the drone could evaluate if a stuck person is diabetic and needs insulin. [84]

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82 When "things" such as wearable devices, refrigerators, digital assistants, sensors and other equipment are connected to the internet, can be recognized by other devices and collect and process data, you have the internet of things

83 Kranz M, "Inside the "hive-mind":how AI-powered drone "swarms" can benefit society". InformationAge. February 15, 2019. *https://www.information-age.com/ai-powered-drone-swarms-123479202/#*. Accessed 26 Dec 2019

84 Robert Kirkpatrick, interview with author, December 6, 2019

"I think the most interesting work is going to come later with real autonomy and drones and humans augmenting one another work. The drone is kind of an extension of human awareness during an emergency."

- Robert Kirkpatrick

Swarm drones

The most developed uses of AI in humanitarian drone missions to-date is in the uploading and processing of captured images in the cloud after the flight. Thanks to improving communication technology and small-sized supercomputers, UAVs can now process and send only relevant data to the cloud. The next phase of drone implementation that experts envision is a swarm[85] of intelligent drones that operate together, communicate with each other and use AI to make real-time decisions together.[86]

There are two main components for a drone swarm to operate: communication between its members and AI. Being able to communicate with the other drones establishes a feedback system that aims for group cooperation[87]. AI enables each drone to fly on its own and to act on its environment, including the swarm, via pre-programmed choices or choices made via AI.

The main challenge for an effective use of swarm UAVs is networking the devices to ensure that they are aware of their surroundings and have the ability to execute a single mission profile.[88] Coordinated exploration is key to efficient swarm drone missions. It refers to the decision of drones to move through an environment together in order to efficiently explore that environment. Each drone deployed decides where to go based on its surroundings, they communicate at regular intervals to share information on their environment and make further decisions regarding their coordinated exploration based on a collective model.[89]

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85 Swarm robotics is a branch of robotics that applies swarm intelligence methods to multi-robot systems. Swarm intelligence studies how the interaction or synergy between simple individual actions enables the emergence of collective and complex behaviors.

86 Kranz M, "Inside the "hive-mind":how AI-powered drone "swarms" can benefit society". InformationAge. February 15, 2019. *https://www.information-age.com/ai-powered-drone-swarms-123479202/#*. Accessed 26 Dec 2019

87 Dorigo, M & Birattari, M (2007). Swarm Intelligence. Retrieved from Scholarpedia website: *http://www.scholarpedia.org/article/Swarm_intelligence*. Accessed Jan 2 2020.

88 Romeo Durscher, interview with author, November 19, 2019

89 Michael, N. "What is coordinated exploration?" Shield AI. August 30, 2019. *https://www.shield.ai/content/2019/7/15/what-is-coordinated-exploration*. Accessed Dec 31, 2019

Thanks to technological advances in data transmission technology and in onboard supercomputer power, deployment of swarm drones is technologically feasible. To-date they have mainly been used to execute simple tasks for entertainment purposes such as at the 2017 Super Bowl halftime show where Intel flew hundreds of drones. [90]

There are also many potentialities for more complex tasks in humanitarian actions. In 2014, Duarte & al. showed via a simulation applied to the case of the island of Lampedusa, that a swarm of 1,000 small aquatic UAVs dispersed at sea from two bases could in 24 hours make a surveillance assessment over a 20 km long maritime band. [91]

Coordinated UAV flight could be used to gain much more situational awareness. For example, first responders could unleash a SAR operation of hundreds of drones to scour a devastated area, map it, and use AI to identify potential victims in a short amount of time.

These scenarios are becoming potential realities. In late December 2019, the US Pentagon Joint Artificial Intelligence Center issued a request to build a self-starting, AI-enabled drone swarm capable of recognizing and tracking a target on its own. [92] This R&D investment aims at using swarm drones in search and rescue efforts. Similarly, the project 5G-Dive, led by the Universidad Carlos III de Madrid and the research laboratory 5TONIC, uses 5G networks and AI to coordinate autonomous drone flights from a central base and detect anomalies such as a person in danger during a wildfire.[93]

Moreover, the Verizon First Responder Lab organized a successful drone swarm mission during its yearly Operation Convergent Response Week in November 2018. During this event, crisis scenarios are simulated for trials and live demonstrations of developed solutions. After simulating a flood in

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90 Feist, J "Intel flies hundreds of drones during Super Bowl Halftime with Lady Gaga". Drone Rush. February 6, 2017. *http://dronerush.com/intel-shooting-star-drones-super-bowl-halftime-lady-gaga-5984/.* Accessed 31 Dec 2019.

91 Duarte M, Oliveira S.M & Christensen A.L (2014) Hybrid control for large swarms of aquatic drones [archive] ; in 14th International Conference on the Synthesis & Simulation of Living Systems (ALIFE), pages 785–792. MIT Press, Cambridge, MA (PDF, 8 pp)

92 "The Pentagon want AI-driven Drone swarms for search and rescue ops". Daloop. January 2, 2020. *https://www.oodaloop.com/briefs/2020/01/02/the-pentagon-wants-ai-driven-drone-swarms-for-search-and-rescue-ops/.* Accessed Jan 2 2020.

