CONCEPT MODEL FOR DRONE SELECTION IN SPECIFIC DISASTER CONDITIONS

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KEY WORDS: Drones, Disaster Relief, Selection Criteria, Performance Mapping

ABSTRACT:

Drones come in huge variety of shapes, sizes and flight characteristics. They can fly in places where no manned aircraft flies or where a person is not desirable to be. Their ability to perform "3D" – here standing for dirty, dull and dangerous. All these properties turn them into a valuable asset into disaster responders' toolkit. In the very first moments of disaster it becomes confusing for non-experienced person to decide, which drone to be deployed first or to what task to be assigned to.

In order to perform their mission in safest and most successful way in this paper we discuss a decision-making model to aid first responders in the early stage of reaction. In particular, a performance mapping model is design as a hierarchical structure with several inputs and more than one output. Several limitations are considered as inputs. On one hand there are "external" factors briefly known a prior – disaster type (wildfire, CBRNE, flood etc.) and weather conditions (wind speed, fog, cloud cover, etc.). On other hand there is certain correlation with some "internal" characteristics such as drone type, flight performance (stall speed, turn radius, flight endurance etc.) and payload capabilities: resolution, accuracy, weight (sensor resolution, size, weight, etc.). Given this and mission type as an output from the model a specific drone and equipment is advised to the first responders.

This model can be later on introduced in disaster responders training and documentation helping them to properly utilize their drone fleet, raising preparedness and by so increasing disaster management capabilities and reaction effectiveness.

1. INTRODUCTION

Drones already prove to be of great assistance in both commercial and military application. Key role to their success is the huge variety of shapes and sizes they come. This innovation technology already disrupts societies and business models. One such application domain is disaster relief effort. Although they were open to the public relatively recently, militaries around the world have a decade history of usage. Drones have provided crucial support to counterinsurgency and counterterrorism operations over the past decade. As these operations come to a close, the Air Forces from around the world have begun to evaluate additional unmanned concepts to meet future needs. It is then no surprise that they have 1) Cutting-edge technology of flight platforms and payload sensors to evaluate; and 2) some of the most sophisticated reports and methodologies for the usability of drones. After this technology has come available to the for commercial and government use it is no surprise that drones have found their way into the first responders' toolbox.

The first step in introducing anything into a system, such as emergency disaster respond, is to acknowledge the necessity of it and to evaluate the impact onto the system. In this concept drones offer capability boost. The process includes usability reports (also use cases from the military, commercial etc.), Risk Assessment reports and reliability analysis. Adapting and developing these use cases for disaster relief effort identifies how drones can help filling this necessity. Although outside the matter of this paper, additional systems also must be evaluated (manned platforms, space or ground based solutions) next to the drones, since a better solution may be more desirable for the selected use cases under range of operational limitations. Results from such an analysis are input in an effectiveness algorithm, which outlines the specific conditions under any platform and/or configuration can be effective.

Performance evaluation and selection of a drone for a mission can be defined as the improvement of the success rate of the users – disaster responders or, on the other hand, enhances their capabilities in range of various new conditions. In this paper it is proposed a performance mapping. Results from this evaluation are then outlined logic tree. It is also a represents the relevance in usability of specific unmanned system. Further this algorithm can be expanded with results from employment of fleet of drones and their cooperative action. The result provides understanding of a drone and sensor performance based on experts opinion. (Lingel et al, 2012)

In his report on employment of drones European Emergency Number Association – EENA defines the experience of the emergency services as crucial for the proper deployment of a drones. Once the initial approval for drone operation is given, considering the following: What is the nature of the request? What is the exact reason for the drone (What explicitly will the drone provide that normal resources are unable to do)? Time to tasking and deployment? Duration of the tasking? Expected outcome? Does the drone have the capability to meet the requirements? Is it desirable to use drone? In specific relation to the various legislative instruments that would need to be complied to. (EENA, 2015)

The main users of the current analysis should be the emergency service departments making decision on 1) Acquisition on new drone platforms and payload; 2) Disaster management decision makers. As the technology matures further new roles can be employed to unmanned systems either to answer new necessities or to assist manned operations. Further studies need to be performed to help emergency responders utilize drones in safest, most reliable and cost-effective way. New mission areas can be identified and platform alternatives can be considered taking advantage of the capabilities they have or will acquire in the future and by so contributing to operations and overall campaign.

