LITERATURE REVIEW OF THE APPLICATIONS OF UAVS IN HUMANITARIAN RELIEF

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The use of Unmanned Aerial Vehicles (UAVs) to support humanitarian actions has grown since 2001, after the terrorist attack of 9/11. UAVs are valuable tools due to their flexibility, safety, ease of operation, and relatively low-cost for the owner and the operation, which facilitates the using in disaster situations. This paper provides a systematic literature review on the applications of UAVs in humanitarian relief which aims to analyze the main characteristics of publications on the subject and discuss trends for future research directions. The main applications are intended to map affected areas after a disaster, analyze the images collected, coordinate UAV's networks, detect disasters through chemical sensors, and integrate UAVs with other vehicles to improve the speed and quality of information's transmission. The paper also contributes with a discussion on the opportunities that are opened up and the challenges that need to be addressed.

Palavras-chave: UAV, drone, humanitarian relief, disaster

1. Introduction

One of the most significant difficulties facing United Nations (UN) Agencies and Non-Governmental Organizations (NGOs) when responding to rapid onset disasters, like floods, earthquakes and hurricanes, is to understand the requirements of the affected population accurately and swiftly. Current direct assessment methods are time consuming and the data captured is often not conducted in a systematic way with the locations sampled not being geographically representative (too clustered and too few), and the subsequent reports being produced too late (TATHAM, 2009).

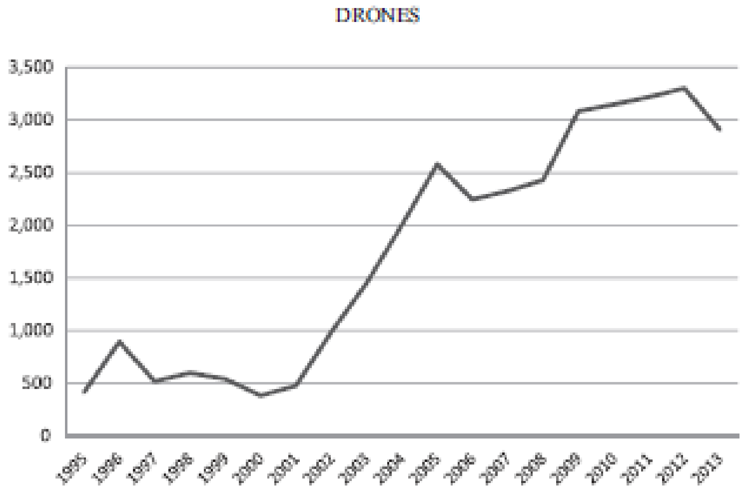
Unmanned Aerial Vehicles (UAVs), or drones, have being used in humanitarian response since 2001, after the terrorist attack of 9/11. An unprecedented number of small and lightweight UAVs were launched in the Philippines after Typhoon Haiyan in 2013, in Haiti following Hurricane Sandy in 2012 and, more recently, they were flown in response to the massive flooding in the Balkans and after the earthquake in China (MEIER, 2014).

UAV refers to a class of aircrafts that can fly without the onboard presence of pilot. They can be flown by an electronic equipment adapted to the vehicle and on a GCS (Ground Control Station), or directly from the ground. In this last case, it is common to associate the system with the expression RPV (Remotely Piloted Vehicle), since the vehicle is remotely piloted and operated by radio-controlled devices. In the literature other terms also indicate such category of vehicles, such as: Drone, ROA (Remotely Operated Aircraft), UVS (Unmanned Vehicle System) and UAS (Unmanned Aerial System) (BENDEA *et al.*, 2008).

According to Hall and Coyne (2014), world governments spent more than \$6.6 billion on “drone” technology in 2012. This number is expected to increase to \$11.4 billion a year over the next decade for a worldwide UAV market worth more than \$89 billion.

The increased demand for drone technology following the Gulf conflict was augmented substantially by the post-9/11 conflicts, in Afghanistan and Iraq. These conflicts, coupled with the broader Global War on Terror, created an opening for the expanded use of drones on an unprecedented scale. Figure 1 shows the Department of Defense spending on UAS (HALL; COYNE, 2014).