93 Alonso, F "Deployment of 5G technology in drones and robots". EurekAlert!. December 18, 2019. *https://www.eurekalert.org/pub_releases/2019-12/ucid-do5121819.php.* Accessed Dec 31, 2019

a town, six drones were sent simultaneously with the mission of identifying survivors in the flooded area, underwater, in houses and on top of houses using their infrared cameras. Each drone was responsible for its own area and the six drones "talked" to one another to match their information so as not to explore an area that was the responsibility of another drone. [94]

While these types of operations were considered science fiction in the past, many successful projects show that they are technologically feasible. However, such missions can only be tested on a larger scale when regulations are ready. [95]

Hardware improvements

Drone delivery is an expanding field due to rapid technological evolutions and to interest from high tech companies in this application. The rapid, reliable and cost-effective delivery of vital supplies to communities affected by major disasters is a central element of humanitarian relief. However, the transport of loads can be hampered by a number of factors such as damaged infrastructure, roadblocks and floods. Thus, drones can play an important role in the "last mile" delivery. They have been used to transport small payloads over short distances and at a high rate. [96] In the humanitarian sector, the NGO Wings for Aids has developed drones capable of carrying eight payloads as heavy as 20 kg. The boxes contain food, water, shelter kits or medical supplies. [97]

Advancements in battery technology, like hydrogen fuel cells, and the ability to transport increasingly heavy payloads will drive the drone delivery industry in the coming years. [98] Along with artificial intelligence software, the drone's ability to transport payloads could improve humanitarian response

94 Nicholas Nilan, interview with author, November 27, 2019

95 Tautvydas Juskauskas, interview with author, November 27, 2019

96 Soesilo, D, Meier, P., Lessard-Fontaine, A., Plessis, J. D., Stuhlberger, C., & Fabbroni, V. (2016). Drones in Humanitarian Action » Drones in Humanitarian Action. Retrieved from Swiss Foundation for Mine Action website: *http://drones.fsd.ch/en/drones-in-humanitarian-action/*. Accessed 25 Nov 2019.

97 Calder, S. "Charity Plans to Airdrop Aid Using Fleet of Drones". Independant. November 27,2019. *https://www.independent.co.uk/travel/news-and-advice/charity-aid-drones-airdrop-ings-for-aid-netherlands-a9219601.html*. Accessed Jan 3 2020.

98 Tardif, A. "Deniz Kalaslioglu, Co-Founder & CTO of Soar Robotics – Interview Series". January 2, 2020. *https://www.unite.ai/deniz-kalaslioglu-co-founder-cto-of-soar-robotics-interview-series/*. Accessed Jan 3 2020.

to disasters. In SAR missions, experts envision that drones will not only be valuable for searching affected people but also for rescuing them. [99] After autonomously identifying people to be rescued, drones could drop goods such as food, two-way radio communication, cell phones or medicine to the victims.

Some experts imagine a future in which drones would have the ability to transport payloads as heavy as a human. Investments in research and development for UAVs capable of carrying increasingly heavy loads is very important. During the Amsterdam Drone Week in 2019, the passenger drone company Ehang revealed that they were about to streamline production and processes to make drone taxis commercially viable. [100]

99 Sophia Rosa, interview with author, December 12, 2019

100 McNabb, M. "Passenger Drone Company Ehang Announces IPO". DroneLife. December 12, 2019. *https://dronelife.com/2019/12/12/passenger-drone-company-ehang-announces-ipo/. Accessed Jan 2 2020.*

Section 4:

Challenges related to the use of intelligent drones in humanitarian action

In 2014, OCHA highlighted the challenges preventing the effective use of UAVs for humanitarian response. The challenges included legal issues; ethical procurement and partnerships; privacy and data protection; informed consent; and community engagement. [101] Despite these challenges, the use of drones in humanitarian action has grown considerably so the question now is:

"How do we best use this technology in a way that is ethical, responsible, accountable, effective, needs-based, needs-driven, and in line with humanitarian principles?"

- Patrick Meier

To help answer this question, the international community has developed policies, guidelines and principles to guarantee the responsible implementation of emerging technology. UAV operators can refer to the *Humanitarian Drone Code of Conduct* developed in 2014 by the Humanitarian UAV Network (UAViators). [102] And, the principles developed during the 2015 World Humanitarian Summit can serve as a base for ethical innovation in humanitarian action. [103]

At the same time, some challenges have been exacerbated by the constant development of technology requiring perpetual adaptation from tech users. Also, the introduction of AI in the humanitarian space has brought new issues that need to be addressed. Consequently, the UAV

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101 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://docs.unocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. Accessed 23 Dec 2019

102 See *http://uaviators.org/*

103 (June 2015) Principles for Ethical Humanitarian Innovation. Retrieved from Refugee Studies Center website: *https://www.refugee-economies.org/assets/downloads/Principles_for_Ethical_Humanitarian_Innovation_-_final_paper.pdf*.

Code of Conduct is currently being updated by UAViators and the Harvard Humanitarian Initiative. [104] Similarly, based on a compilation of reports and a multi-stakeholder conference in 2017, the Future of Life Institute established the *Asilomar Principles* for AI innovations to be in line with human values.

Experts are still divided on the introduction of drones into the humanitarian space. Some believe drones can be valuable tools in assisting humanitarians whereas others underline the negative effects of large scale drone deployments which could lead to the violation of humanitarian principles. This section provides an overview of the challenges associated with the use of this technology and highlights the efforts made or need to be made to address these challenges.

Operational challenges

Data management

While drones are becoming increasingly affordable and autonomous, the difficulty lies in exploiting the data collected, which often requires powerful computer capabilities and technical expertise. As more information is collected, challenges for storing, processing and analyzing aerial data increase. While AI has partly solved the latest issues, some humanitarians still don't have sufficient capacities to manage the data collected.

First, the storage capacity of a UAV limits the amount of data that a drone can capture in one flight. For now, most mapping and data analytics happen post-flight. This storage capacity can be so limited that drones equipped with onboard processing for navigation and collision avoidance capacity diminish the capacity for streaming imagery.[105] While edge computing or transmission technology enable data transmission during the flight, those solutions are still under development and rarely accessible to the humanitarian drone community.

104 "Partnering with Harvard on the Humanitarian Drone Code of Conduct". WeRobotics. March 14, 2019. *https://blog.werobotics.org/2019/03/14/hhi-code-of-conduct/*. Accessed Nov 22 2019.

105 Diaconu, C. "Three main obstacles hindering Wide-Spread Adoption of Drone Flights". Manufacturing and engineering magazine. December 2, 2019. *memuk.org/technology/three-main-obstacles-hindering-wide-spread-adoption-of-drone-flights-52800*. Accessed Jan 2 2020.