The remaining of the current paper is organized as follows: In Section 2 a brief classification on drones is proposed, comparing also some of the trade-off between different flight platforms. Description of the payload and a sensor behaviour is also proposed. Image quality between different types of sensor is commented and the required image quality level is selected. In Section 3, operational environment in terms of terrain and weather condition is discussed. In Section 4, the logic tree for drone selection proposed in this paper is described and results are summarized. Thereafter, in Section 5 having all the components reviewed conclusions are presented.

2. CLASSIFICATION OF DRONE PLATFORMS AND PAYLOAD MODELLING

2.1 Drone Platforms

There are different drones for a wide range of applications with different sizes. Drones can be classified in many ways: Use (civil vs military), Lift (fixed-wing vs multi-rotors), MTOW (maximum take-off weight), and so on. For a conceptual approach, a good way is to look at drone's performance, so it becomes easier to understand the underlying capabilities. Drones could be usefully classified based on their size and payload since those are essential features from a functional point of view (ARC, 2015):

- Hand-launched, lightweight, low payload, multi-rotor and fixed wing drones, weighing less than 25 kg and flying at altitudes under 300 m. – they can handle localized imaging and be used for mapping with light payload, very low flight endurance;
- Reconnaissance and surveillance, fixed wing drones, weighing between 25 kg. and 150 kg., and flying at altitude under 3500 m. above ground level (AGL) – they can handle wide-area imaging and be used for mapping with light payload;
- Long endurance, medium altitude, large payload drones, weighing up to 600 kg. and flying at altitudes under 6000 m. mean sea level MSL – they can handle localized imaging and be used for mapping with heavy payload;
- Heavy lift helicopter drones, often weighing more than 600 kg. Rotor wing aircrafts are characterized with the ability to take-off and land vertically and also high maneuverability;
- Long endurance, high altitude reconnaissance and surveillance drones, weighing more than 600 kg. and having approximately the same size (and similar capabilities) as traditional manned aircraft and operating above 6000 m MSL – they can be used for wide-area searches.

All those platform choices concern corresponding platform characteristics and application needs, and often considering the trade-offs between the two is necessary, as depicted in Figure 1:

Figure 1. Trade-off between platforms and applications (EENA, 2015)

2.2 Payload Sensors

While platforms dictate the drone's ability to access certain environments, its payload often determines the type of data it can collect. Remote sensors like Electro-Optical (EO) and Infrared (IR) (EO/IR) cameras can help establishing situation-awareness while communications relay payloads can be used to broadcast wireless frequencies wherever the drone travels. Other sensors are used in scanning the ground nevertheless – those are called Mapping Sensors. In the remaining of this sub-section, we briefly consider EO/IR sensors and mapping sensors.

EO/IR sensors are the workhorses of drone-based sensing technology. These sensors provide the most commonly used data collected from drone platforms:

- EO Sensors, mainly used for day operations; widely available, varying in quality of image and weight.
- IR Sensors are excellent for night operations; those sensors detect the heat signatures of various objects; this is particularly useful at night and in large, open environments.
- Dual EO/IR Sensors (combined into a dual package) can be used for both day and night operations.
- Gimbal mounting platform – in order to pinpoint a target and follow it without to be concerned of the direction of the drone flying, gimbal is required.

In selection of EO, IR, and SAR sensors resolution, focal length, etc. are mission critical, so is weight (as a matter of payload compromises), additional stabilization, However, they are not sufficient to determine image quality. To express the EO, IR, and Synthetic Aperture Radar (SAR) sensor characteristics into this paper the US National Imagery Interpretability Rating Scale (NIIRS) is used. On basis of general image quality equation, which is a regression-based predictor of image quality in terms of the NIIRS, an empirical zero-to-ten scale that describes the types of exploitation tasks an image may be expected to support. Each sensor or stack of multispectral sensors is presented by this NIIRS value as an integer number. Civilian and military tables (FAS, 1998) give threshold NIIRS requirements for detection, classification, and identification for a wide variety of fixed and mobile targets within an image. NIIRS values are considered as an input later on in the model proposed in this paper. (Menthe et al, 2014)

EO NIIRS and IR NIIRS reveal different sensor characteristics for the same value. In other words, EO scale does not deliver the same ability to detect and identify as an IR NIIRS of the same value. This however is true with all things equal, which is not the common case. IR sensor has poorer resolution, also its image parameters vary significantly in day/night cycle and when integrated it heavily dependent on ambient temperature.

