Low Cost Aerial Mapping Alternatives for Natural Disasters in the Caribbean

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SUMMARY

The Caribbean region is vulnerable to natural disasters as reflected by the frequent exposure to flooding, hurricanes, and earthquakes. The ability of Caribbean island-states to react effectively to such natural events is particularly low due to their small economies and geographic size. This, in turn, impacts negatively on the accessibility to current and accurate spatial information that is critical for the effective response to a crisis by the relevant agencies.

Innovations in aerial photogrammetry have allowed it to become a valuable tool in capturing and assessing the extents and amount of damages due to a natural disaster. However, due to the high cost of metric cameras and aircraft for mapping, it is imperative to examine other alternative systems affordable for the small island developing states. For small area coverage, such a system would have the other advantages of being more flexible, rapid, efficient, and weather independent when compared to standard airborne aerial surveys.

This paper presents an overview and assessment of the technology relevant to low cost cameras and platforms to acquire aerial photographs. Considering the cost factors and the operational nature in the tropical small developing islands of the Caribbean, the paper recommends adopting unmanned aerial vehicles (UAV) as they represent a viable alternative solution over other mapping systems for disaster mapping and management activities. Finally, the paper presents certain criteria for considering a suitable system.

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1. INTRODUCTION

The Caribbean is situated to the south east of North America, east of Central America and north of South America. The region primarily consists of an arc of islands stretching from the Bahamas and Cuba off the southeast tip of Florida in the north to Trinidad just off the coast of Venezuela in the south. The islands form an extensive archipelago which separates the Caribbean Sea from the Atlantic Ocean and spans a large geographical area (Figure 1).

The climate of the region is tropical but rainfall varies with elevation, size and water currents. Warm, moist trade winds blow consistently from the east creating rainforest/semi-desert divisions on mountainous islands. The seasonal patterns consist of 'dry' and 'wet' seasons, with the last six months of the year being wetter than the first half. The topography for the islands ranges from generally flat terrain of non-volcanic origin to rugged volcanic landscapes (with mountain-ranges).

Figure 1. Map of the Caribbean region

These small island developing states (SIDS) are characterized by their unique biodiversity and highly fragile ecosystems and are highly dependent on their marine and coastal resources. Development on these small islands is mostly challenged by their limited physical capacity and financial constraints which make them susceptible to disasters and external impacts (UNDP 2002).

1.1 Regional Vulnerability

The region's geographic location along the subduction zone of the Caribbean and South America plates as well as the Atlantic hurricane belt predisposes it to several natural disasters. The Caribbean is commonly affected by the natural events of hurricanes, floods, landslides, droughts, earthquakes, volcanic eruptions, and forest fires that result in damages and disasters. Its vulnerability is reflected by the recent exposure to frequent natural disasters along with the historic occurrence of hurricanes, volcanoes and earthquakes (Bisek et al. 2001).

Countries in the region are similar to the rest of the developing countries in being disproportionately affected by disasters. Economic losses attributable to natural hazards in developing countries are about 5 times higher per unit of gross domestic product than those of more affluent countries. Furthermore, developing countries accounted for over 50% of all disaster fatalities that occurred in the period 1992 - 2001, which translates into approximately 13 times more fatalities per reported disaster than in developed countries (Van Westen 2002).

The low-lying states in the Caribbean are more vulnerable to disasters due to their small land masses, human activities (intensive land development and high population density in coastal zones, and poorly developed coastal infrastructure), and socio-economic dependence on coastal zone activities. At the same time, the ability of the Caribbean states to adequately respond to natural disasters is particularly low due to their small economies, geographic size and limited technological resources, all of which contribute to their low adaptive capacities (Specter and Gayle 1990).

Natural and human-induced disasters have cost the region billions of dollars in damage and loss over the past two decades and have challenged the economic and physical development of Caribbean states. It is reported that 11.9 million persons had been affected by natural disasters in the region in the period 2000-2009. For that same period, 7,761 deaths were recorded and damage estimate exceeded US$17,223.5 million (EM-DAT 2011).