For larger mapping missions, when large amounts of aerial data is collected, computing power needs are also large.. For example, in the Zanzibar Mapping Initiative, difficulties arose in processing all the visual data. This project, launched in 2016 by the Tanzania Commission for Science and Technology (COSTECH) and the Revolutionary Government of Zanzibar (RGoZ), aimed to map the islands of Zanzibar and Pemba, an area totaling over 2,300 square km.[106] The capacities of their computers only enabled the processing of nine square km in about eight hours.

"The big issue when we are talking of AI is, as we collect huge amounts of data, we need a big size for storage and then we need another platform to organize the data, and without a good processor and a high capacity computer, you can't even see the data. What is challenging is how you can afford the cost of powerful machines that can work according to your project."

- Khadija Abdulla

Applying AI algorithms requires high resolution imagery which means increasing the overlap of images and consequently the amount of data. [107]

The challenge related to analyzing data has been partly overcome as computer vision algorithms can now quickly analyze a large amount of aerial data. However, integration of AI into analysis raises new challenges related to the development of AI models and their applications.

First, AI performance of computer vision relies upon extremely large training data sets for computer vision algorithms. Thus, many data sources need to be available to create a reliable AI model. Also, even though labialization tasks are becoming less cumbersome, there is still a need for substantial human input to label or categorize data. For example, in order to be used in different contexts, WFP is adapting its DEEP tool for each country where their model would be needed.

Secondly, using AI models for analyzing aerial data can be challenging if humanitarians do not have the necessary expertise. Thus, the technological solution must be simplified so that the application of machine learning to drone imagery could be simplified and streamlined. [108]

106 Khadija Abdulla, interview with author, November 22, 2019

107 To obtain orthomosaic maps from drone imagery, it is important that each individual image is overlapped with the images around it. The greater the image overlap, the easier it is for the photogrammetry software to process the images and the better the resolution is.

108 Nathaniel Raymond, interview with author, December 4, 2019

Finally, the integration of artificial intelligence into data analysis implies new steps in emergency response (using machine learning to assess damage) and new actors (private companies offering AI solutions) which complicate the disaster response workflow. Humanitarians are distracted by different components such as the drone itself; the accessories; how to capture imagery; and how to analyze and process the imagery. [109] So *"humanitarians need an all in one solution to not worry about all the components".*

- Tautvydas Juskauskas

In this sense, WFP has found a way to simplify workflow and speed up disaster response by creating in its own AI model and by training local communities on the whole disaster assessment workflow.

Legal requirements

While the technological potential is tremendous, the expansion of such technology requires an appropriate legal framework. In Europe, the Drones Amsterdam Declaration was adopted in November 2018 by European and national stakeholders to unify and decide on a responsible framework for the use of drones. [110]

"The democratization of technology has also helped for its admission (...) National regulations have evolved and actually incorporate drones in their aviation space. It has evolved in the last years at a very rapid rate and it will continue in the future".

- Sanjana Hattotuwa

With the introduction of BVLOS flights, mitigating airspace raises new regulation challenges.

"Regulations need to go hand and hand with the technology because if technology is here but we are not able to utilize them because of regulations, this could hinder the industry but also prevent us from having access to the information that can be obtained quickly at higher resolution. "

– Tautvydas Juskauskas

109 Tautvydas Juskauskas, interview with author, November 27, 2019

110 Diaconu, C. "Three main obstacles hindering Wide-Spread Adoption of Drone Flights". Manufacturing and engineering magazine. December 2, 2019. memuk.org/technology/three-main-obstacles-hindering-wide-spread-adoption-of-drone-flights-52800. Accessed Jan 2 2020.

Financial limits

While the financial challenge in the field of drones has always existed, it has decreased with the democratization of access to affordable drones. However, the development of increasingly intelligent drones such as live-AI drones or swarm drones are dividing the drone sector between affordable drones used by civilian organizations and highly intelligent drones developed for the military or for big corporations. As AI experts are in-demand across all sectors of the economy, humanitarian organizations are not prioritized. [111]

Unleash Live has identified 20 AI models that could be used on imagery for humanitarian purposes, but they lack the right partners to implement them. According to Hanno Blankenstein, CEO of Unleash Live, coordination between academia and humanitarians on the field could be the solution. [112]

"At the moment there is a gap between university research and what is happening in the field. I foresee that with Unleash Live, AI experts will have the infrastructure to very quickly deploy, and improve algorithms thanks to a feedback loop enabling the researcher to be much closer to the reality of the field."

– Hanno Blankenstein

Humanitarian space is generally not a viable market to push innovation independently. The exception in disaster response is where local governments have the necessary funds to purchase cutting-edge technology. [113] Within the framework of the Verizon 5G First Responders Lab, many investments and efforts were made to put in place drone solutions for emergency response. They are currently reflecting on how public agencies could buy or use this technology in a responsible way with the objective of making this technology available to all public safety agencies. [114]

As major investments in intelligent drones are being made by public safety agencies, ***"best case scenarios are coming down the line and there will be opportunities for humanitarians to access them through government services. Drone fleets for humanitarians would be something available from one government to another, through intergovernmental mechanisms."***

- Daniel Gilman

111 Ibid
112 Hanno Blankenstein, interview with author, November 27, 2019
113 Daniel Gilman, interview with author, November 20, 2019
114 Nicholas Nilan, interview with author, November 27, 2019

According to humanitarian expert Nathaniel Raymond, the "humanitarian community has not made a concerted investment to the economic level required to make humanitarian featured extraction viable in the research community". The challenge is "political will, financial commitment and management science because it requires leadership to launch the R&D process that can take months to years and then make it in a way that non-experts can use the tool for decision support." In terms of rapid need assessments, the smartest thing to do seems to be to make major investments in remote sensing feature extraction development.