Mapping sensors scan the ground and create 2D or 3D maps of the surrounding area. Much drone-based mapping is currently geo-referenced, allowing it to be easily transposed onto existing geographical information systems:

- LiDAR: capable of creating highly detailed topographical maps and 3D maps of border areas, useful in specifying maps of high precision.
- SAR: capable of providing detailed imagery of the ground day or night through cloud, fog, and smoke. When integrating it into a system, weight penalties should be considered.

Further, communication relay payloads that allow drones to act as mobile communication stations, beaming Wi-Fi Internet, cellular service, radio, and other important signals to disaster relief personnel can be considered.

Hence, given their ability to quickly reach high altitudes (and hover in place for a prolonged period – this is particularly valid for rotary-wing drone platforms), drones provide ideal stopgap solutions when communication infrastructure is unavailable. (Hristozov et al, 2017)

3. ENVIRONMENT AND DISASTER TERRAIN MODELS

Being +- type of aircraft drones will always be subject of the weather and environmental conditions. Severe weather conditions (such as high winds or icing) may ground the use of drones for indefinite period of time. Also environmental factors play a role in sensor effectiveness. Smoke from wildfire or wreckage obscure the sensors restricting their performance, while microbursts can inflict drones' flight and even pose a threat. In this subsection, we describe the particular models used in this scenario: terrain, fog, and cloud cover.

3.1 Terrain and Terrain Elevation

Terrain affects mission performance three ways

- Drone flight characteristics should be considered should respond to the obstacles – in tight areas and urban canyons drone with smaller turn radius or even hover characteristics may be applicable and
- Elevation of the 'ridgelines' may hinder the ability of the sensor to follow or to spot target being in line-of-sight. Respond is higher altitude, if possible.
- Different areas require different sensor characteristics – crops field or high plateau need lesser performance than buildings and urban sites.

All this considered, the drone is capable of maintaining the observation or not. In order to increase mission chances of success cooperation of two or more drones might be considered. Each one entering the observation area as the previous leaves, maintaining point observation from different perspective. However, such a search can be performed via a slower flying drone for more time.
Another characteristics of the terrain is with urban landscape and flying of drones. Lacher, 2012 investigates the correlation of a drone falling out of the sky and kinetic energy versus the probability of fatality. In other words, large and heavy drones are not advisable flying above populated areas.

3.2 Fog and Smoke

Atmospheric conditions can have significant impact on EO and IR performance. Although they must be modelled separately integrated EO/IR prove to step in, providing better performance. Fog density is determined by the way an ideal black body can be seen thru, in other words the attenuation of radiation in EO and IR spectrum as function of range.
To model such an event on image quality, scaling factor is used. This factor represents ratio of the transmittance through fog to the transmittance on a clear day. In other words - ratio of zero would block all emission; a ratio of one would pose no effect. This leads to a significant degradation in EO systems, but less so for IR systems, because infrared wavelengths have better penetration.

3.3 Cloud Cover and Precipitation

Cloud cover may restrict the LOS of the sensors mounted on the drone flying above and thus restricting the mission effectiveness. Overcast skies would make the mission as defined here impossible for platforms flying above the cloud ceiling. An idea of the percentage of the clouds for given period of time or in historical perspective for the region of interest can be acquired from the meteorological services. This information is then implemented as an input to the model.
If cloud cover presents an obstacle only for drones flying above, significant precipitation would hamper operations beneath – the effect rain/snow have on the image is known as "rain fading".
Certainly, more sophisticated model can be incorporated, since the drone can see thru a hole in the cloud cover. This, however, will be a matter of coincidence and it will not be considered as a possibility to maintain mission effectiveness.

3.4 Wind

Wind is weather condition concerning only the flight platform and not its payload. It limits, if not completely cuts out its performance. In high wind situation it is probably best to call drone operations out, instead of creating situation where they can pose treat to the people on ground and complicating the relief works any further.
To a point wind can be counterweighted by employing more energy loaded flight platform that can withstand it, or on the other hand with a platform that flies higher and above the wind conditions.