Figure 1 - DOD spending on UAS: 1995–2013 (in million US$)



Source: Hall and Coyne (2014)

The UAV view from above is central for humanitarian response as they can capture aerial imagery at a far higher resolution, more quickly and at much lower cost than the satellite imagery. Unlike satellites, members of the public can actually own UAV, which means that disaster-affected communities can respond to a crisis (MEIER, 2014).

Liu *et al.* (2014) give an overview of the state of UAV developments and their possible applications in civil engineering, like seismic risk assessment, transportation, and disaster response. Roahcs *et al*. (2006) also summarize the civilian application of the UAVs with focusing on their application in emergency management. Ezequiel *et al.* (2014) present various applications of UAV aerial imagery, in the post-disaster assessment and recovery, in the Philippines. Camara (2015) discuss some possible applications of drones over disaster scenarios. Zhang and Wu (2014) study UAVs application in the field of disaster prevention and mitigation, search and rescue operations, land resources monitoring, and forest fire prevention. Zheng *et al*. (2013) analyze methods of accessing and processing digital image data in mountainous area and its application to emergency response management of geological hazard.

On the previous review papers, the authors did not present the research methodology neither the statistical results about the considered papers. Given the growth trend of works published in this field, it is important to expose the research methodology used in the literature review to allow other authors to update the review in the future. This research presents a systematic literature review about the applications of UAVs in humanitarian relief with the purpose of helping researchers to understand what can still be explored in this area. This paper aims to identify trends and suggest directions for future research.

The remainder of this text is organized as follows. Section 2 presents the Humanitarian Logistics definitions. Next, the research methodology used to categorize the previous works is presented in Section 3. Trends and challenges are discussed in Section 4. The concluding remarks are given in Section 5.

2. Defining humanitarian logistics

According to the International Federation of the Red Cross and Red Crescent Societies (IFRC), disasters can be defined as sudden, calamitous events which disrupt the activities of a society or a community and cause human, material, economic, or environmental losses that exceed the recovery capacity of the affected community or society using only its own resources (NATARAJARATHINAM *et al*., 2009).

Van Wassenhove (2006) proposed a classification of natural and man-made disasters according to the speed with which the disaster strikes: slow-onset or sudden-onset. Famine, drought, political, and refugee crises are examples of the former category, whereas the latter includes, for example, earthquakes, hurricanes, technological failures, and terrorist attacks.

There are four primary stages of a disaster: mitigation, preparedness, response, and recovery. Mitigation is assessing possible sources of crisis and identifying sets of activities to reduce and/or eliminate those sources so that crisis never happens or its impact is reduced. Preparedness is developing a crisis response plan and training all the involved parties so that in the case of a crisis people know their roles and will effectively be able to deal with it. Response constitutes the set of immediate actions taken after a crisis occurs, and it aims to reduce the impact by utilizing the plans created during the preparedness stage. Recovery is the final set of activities in which the objective is to support all involved parties until they resume their normal operations (NATARAJARATHINAM *et al*., 2009).

Humanitarian logistics is the processes and systems involved in mobilizing people, resources, skills and knowledge to help vulnerable people affected by disaster (VAN WASSENHOVE, 2006).

3. Research methodology

The research methodology adopted in this research consists of four steps:

a) Select databases: Scopus, Web of Science, ProQuest, Scielo International, Emerald and Science Direct;
b) Filter the databases with terms "UAV OR Drone" and "Humanitarian OR Disaster OR Relief OR Emergency OR Crisis" in their topic, title, abstract or keywords. There are others synonyms for UAVs but they were not considered due to the fact that the only 6 papers found with these keywords were not relevant. Time restriction filters were not used;
c) Read the abstract to confirm the relevance of the papers;
d) Categorize papers as:
    - Type of disaster (VAN WASSENHOVE, 2006);
    - Phase of the disaster in which the application of UAV was used (NATARAJARATHINAM *et al*., 2009);
    - Year of publication;
    - Approach – it can be a theorical application or a practical case study;
    - Purpose of the applications:
        - 3D Mapping;
        - Mapping of Affected Areas;
        - Image Analysis;
        - UAV’s Network;
        - UAV’s with Sensor in Detection Operations;
        - Cooperation between UAV’s and others vehicles;
        - Review Papers;
        - Route Planning Algorithm;
        - Optimization Problem;
        - Security;
        - Medical Surgery.