Therefore, some international organizations are investing in the use of AI and drones in their actions as demonstrated by the UNICEF drone corridors or the machine learning models developed by WFP. Also, the Emergency Telecommunication Cluster (ETC)[115] - one of the 11 clusters designated by the Inter-Agency Standing Committee - has adopted drones as a service in 2018 and will further integrate drones into its catalog of services. [116]

Multiplication of actors

A growing number of humanitarian organizations are leveraging drone technology as it becomes more accessible. But, according to humanitarian drone specialist, Patrick Meier, many of them are still a long way from making the best use of this technology. "A lot of learning is needed and it is not because you learn how to fly a drone that suddenly you become an expert in humanitarian drone missions. Technology is at most ten per cent of the solution, and it is the other ninety percent that people often completely overlook." [117]

Following the Nepal earthquake in 2015, many UAV operators, including a wide range of foreign organizations and individuals, decided to intervene to help disaster response efforts. However, as the drone operations were not led in collaboration with the Nepali authorities, they resulted in hindering the work of the government. [118] This example demonstrates the need to coordinate action with relevant authorities. UAV operators should "operate with relevant permissions" (UAV Code

115 See *https://www.etcluster.org/about-etc*

116 Emma Wadland, interview with author, December 17, 2019

117 Patrick Meier, interview with author, November 26, 2019

118 Sharma, G. "Armed with drones, aid workers seek faster response to earthquakes, floods". Reuters. https://www.reuters.com/article/us-humanitarian-summit-nepal-drones/armed-with-drones-aid-workers-seek-faster-response-to-earthquakes-floods-idUSKCN0Y7003. Accessed Jan 2 2020.

of Conduct, rule n°5) and coordinate their actions "with relevant local and international actors and authorities" (UAV Code of Conduct, rule n°7). As AI complexifies the disaster response workflow,

"without appropriate collaboration with the local government and institutions before an emergency, machine learning is of little concrete value"

- Marco Codastefano

The Nepali example also demonstrates how foreign-led interventions in the Global South can create more harm than good. There are concerns that the "heros come from outside" [119] as most of the AI-research and development is undertaken by Northern countries. These organizations then intervene in foreign countries prone to disasters.

Drones should be part of national disaster preparedness plans and accessible to disaster affected communities as they are the first responders on the ground. Humanitarians should "engage with communities" (UAV Code of Conduct, rule n°6) and empower local experts with knowledge of the local language, customs and traditions. [120] In this sense, building local capacity and prioritizing South-South collaboration are fundamental for responsible humanitarian drone missions.

The Flying Labs, co-created by WeRobotics and established in 26 countries throughout Asia, Latin America and Africa, [121] are local knowledge hubs run by local professionals. WeRobotics supports them with equipment and training, if needed, but professionals often train each other and work on joint projects. Patrick Meier, co-founder of WeRobotics explains:

"We co-founded WeRobotics with the goal of enabling local experts to take leadership roles on drone technology for good projects around the world .... Local experts are in the best position to lead this humanitarian technology in a way that is more effective, sustainable and ethical."

- Patrick Meier

As countries most affected by natural disasters need to integrate the workflow without the intervention of external actors, WFP implements a training package - as a pillar of its UAV program. Following Cyclone Idai in Mozambique, the WFP team organized a 10-day workshop to train local

119 Robert Kirkpatrick, interview with author, December 6, 2019

120 Patrick Meier, interview with author, November 26, 2019

121 See *https://werobotics.org/flying-labs/*

experts - 10 participants from the National Institute of Disaster Management of Mozambique (INGC) and from the University Eduardo Mondlane - on how to integrate drones and machine learning into disaster response. They covered training in machine learning basics, data investigation and annotation, classification modeling, damage assessment modeling and visualization. [122] "The objective was for the knowledge to stay within the country and for the national team to be able to conduct damage assessment on their own in the case of a future disaster,'' said Sophia Rosa from WFP.

Following several training sessions organized by WFP since 2017, a South-South collaboration has also been implemented. In December 2018, WFP organized a 10-day exercise pairing facilitators from governmental disaster management departments of Mozambique and Madagascar. This encouraged best practices sharing between the two countries. [123]

As many organizations are using drones and AI, ***"experience sharing is critical to understand what are the key learnings and key takeaways. Knowledge sharing is a challenge but also an opportunity."***

- Tautvydas Juskauskas

UAV operators should "contribute to learning" (Code of Conduct, rule n°14) and "be open and collaborative" (Code of Conduct, rule n°15) by sharing lessons learned and best practices for a better use and coordination of drones in humanitarian missions. Understanding the importance of sharing knowledge, WFP will release their machine learning tool DEEP as an open source so that it can be a benefit to other organizations. They are also sharing experiences on machine learning activities with the International Telecommunication Union and the Red Cross. [124] The organization ambitions are to take a ***"leadership position in the humanitarian world for sharing information and technology and different approaches to drones as well as the legality and safety issues that come up with drones. Our spirit is one of inclusivity, sharing with governments and other humanitarian NGOs and agencies"***

- Emma Wadland

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122 Marco Codastefano, interview with author, December 17, 2019

123 "A South-South collaboration takes flight: Madagascar and Mozambique launch advanced drone training". Retrieved from WFP website: *https://sway.office.com/zMaq9IrwUj8gD833?ref=Link*. Accessed Jan 9 2020.

124 Marco Codastefano, interview with author, December 17, 2019

Humanitarian organizations should engage in network initiatives like the Humanitarian UAV Network, which created a community of practices for UAV organizations [125], or the new Global Alliance for Humanitarian Innovation which works to scale innovation in the humanitarian system. [126]

Ethical issues

“Challenges of autonomous UAVs are mainly ethical, not operational.”

- Regina Surber

Responsible partnership

The military is the main user of UAVs and it has sufficient funds for major R&D investments to develop AI programs and to hire innovative companies. Unfortunately, the abilities of intelligent drones are more developed and explored for military purposes than for humanitarian purposes. One of the major problems in the development of intelligent civil solutions by private companies is that these companies are often hired by the military. Thus, the ethical issues raised by D. Gilman and M. Easton in 2014 on the association, even indirect, of humanitarian actors with defense companies are still relevant today.[127] To comply with the humanitarian principle of Neutrality, humanitarians should ensure their partner company does not have any military interest in their drone humanitarian mission.