4. SELECTION MODEL FOR SPECIFIC DISASTER CONDITIONS

The proposed methodology shown on Figure 2 advices on selection of drone platform in the very first moments of disaster when establishing a situational awareness and starting the extract of survivors is at upmost importance. On one hand there are "external" factors impacting the flight platform and sensor selection briefly known a prior – disaster type (wildfire, CBRNE, flood etc.) and area (urban, mountain, plain). Each scenario calls for specific concept of operations – urban area disaster may need platforms with greater manoeuvrability. Wind speed handicaps the drone performance and flight endurance, inflicting the mission duration and swipe radius. Also weather conditions described as employing "noise" into the sensor performance – fog, cloud cover, etc. In such conditions is advised the use of more sophisticated sensors with more than one spectrum of interception (EO/IR, multispectral cameras etc.).
On other hand there is certain correlation with some "internal" characteristics such as drone type, flight performance (stall speed, turn radius, flight endurance etc.) and payload capabilities: resolution, accuracy, weight (sensor resolution, size, weight, etc.). This makes it complex to recreate a full environment conditions without expensive computer simulation. As an example to this statement can be given the gimbal, which accuracy can degrade the whole system performance if not enough.

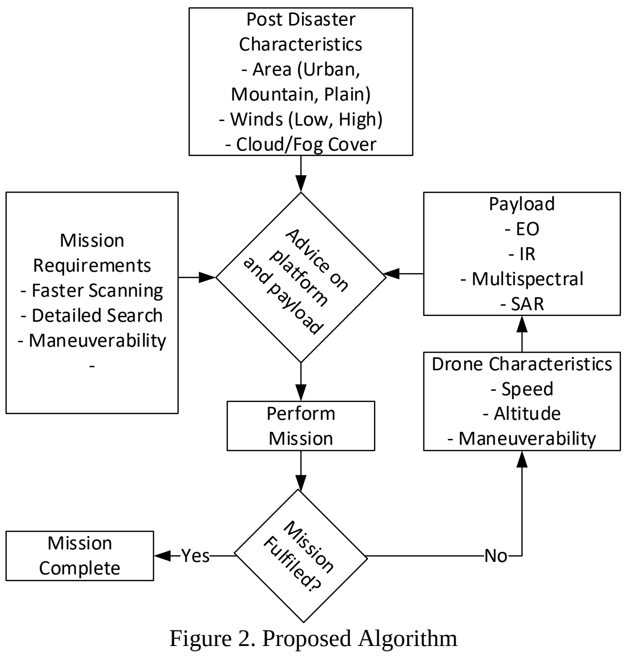

Figure 2. Proposed Algorithm

Therefore, it is proposed a simpler model given only basic drone and sensor characteristics and the requirement for successful mission. As an output from the model a specific drone and equipment is advised to the first responders. This advice is based on previous available information that may result from measures, historical analysis, subjective testimonies, possibly conflicting, and assessments done by the experts themselves. (Zlateva et al. 2016)

Drone Type	Mass	Altitude	Payload
Flying Wing	25kg	300m	EO
RotorWing	25-150kg	3000m	IR
	Above 150kg	Above 3000m	EO/IR

Table 1. Drone Characteristics

Two main types of drones are considered – fixed and rotor wing in terms of speed and agility or manoeuvrability respectively. Afterwards the selection process follows the mass as criteria for wind resistance and the ability of the platform to reach higher operational altitudes and to carry more sophisticated payload for extended duration of time. The next characteristic is type payload to answer the weather conditions – both EO or IR camera and multispectral camera. Required image quality (NIIRS) is not introduced in this model, although the necessity of it is discussed in the paper.

Area	Weather		Mission Requirements	
	Visibility	Wind		
Urban	Clear	Low	Viewing angle	Speed
Mountain	Fog	Middle	Accuracy	Manoeuvrability
Plain	Clouds	High		

Table 2. Mission Characteristics

Defining the specific request for the selection starts with the operational area, where the drone will be employed – urban (operation of larger drones is not advisable), mountain (both characterised with high ridgelines, requiring higher operational altitudes) and plain, where most of the previously mentioned limitations are not applicable. Wind and weather effects are described as follows: three wind speeds – low, middle and high and three weather events – clear, fog, clods. The process continues with mission specific requirement such as higher viewing angle or more accuracy and drone speed versus manoeuvrability. Even though the fog and cloud cover are described above as percentage of cover, here they are discrete – either it is there or not.

Since it is extremely simplified model some failure scenarios are not considered – command and control link or navigation signal degradation. In all these models, drones have sufficient communications and processing, exploitation, and dissemination capacity. This shifts the focus to overall performance characteristics. This is not the case in reality. These constraints can be quite significant, and the issue requires further attention.

The focus is then shifted on the broader trade-offs between platform size (weight) sensor performance; and the disturbance effects wind, fog, and cloud cover. They, however, also inherently limit the applicability of our findings regarding these trade-offs.