The categorization approach, year of publication and purpose are suggested by the author of this paper. The purpose categorization was created based on the author's experience over the reading of the relevant papers and each paper was categorized in only one type of purpose.

Results

After applying the methodology above, 117 relevant papers were found (see https://www.sendspace.com/file/zbjdm2 for the complete reference list). Conference proceedings address 77% of the relevant papers and journals represent 23% of them. The 26 papers from journals were published each one in a different journal.

With the categorizations proposed, some statistic information about the application of UAVs in humanitarian relief is presented.

Type of disaster

Table 1 shows the papers categorized by origin and speed of disaster.

Table 1 - Papers categorized by origin and speed of disaster

	Sudden-onset	Slow-onset	ND	Total
Natural	62	0	8	**70**
Man-made	3	5	1	**9**
ND	18	0	20	**38**
Total	**83**	**5**	**29**	

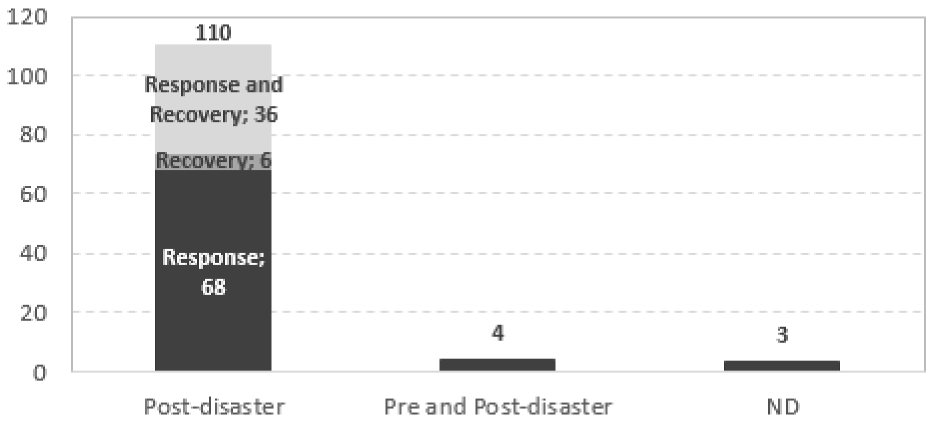
Source: Author

Only 4,3% of the papers address slow-onset disasters, where the use of UAV's occurs mostly in the military context, such as demining of battlefields (Kruijff *et al*., 2013). 7,7% of the papers address man-made disasters, such as hazardous chemicals (Wang *et al*., 2013), atmospheric environmental emergency (Xie *et al*., 2013) and battlefield's demining (Moussally and Breiter, 2004). The natural sudden-onset disasters account for 53% of the papers, where the use of UAV's consists mostly in the mapping of affected areas. 40% of the papers were not classified (ND), in both classes (origin and speed). 10% are review papers.

Phase of disaster

Figure 2 shows the papers categorized by phase of disaster. There were some papers where UAV application occurs in the response and/or recovery phases.