Data collection and privacy

The issues regarding the protection of privacy and the ethical collection and use of data are highly significant when talking about intelligent drones, especially when they operate in densely settled

125 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://docs.un-ocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. P. Accessed Jan 9 2020

126 See *https://www.thegahi.org/*

127 Gilman, D, & Easton, M. (2014). Unmanned Aerial Vehicles in Humanitarian Response (Occasional Policy Paper No. 010). Retrieved from United Nations Office for the Coordination of Humanitarian Affairs website: *https://docs.un-ocha.org/sites/dms/Documents/Unmanned%20Aerial%20Vehicles%20in%20Humanitarian%20Response%20OCHA%20July%202014.pdf*. P. 9 Accessed 23 Dec 2019

places and capture high-resolution images. [128] Indeed, *“the more data is collected the worst privacy issues become. (...) Is it justifiable morally to violate privacy rights for marginal gain and efficiency? (...) I understand the benefits of this technology, but this is an incredibly slippery slope”.*

- Daniel Gilman

As UAVs involve data collection, analysis, creation and storage, they create property to whose security is difficult to ensure. In that sense, it may create a new platform for doing harm. [129] The potential misuses of data collected by humanitarian drones have several unintended consequences from the violation of humanitarians principles to unintentional harm.

According to the Independence principle, humanitarian action must be autonomous from political, economic, or military objectives. [130] This principle requires that the data collected by humanitarian UAVs

“will never be used for informing anything other than the humanitarian situation, i.e., no national intelligence, no businesses focused on behavioral analytics, no environmental agencies, etc”.

- Regina Surber

Considering the growing number of AI military programs launched in recent years, AI applied to drones is increasingly used for intelligence purposes. In the US, the government has already prevented drones produced in a foreign country from operating for fear that they might be collecting data for espionage. [131] Working with companies that also operate as defense contractors would give them access to countries where humanitarian drone missions take place. Thus, there is a risk that data collected could be used for surveillance purposes leading to a violation of the neutrality and independence principles. [132]

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128 Soesilo, D, Meier, P., Lessard-Fontaine, A., Plessis, J. D., Stuhlberger, C., & Fabbroni, V. (2016).Drones in Humanitarian Action. Retrieved from Swiss Foundation for Mine Action website: *http://drones.fsd.ch/en/drones-in-humanitarian-action/*. P.33. Accessed 25 Nov 2019.

129 Regina Surber, personal communication with author, January 6, 2020

130 Bagshaw, S. (2012). OCHA on Message: Humanitarian Principles (p. 2). Retrieved from *http://www.unocha.org/sites/dms/Documents/OOM-humanitarianprinciples_eng_June12.pdf* . Accessed Jan 7 2020.

131 DeAngelis, M. “Interior Department grounds drone fleet over security concerns”. Engadget. October 31, 2019. *https://www.engadget.com/2019/10/31/doi-grounds-800-drones/*. Accessed Nov 5, 2019.

132 Nathaniel Raymond, interview with author, December 4, 2019

The risk of mass surveillance with drones has often been highlighted as the main ethical issue. When shared with governments, data can be used for domestic surveillance. For example, having really accurate information on building types and damage assessment is useful for humanitarians to improve disaster risk reduction. But this kind of data can also be used by governments to collect information on illegal settlements or tax dodging. [133]

In some instances, data collected on vulnerable populations could put their lives at risk. A relevant example would be the potential risks associated with publishing drone imagery, taken by IOM, of Cox's Bazar Rohingya Refugees Settlements in Bangladesh on OpenStreetMap. While these images have proven to be useful for humanitarian purposes, they give information on a population displaced by genocide issuing security threats. [134]

In general people may disagree with being photographed as it violates their privacy. As drones get smaller and more autonomous, privacy risks get higher. In theory, drones could identify people, see through walls or fly up to one's window. This can be really useful to alert first responders or hospitals that someone is in danger but treads the line of privacy invasiveness.[135] Yet, to protect people's privacy, technology can be the solution: UAVs can use automated processes to blur out sensitive information including people and places to protect anonymity. [136]

Using drones to collect human data such as emotional or biological data raises issues on the potential violation of human dignity, especially when this data collection is made on vulnerable populations. [137]

Acknowledging these risks, the Harvard Humanitarian Initiative (HHI) has established a list of nine ethical obligations for Humanitarian Information Activities (HIA)[138] and the UAV Code of Conduct has been updated to take into account such risks.

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133 Daniel Gilman, interview with author, November 20, 2019

134 Ibid.

135 Ibid

136 Robert Kirkpatrick, interview with author, December 6, 2019

137 Regina Surber, personal communication with author, January 6, 2020

138 Campo, S. et al. (May 2018) Signal Code: Ethical Obligations for Humanitarian Information Activities. Retrieved from Harvard Humanitarian Initiative website: *https://hhi.harvard.edu/sites/default/files/publications/signal_obligations_final_05.24.2018.pdf.* Accessed Jan 10 2020.

As humanitarians have "to ensure data privacy and security before, during, and after the implementation of a HIA" (HHI Signal Code, obligation n°6), UAV operators need to be transparent (Code of Conduct, rule n° 13) regarding their drone operations. They should inform local communities as widely as possible of the timing of flights, what data will be collected and why, and who will have access to it. They have to be accountable (HHI Signal Code, obligation n°9) for unintended consequences creating accountability mechanisms and reporting procedures. [139]

Finally, UAV operators have to use, manage and store data ethically "using a needs-based approach, applying informed consent where possible and employing mitigation measures where it is not." (Code of Conduct, rule n° 11). But, ensuring data safety is hard as data is intangible and easily manipulated or stolen.

"More importantly, whether or not we want this to be ensured (e.g., data is money, also for humanitarian organizations; also consider: humanitarian data can be useful for developmental purposes, which would require either a stretching of the term 'humanitarian' or a violation of the principle of independence), are key questions that need to be addressed by high-level institutions"

- Regina Surber

Uncertainty on risks related to new technology

There is a need to take advantage of emerging technologies in humanitarian action while recognizing they create new risks and proactively manage those risks. [140] One overall challenge related to the use of intelligent UAVs is that we ignore the risks posed by this technology. Humanitarians have to analyze and minimize the risks of new technologies, especially when their use involves affecting topics such as human life and human physical integrity and health. [141]

To mitigate risks during a drone operation, UAV operators should assess and mitigate the risks of their mission" (Code of Conduct, rule n°4).