4.1 Commenting Results

Specialists are then asked to map the operational conditions and requirements for the mission at stake, namely preliminary sweep and secondary sweep – each of which expects a compromise between larger viewing angle or more accuracy and faster search with more speed or manoeuvrability (Table 2); with the drone and payload characteristics from Table 1.

To gain an overview what the logic tree looked like it is presented in Table 3. Resutls must be understood as: first letter F stands for Fixed Wing; R for Rotor Wing; followed by the number from 1 to 3 pointing to the mass and altitude from Table 1; and the last letters cohere to the installed payload. N/A – Not applicable answer is given when there is no adequate solution to the task.

Several things stand out from the quiz answers:

- Experts would rather not use heavier drones in cities, probably dictated from good practices, no such observation can be done for mountainous area;
- If possible (no wind) in cloud cover conditions drones flying below it will be employed for any area, despite the ability to be armed with multispectral camera;
- If possible all experts would install multispectral camera to perform their mission, even though in clear day it would proof useless. Not the best practice, however, yet probably drone operators prefer to back themselves up;
- When choosing between speed and manoeuvrability usually the selections is between fixed and rotor wing respectively;
- Even tough cost-effectiveness criteria were not introduced, if we can say that the heavier, flying higher drone is more expensive (both to acquire and to operate), experts tend to prefer smaller machines, when possible;
- Most of the operators would avoid flying in fog;
- When most limitations are clear – no wind, fog or clouds, no terrain thread, experts would go with the whole available fleet as long as each operator doesn't disturb the work of the others.

Weather		Mission Requirements		Drone Type
Visibility	Wind	View Angle/Accuracy	Speed/Manoeuvrability	
Clear	Low	Scope	Speed	F2EO
			Manoeuvrability	R2EO
		Accuracy	Speed	F1EO
			Manoeuvrability	R1EO
	Middle	Scope	Speed	F2EO
			Manoeuvrability	R2EO
		Accuracy	Speed	N/A
			Manoeuvrability	R2EO
	High	Scope	Speed	N/A
			Manoeuvrability	N/A
		Accuracy	Speed	N/A
			Manoeuvrability	N/A
Fog	Low	Scope	Speed	F2IR
			Manoeuvrability	R2IR
		Accuracy	Speed	F1IR
			Manoeuvrability	R1IR
	Middle	Scope	Speed	F2IR
			Manoeuvrability	R2IR
		Accuracy	Speed	N/A
			Manoeuvrability	R2IR
	High	Scope	Speed	F3IR
			Manoeuvrability	R3IR

https://doi.org/10.5194/isprs-archives-XLII-3-W4-245-2018 | © Authors 2018. CC BY 4.0 License.

		Accuracy	Speed	N/A
			Manoeuvrability	R2IR
Cloud	Low	Scope	Speed	F2EO/IR
			Manoeuvrability	R2EO/IR
		Accuracy	Speed	N/A
			Manoeuvrability	N/A
	Middle	Scope	Speed	F2EO/IR
			Manoeuvrability	R2EO/IR
		Accuracy	Speed	N/A
			Manoeuvrability	N/A
	High	Scope	Speed	F3EO/IR
			Manoeuvrability	R3EO/IR
		Accuracy	Speed	N/A
			Manoeuvrability	R2EO/IR

Table 3. Results shown for Urban Area as most restrictive for drone usage

5. CONCLUSION

Some important, basic considerations in drone employment in disaster relief effort are illuminated in this paper. Although, statistically some platforms had to be preferred, the common opinion is that more than one can do the job. When possible experts on tactical and operational level would employ smaller drone (up to 150kg) instead to request larger strategic level platform (above 150kg).

A contribution of the current work is that it provides a basic modelling basis for reasoning about values and experts opinion and makes such a reasoning explicit particularly featuring disaster relief.

Only single flying platform was considered in this paper. Numbers can boost additionally the capability. Two or three smaller less-capable drones may to equal or exceed the performance of the larger drone employed singly.

Although cost-effectiveness analysis was not introduced, upgrading the sensors to multispectral cameras would permit greater operational flexibility and would offer enhanced operational effectiveness for disaster operations scenario.

A serious limitation to this work is that no explicit simulation solutions that assume weaving in compromises between platform and sensor employment and disaster conditions is being proposed. This challenge will inspire our further research activities. The proposed model needs additional work. In order to follow the weather conditions more accurately and the expert opinions on performance a fuzzy logic model can be introduced.

ACKNOWLEDGEMENTS

This work was supported by the Bulgarian Academy of Sciences (“Supporting Young Scientists” Program 2017).

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