Figure 2 - Papers categorized by phase of disaster



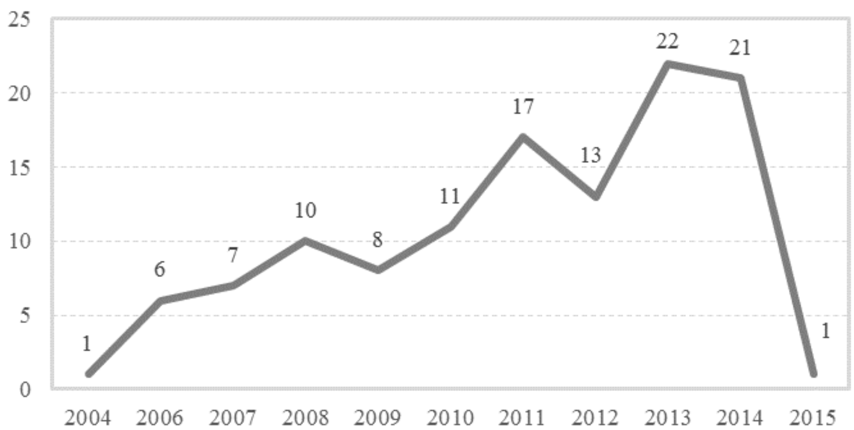
Source: Author

Four papers consider pre and post disaster phase and 3 papers are Not Defined. Figure 2 shows that 94% of papers focused on post disaster phase. It can be concluded that research on the post-disaster stages, such as response and recovery, is more widespread than research on the pre-disaster stages, such as mitigation and response. As the number of disaster is still increasing, it indicates that there is a need for research on UAV applications on the pre-disaster phases.

Year of publications

It is important to reinforce that 73% of the papers were written after 2009 (last 5 years), as presented in Figure 3, which means that the literature review reflects recent applications of UAVs.

Figure 3 - Papers categorized by year of publication

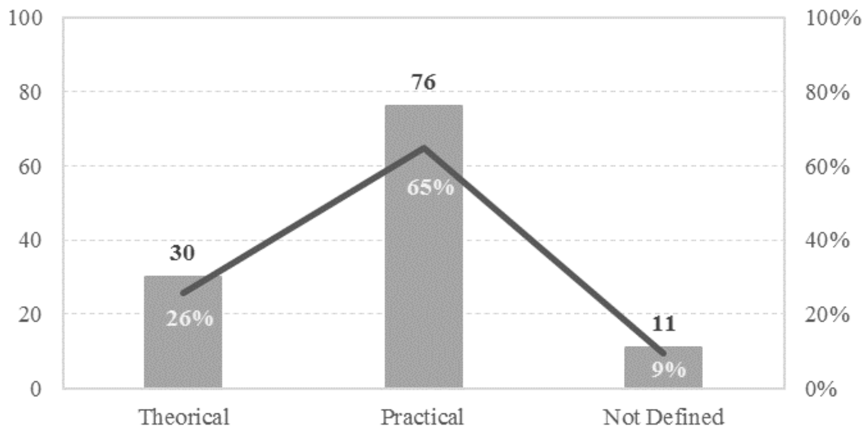


Source: Author

Approach

In the Figure 4, it is possible to see that 65% of the papers showed a case study, which means that UAV's were actually used to evaluate the methodologies, algorithms and models proposed. This finding represent that UAV use in humanitarian logistics can already be seen as a highly feasible possibility, besides being an efficient and effective implementation