139 Campo, S. et al. (May 2018) Signal Code: Ethical Obligations for Humanitarian Information Activities. Retrieved from Harvard Humanitarian Initiative website: *https://hhi.harvard.edu/sites/default/files/publications/signal_obligations_final_05.24.2018.pdf*. P. 14. Accessed Jan 10 2020.

140 Patrick Meier, interview with author, November 26, 2019

141 Regina Surber, personal communication with author, January 6, 2020

To guarantee an ethical development of AI technology, "[i]nvestments in AI should be accompanied by funding for research on ensuring its beneficial use, including thorny questions in computer science, economics, law, ethics, and social studies." (Asilomar Principle)

AI bias

"Bias has turned out to be a major issue in AI and machine learning."

- Einar Bjørgo

As AI systems are "black boxes" that are not programmed but have learned by themselves, there is an inability to detect or mitigate against biased data and an inability to explain outcomes or decisions of an algorithm. [142] Drone only relying on computer vision algorithms to fly autonomously, is highly dangerous. Indeed, there is a risk that AI algorithms learn human prejudice from biased data [143] and consequently misunderstand an object or situation. For example, in March 2018, a woman was killed in Arizona by a self-driving car because the AI system could not recognize her as a pedestrian since she was not crossing at a crosswalk. [144] Finally , since autonomous UAVs run on software, the risks of hacking and misuse exist so exist as with any technological solution. [145]

It is extremely important to have proper training data sets to leverage risks against biased data. In that sense, UNOSAT developed an archive of training data sets for looking at the extent of a flood, refugees tents and building footprints. Transparency over the methodologies used in AI are fundamental especially in the humanitarian domain where methods are clearly defined and documented. Humanitarians must be careful as some AI companies claim a high level of accuracy but are not clear on the methodology they use. [146]

142 Chui, M, Harryson, M, Manyika, J, Robertsm R, Chung, R, van Heteren, A & Nel, P. (2018) Notes from the AI Frontier: Applying AI for Social Good. Retrieved from McKinsey Global Institute website: *https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Artificial%20Intelligence/Applying%20artificial%20intelligence%20for%20social%20good/MGI-Applying-AI-for-social-good-Discussion-paper-Dec-2018.ashx* (see p. 24). Accessed 17 Dec 2019.

143 Surber, R. (February 2018) Artificial Intelligence: Autonomous Technology (AI), Lethal Autonomous Weapons Systems (LAWS) and Peace Time Threats. Retrieved from ICT4Peace website: *https://ethicsandtechnology.org/wp-content/uploads/2018/03/2018_RSurber_AI-AT-LAWS-Peace-Time-Threats_final.pdf*. Accessed Jan 7 2020.

144 Wakabayashi, D. "Self-Driving Uber Car Kills Pedestrian in Arizona, Where Robots Roam". The New York Times. March 19, 2018. *https://www.nytimes.com/2018/03/19/technology/uber-driverless-fatality.html*. Accessed 17 Dec 2019.

145 Regina Surber, personal communication with author, January 6, 2020

146 Einar Bjørgo, interview with author, December 12, 2019

"I think we are excited and want to invest in this technology but it is important to take a little step back and truly understand the limitations of AI and machine learning. (...) Before going into the operational phase you have to be sure and transparent of the results that you are getting and then be open and transparent on the methods."

- Einar Bjørgo

Autonomous decision-making

An agent is autonomous when it has a goal, works toward it by analyzing a vast amount of data from its environment, makes predictions on how the environment can change and modifies its outputs based on said predictions. [147] But miming human intelligence raises technical and ethical issues and depending on the degree of autonomy and the nature of the decisions, UAVs can violate humanitarian principles.

According to the Impartiality principle, humanitarian action must be carried out on the basis of need alone.[148] In the case of a drone used for delivering aid autonomously, impartiality requires that the drone prioritize the most urgent cases and identify different levels of needs. This would pose a challenge in terms of AI biases and technological feasibility. [149]

Also, when drones are replacing humanitarians in missions where human-human interactions is key – for example when they are used for inspection of detention centers - this threatens the principle of Humanity.[150] When using AI, drones take decisions considering data points, vs humans, which could be considered as a violation of human dignity. [151]

These examples raise the fundamental questions about the degree of autonomy that should be

147 Zurich Hub for Ethics and Technology. "Artificial Intelligence:Lethal Autonomous Weapons Systems (LAWS) and Peace Time Threats". Youtube. January 21, 2018. *https://www.youtube.com/watch?v=eY5JT-i1CKA*. Accessed Dec 17, 2019.

148 Van Wynsberghe, A & Comes, T. (October 2019) Drones in humanitarian contexts, robot ethics, and the human-robot interaction. Retrieved from Springer website : *https://link.springer.com/content/pdf/10.1007%2Fs10676-019-09514-1.pdf*. Accessed Jan 2 2020.

149 Regina Surber, personal communication with author, January 6, 2020

150 Van Wynsberghe, A & Comes, T. (October 2019) Drones in humanitarian contexts, robot ethics, and the human-robot interaction. Retrieved from Springer website : *https://link.springer.com/content/pdf/10.1007%2Fs10676-019-09514-1.pdf*. Accessed Jan 2 2020.

151 Ibid

attributed to humanitarian drones:

“What kind of decision you would allow a drone to take in case of search and rescue mission? (...) would the algorithm make triage decisions on who lives and who dies? ”

- Daniel Gilman

As autonomous drones are not developed by humanitarians, they don’t have the ownership nor control over this technology. The question is whether it results in humanitarians becoming the beneficiaries, the victims or the collaborators. Perhaps the best thing humanitarians can do is act as moral arbiters by shaping the discussions over legitimate and illegitimate uses of UAVs; make the case for the right partners and tools; and advocate against unethical biases. [152]

As full autonomy is reached when humans are out of the loop, creating autonomous technology means that “humans take a conscious decision to create instruments whose results they cannot control, nor bear responsibility for.” According to the researcher Regina Surber, this “reflects a particular psychological attitude: humans do not want to bear responsibility for those results.” She recommends that discussions around autonomous technology shift to their human creators to identify the core human capacities that might be de-humanized if they are re-created artificially and “evaluate to what extent we treasure what we are as a species.”

152 Daniel Gilman, interview with author, November 20, 2019

Conclusion

To what extent should AI drones be implemented in humanitarian action? While intelligent drones can bring tremendous added value to humanitarian action, the many challenges highlighted above raise the question of whether and how to apply this technology in humanitarian action.

On one hand, as natural disasters increase around the world, organizations involved in disaster response should adopt AI and drone innovations to respond in a faster and safer way. [153] The ability of drones to collect information, deliver supplies, operate in dangerous places and, one day, their ability to operate in swarm or transport someone injured are valuable capacities for emergency response. [154]

Some experts consider humanitarian action as the ideal context to apply those technologies for good because there is no one who needs the technology more than humanitarians. The privacy risks can also be lowered as humanitarian action often occurs in a context where people want to be seen. The best way to ensure that a technology works is to test it. Considering the difficulties of simulating a disaster, innovation teams should be deployed in humanitarian emergencies to experiment on new technology and identify how to make the best use of drones. Experimenting with drones should be prioritized by humanitarian agencies. [155] However, according to the director of the UN Global Pulse, Robert Kirkpatrick, "they should not be tested for life and death decisions until it is clear that this new approach is useful, credible and accurate".

But considering the ethical issues around data privacy and AI, some experts condemn the deployment of drones especially in humanitarian action. According to Daniel Gilman, "Humanitarian use of AI and of new technology should start with the humanitarian approach which is not an efficient approach."The need for human judgement and moral and legal accountability as well as the duty to protect data privacy and leverage the risk of potential mass surveillance should not be undermined by efficiency needs.

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153 Greenstein, B. "When is it not ethical to not replace humans with AI?". InformationWeek. December 12, 2019. *http://www.informationweek.com/big-data/ai-machine-learning/when-is-it-ethical-to-not-replace-humans-with-ai/a/d-id/1336661.* Accessed 17 Dec 2019

154 Robert Kirkpatrick, interview with author, December 6, 2019

155 Ibid

All the benefits of using drones and AI should be weighed against the risks. This depends on value-judgments and value-weighing which require a general and situational analysis. For example, a general analysis underlying the importance of human dignity would lead to a general proscription of autonomous drones while a contextual analysis may authorize drones in certain cases. [156]

Ethical innovation must be based on the “do no harm” principle meaning that “risk analysis and mitigation must be used to prevent unintentional harm, including from primary and secondary effects relating to privacy and data security”. [157] This is why risks must be investigated, analyzed and minimized leading to a potential rejection of the technology if it is ethically wrong. If risks are underanalyzed and therefore unknown, humanitarians should consider a general rejection of autonomous drones with potential exceptions. [158]

Without a clear picture of how drones impact humans they cannot be deployed in a morally permissible or acceptable manner. [159] According to Regina Surber, humanitarians should “adopt strong presumptions and decisions against using autonomous UAVs in humanitarian action until (a) risks are analyzed and (b) thorough ethical analyses have taken place, and in the meantime only use autonomous UAVs in situations where we are certain to run no or only minimal risks of harm.”

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156 Regina Surber, personal communication with author, January 6, 2020

157 (June 2015) Principles for Ethical Humanitarian Innovation. Retrieved from Refugee Studies Center website: *https://www.refugee-economies.org/assets/downloads/Principles_for_Ethical_Humanitarian_Innovation_-_final_paper.pdf.* Accessed Jan 9 2020.

158 Regina Surber, personal communication with author, January 6, 2020

159 Van Wynsberghe, A & Comes, T. (October 2019) Drones in humanitarian contexts, robot ethics, and the human-robot interaction. Retrieved from Springer website : *https://link.springer.com/content/pdf/10.1007%2Fs10676-019-09514-1.pdf.* Accessed Jan 2 2020.

Annex 1

List of Interviews

This report was largely informed by semi-structured interviews with experts in the AI, UAV and humanitarian fields. A heartfelt thank you to all interviewees for their time and research recommendations. The report could not have been completed without them.

Name	Title and Organization
Daniel Gilman	Humanitarian Affairs Officer, UN Office for the Coordination of Humanitarian Affairs (OCHA)
Einar Bjorgo	Satellite Analysis and Applied Research, UN Institute for Training and Research (UNITAR)
Emma Wadland	Head of Communications of IT Emergency Preparedness and Response, World Food Program
Frank de Morsier	CTO and Co-founder of Picterra
Hanno Blankenstein	CEO and Co-founder of Unleash live
Joe Sullivan	CEO and Founder of Aerial Application
Khadija Abdulla Ali	Consultant at the World Bank ; UAV pilot, Uhurulabs
Marco Codastefano	Machine Learning and Artificial Intelligence Specialist, World Food Program
Miriam McNabb	CEO, JobForDrones ; Editor in Chief, DroneLife.com
Nathaniel Raymond	Lecture at Jackson Institute for Global Affairs, Yale University ; former director of the Signal Program on Human Security and Technology, Harvard Humanitarian Initiative

Nicholas Nilan	Director of public sector product development, Verizon
Patrick Meier	Executive Director, WeRobotics; Founder of UAViators ; Author of Digital Humanitarians : How Big Data is Changing the Face of Humanitarian Response
Regina Surber	Scientific Advisor, ICT4Peace Foundation; PhD candidate at the University of Zurich, Switzerland
Robert Kirkpatrick	Director of UN Global Pulse ; Founder and co-Chair of the UN Privacy Policy Working Group
Romeo Durscher	Senior Director of Public Safety Integration, DJI
Sanjana Hattotuwa	Special Advisor, ICT4Peace Foundation; PhD candidate at the University of Otago, New Zealand
Sophia Rosa	Earth Observation Analyst, World Food Program
Tautvydas Juskauskas	Drones Lead, UNICEF Malawi