Figure 4 - Papers categorized by approach

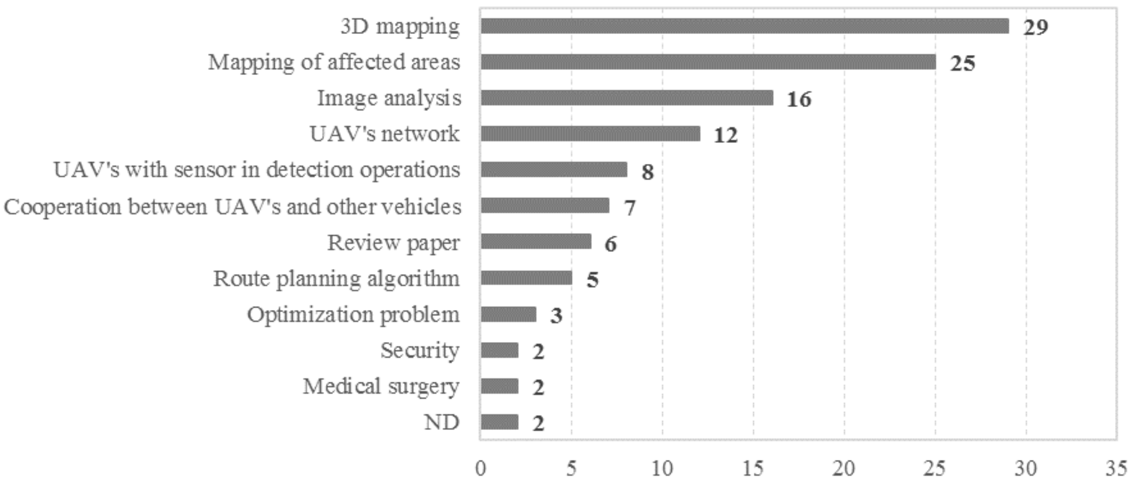


Source: Author

Purpose of the applications

Figure 5 shows the papers categorized by the purpose of the application.

Figure 5 - Papers categorized by purpose of the application



Source: Author

From Figure 5, it can be concluded that 60% of the papers address the first three classes: 3D mapping, mapping of affected areas and image analysis, which are very related topics. This relation is because the main objective of early impact analysis after a disaster is to define the damages of infrastructure and/or to facilities, and that requires suitable data, such as high-resolution satellite images. The 3D mapping and the image analysis provide more clear views of the affected areas as input data for early impact analysis in medium and large-scale map.

Nex and Remondino (2014) report the state of the art of UAV for geomatics applications (3D mapping), giving an overview of different UAV platforms, applications, and case studies, showing also the latest developments of UAV image processing.

Xu *et al.* (2014) present an example of UAS developed for rapidly obtaining disaster information mapping affected areas. Tests showed that the system plays an important role in the work of investigating and gathering information about disaster in epicentral areas of the Lushan Earthquake, Sichuan, China, such as road detection, secondary disaster investigation, and rapid disaster evaluation.

Tatham (2009) use a case study of the 2005 Pakistan earthquake to illustrate how a UAV might be employed and its potential effectiveness.

Patterson *et al.* (2014) present novel work on autonomously identifying Safe Landing Zones (SLZs) through image analysis which can be utilized upon occurrence of a safety critical event.

Delle Fave *et al.* (2012) present a case study whereby it is applied the max-sum algorithm to coordinate a team of UAVs to provide live aerial imagery to the first responders operating in the area of a disaster.

Regarding UAV’s with sensor in detection operations, Xie *et al.* (2013) present a design framework of the UAV platform based atmospheric environmental emergency monitoring system with regard to the components, functions and procedures. The application of UAV’s in atmospheric environment emergency monitoring system has been one of the important future developmental directions.

Lindemuth *et al.* (2011) describe a novel marsupial (one robot deploys another robot) unmanned surface-aerial team for littoral environments as an alternative to a solo UAV or unmanned underwater vehicle (UUV). By itself, a UAV can provide above the waterline sensing but cannot provide details below the surface.

Artemenko *et al.* (2014) develop an UAV that moves around buildings and localizes “survived” devices inside a building. This can help to detect victims and to accelerate the rescue process – in which fast and accurate localization is essential. A LMAT (Localization algorithm with a Mobile Anchor node based on Trilateration) path planning algorithm is being validated using simulations and evaluated in experiments using a real UAV.

Quaritsch *et al.* (2010) deploy an aerial sensor network with small-scale, battery-powered and wirelessly connected UAVs carrying cameras for disaster management applications. The UAVs fly in formations and cooperate to achieve a certain mission. This paper focus on the optimal placement of sensors formulating the coverage problem as integer linear program (ILP).

UAVs must be reliable and have the ability to take appropriate action when some functionality is lost due to failure. Brazenaite *et al*. (2010) present a reconfiguration process, which is based on optimizing the mission reliability under its current conditions and environment. This is demonstrated using a UAV carrying out a search and rescue operation.

Harnett *et al.* (2008) demonstrate an experimental surgical robot using an UAV as a network topology. For the first time, a mobile surgical robotic system was deployed to an austere environment and surgeons were able to remotely operate the systems wirelessly using a UAV.