Annex 2

Drones and AI: terms and concepts

Artificial intelligence - as defined in 2018 USAID report Making AI Work for International Development[160] - "uses computers for automated decision-making that is meant to mimic human-like intelligence. (...) Automated decisions might be directly implemented (e.g. in robotics) or suggested to a human decision-maker (e.g. product recommendations in online shopping); the most important thing for our purpose is that some decision process is being automated. AI often incorporates machine learning (when using data-driven predictions to make better decisions) but doesn't have to. For shorthand, you can think of AI as 'smart automation.'" AI describes the capability of machines to perform human tasks such as reasoning, problem-solving, planning, learning, or understanding and reading human languages.

The field of artificial intelligence is very wide and complex. AI enables machines to perform various human tasks such as: speech and audio processing; capturing and using expert knowledge to provide answers to problems – for example do treatment recommendation for patients; generate content from texts; and process natural language – for example identify people/authors through text or translate language. [161]

With UAVs, the current capabilities of AI have played a significant role in the development of its robotic functions allowing drones to automatically perform physical tasks. Instead of only displaying what their cameras capture, drones, with AI software, can recognize and track objects, integrate environmental data such as winds, temperature, and map areas and integrate new tactical information.

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160 Paul, A, Jolley, C & Aubra, A. (2018) Making AI Work for International Development. Retrieved from USAID website: *https://www.usaid.gov/sites/default/files/documents/15396/AI-ML-in-Development.pdf*. Accessed 12 Nov 2019

161 (April 2019) Artificial Intelligence and International Development. Retrieved from Results For Development website: *https://observatoire-ia.ulaval.ca/app/uploads/2019/08/artificial-intelligence-development-an-introduction.pdf*. Accessed 12 Nov 2019

Machine perception is the ability of a computer system to interpret data similarly to the way humans use their senses in relation to the world. Multi-sensor equipment allow computers to accept sensory inputs similar to human vision, hearing and touch. This ultimately helps drones fly without human guidance. [162]

To enable the machine to perceive its environment, it must be equipped with vision capabilities.

Computer vision is the field exploring how computers can capitalize on data collected from digital images and videos including the task of collecting, processing and analyzing this data. Broadly speaking, computer vision is the ability for computers to see. [163]

Machine learning is a field of AI based on mathematical and statistical approaches to give computers the ability to "learn" from data, i.e. to improve their performance in solving tasks without being explicitly programmed for each task. It uses data-driven algorithms designed in such a way that they can learn and improve over time when exposed to new data. Therefore, it differs from former statistical algorithms where the machine was programmed manually and performed tasks with specific instructions. [164]

Deep Learning (DL) is a machine learning method based on artificial neural networks – computer systems interconnected in the same way as the human brain - and great amounts of data to solve problems and make predictions. [165]

Deep learning methods have been largely developed in recent years, improving many fields of AI such as computer vision, speech recognition, motion planning, and natural language processing. Specifically, the advances noted in computer vision tasks have tremendously expanded the use of UAVs in many industries.

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162 Schroth, L. “Drones and Artificial Intelligence”, Drone Industry Insights, August 28, 2018. *https://www.droneii.com/drones-and-artificial-intelligence*. Accessed 15 Nov 2019

163 Ibid.

164 Schroth, L. “Drones and Artificial Intelligence”, Drone Industry Insights, August 28, 2018. *https://www.droneii.com/drones-and-artificial-intelligence*. Accessed 15 Nov 2019

165 Schroth, L. “Drones and Artificial Intelligence”, Drone Industry Insights, August 28, 2018. *https://www.droneii.com/drones-and-artificial-intelligence*. Accessed 15 Nov 2019

When applied to computer vision, deep learning methods can result in being more effective than statistical or other machine learning algorithms in many computer vision tasks, such as image recognition. In recent years, deep learning algorithms were introduced to solve computer vision problems originally solved by classical computer vision and/or learning methods.[166] Until 2012, the object detection task, which consists of finding particular objects inside an image, did not provide good results. But the breakthroughs of deep learning have exponentially improved the performance of these models.[167] Training deep learning algorithms is a long process, and to be accurate, the machine needs to have access to a large set of images and sufficient processing power.

The improvements of algorithms, graphics cards (GPUs) and data available for the learning phase have led to the increase of deep learning tools in computer vision.[168]

Capturing the environment is at the heart of the decision-making process that makes the robot move. Thanks to deep learning methods, image classification and recognition are becoming simpler tasks enabling better motion planning.

UAVs have become essential tools for collecting visual data due to their intrinsic ability to fly over areas and their integrated visual capabilities. Leveraging AI in its computer vision activities brings an undeniable added value to the images captured by drones.

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166 Tardif, A. "Deniz Kalaslioglu, Co-Founder & CTO of Soar Robotics – Interview Series". January 2, 2020. *https://www.unite.ai/deniz-kalaslioglu-co-founder-cto-of-soar-robotics-interview-series/*. Accessed Jan 3 2020.

167 The 2012 ImageNet challenge, an annual large scale visual recognition challenge, was won by Yann LeCun using deep learning networks. The percentage of error of the winner in 2011 using classical machine learning algorithms was 26%. And in 2012, a deep learning algorithm beats everyone by a wide margin with a 16% of error. The year after, everyone started using deep learning in the challenge, the winner reached a 12% error. It is a milestone in the history of computer vision development. See "Le deep learning - Science etonnante #27" Youtube . April 8, 2016 *https://www.youtube.com/watch?v=trWrEWfhTVg*

168 Singh, R. "Deep Learning + GIS = Opportunity" Arc User, The Magazine for Esri Software Users. P. 10-12. (Summer 2019). Print

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