4. Discussion

The applications discussed in this paper have shown that UAV aerial imagery provides domain experts and decision makers essential data for analysis and effective action.

Earth observation can significantly contribute to improving efforts in developing proper disaster mitigation strategies, and providing relevant agencies with very important information for alleviating impacts of a disaster and relief management. However, technical and financial issues have challenged the traditional use of satellite and aerial images for this task (TATHAM, 2009).

According to Meier (2014), very small and lightweight UAVs are already being used in disaster response, currently to capture high-resolution imagery, but soon for micro-transportation too. Google has already built and tested autonomous aerial vehicles, and believes they could be used for goods deliveries. They could be used after earthquakes, floods, or extreme weather events, the company suggested, to take small items such as medicines or batteries to people in areas that conventional vehicles cannot reach (STEWART, 2014).

In the military context, armed UAVs pose ethical issues not only with respect to their use in armed conflict, but also concerning the prevention of war. In order to prevent dangers for arms control, international humanitarian law, for military stability as well as for society, armed UAVs should be limited (ALTMANN, 2013).

From social acceptance perspective, it is extremely important that concerns of privacy are addressed appropriately. Public concerns of insufficient safeguards to ensure that UAVs are not used to spy on citizens and unduly infringe upon their fundamental privacy, need to be thoughtfully addressed before allowing UAVs to fly in the national airspace. The guiding principles for Federal Aviation Administration (FAA) policies include mainly the safety of people in the air and on the ground (NAMADURI *et al*., 2013).

Another challenge that needs to be considered, for practical applications, is related to the access of airspace. According to Namuduri *et al*. (2013), after Hurricane Katrina, Joint Terminal Air Controller (JTAC), located in New Orleans, deployed their Evolution Tactical UAVs. Their attempts to use these UAVs were restricted due to FAA regulations on accessing airspace. The workaround was to attach small Evolution UAV to the bottom of a UH-60 helicopter. In response to the growing demand for civilian use of UAVs, FAA has been rigorously pursuing policies for safe and secure use of UAVs in the national airspace.

Given that the cost of building and operating a UAVs is reducing whilst its operational capabilities are increasing, it would seem likely (if not inevitable) that UAVs would perform an useful and cost-effective function within the overall post-disaster needs assessment process and, thereby, assist in the mitigation of the risk in the response to such disasters (TATHAM, 2009).

Innovations in UAVs become valuable tools in capturing and assessing the extents and amount of damages (XU *et al*., 2014). Their UAS is becoming increasingly popular for civilian use due to their relatively low cost, ease of operation and the emergence of low cost navigation and imaging sensors, with performances comparable to higher priced sensors. The operational nature and cost factors make this technology applicable to build a low cost mapping system (TATHAM, 2009).

This increasing use of UAVs for humanitarian purposes explains why the United Nations (UN) recently published an official policy brief on the topic. A number of UN groups like the Office for the Coordination of Humanitarian Affairs (OCHA) are actively exploring the use of UAVs for disaster response. These organizations have also joined the Humanitarian UAV Network (UAViators, 2014) to promote the safe and responsible use of UAVs in humanitarian settings (MEIER, 2014).

5. Conclusion

This paper presented a systematic literature review about the applications of UAVs in humanitarian relief and showed an increase in the number of publications on the subject over the past ten years. Although humanitarian relief is a recent and growing area, it should be noted that only one author of this area is studying the use of drones in emergency situations (Tatham, 2009). The most part of contributions in this area, which comes from robotic and mechanical engineering, are to improve the equipment’s performance. In this paper, 117 papers were surveyed, classified, and some gaps were identified, allowing suggestions for future research. The conclusions are the need for more studies about mitigation and preparedness and the small number of papers on man-made and slow-onset disasters. It should be noted that UAV is a promising technology, which continues to be technically developed, that have positive impact in humanitarian settings and is already been used by universities and private organizations, such as Google, to test and improve their methodologies, algorithms and models.

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