1.2 Geoinformatics to Address the Needs

Given the severe negative impacts of disasters on the social and economic sustainability of the region there is a dire need to introduce proper management measures to ensure that vulnerable areas are protected and disaster impact is minimized. Improving the capabilities to mitigate and respond to disasters would require better understanding and mapping of the hazards, as well as identifying the nature and extent of vulnerability of the areas under consideration.

To enhance the planning and execution of tasks in disaster management a wide range of factors must be utilized, most of which are of a spatial nature. However, there is a severe shortage of reliable and compatible spatial datasets in the whole Caribbean region. Information needed for accurate planning is often outdated, non-existent, or very expensive and time consuming to collect (Al-Tahir et al. 2006). Without such information, the investigation of disaster susceptibility and the formation of proper national planning policies in many Caribbean island states would be both difficult and error prone.

A way forward to effectively fill the information void is to use geoinformatics technologies that have emerged as powerful tools in the prevention, preparedness and relief management of disasters. Modern geospatial technologies, especially in the disciplines of photogrammetry, remote sensing, and spatial information science, can assist in crisis management through observation, mapping, and analysing relevant information in each of the critical disaster management phases (Altan and Kemper 2010). Geospatial data and tools have a key role in saving lives, limiting the damage, and reducing the costs to society of dealing with emergencies. Further, they are essential for the development of management scenarios to evaluate mitigation strategies.

Innovations in remotely sensed and photogrammetric imagery data and their applications have allowed them to become key tools in assessing the vulnerability of urban areas and capturing the distribution of natural disaster imposed damages (Shinozuka and Rejaie 2000; Yamazaki 2001). Remote sensing efficiently allows the acquisition of repetitive, non-intrusive, and synoptic data quickly and at comparatively low cost. Consequently, satellite remote sensing data have the potential to guarantee data currency, sufficient accuracy, and uniform and comprehensive coverage (Al-Tahir and Ali, 2004).

1.3 Constraints and Alternatives for Geo-Data Acquisition

In the Caribbean, geospatial technology has not been meaningfully utilized in disaster management because of technical and financial issues. One of the critical obstacles that have impinged on the transfer of geospatial technology to the region is the number of trained experts. Without experienced personnel, the ability to implement projects using this technology is significantly curtailed. Economic constraints also form a major obstacle since they can affect the availability of experienced personnel, hardware, software and necessary data (Specter and Gayle 1990; Al-Tahir et al. 2006). As such, and considering their sizes, none of the individual Caribbean states possess the indigenous capacity and means for acquiring aerial photography.

A persistent cloud cover adds another hindrance specific to tropical environments such as the Caribbean region. It poses a major challenge to the use of optical wavelength satellite images despite their worldwide successful use for mapping and monitoring disasters (Al-Tahir and Ali 2004). In addition to directly obscuring the surface beneath them, clouds also cast their shadows on the ground, hence indirectly contributing to further masking surface information. These areas of obstruction represent information gaps and loss of valuable data. One expects that this problem would be compounded when changes on the ground need to be assessed using images from two different dates.

Another challenge specific to natural disaster mapping and management is the need for delivering on short notice critical information on the location of affected areas and the scale of the damage, as well as guiding the rescue services and relief efforts. Most of this information would be required urgently in a hostile weather conditions, such as hurricanes, though typically for areas of limited extents.

As an alternative to traditional satellite imagery and photogrammetry, this paper argues for using unmanned aerial vehicles (UAV) to collect geo-data that will satisfy the needs for the pre- and post- disaster mapping of natural disasters. UAVs are mostly low cost systems and flexible and therefore a suitable alternative solution compared to other mapping systems (Eisenbeiß 2004). This study will be evaluating the options with the aim to adapt and use the most appropriate and practical choices for the region. The decision on the use of a specific sensor and platform must be researched with a focus on maintaining a low cost system while still achieving suitable accuracies and response speeds.

2. UNMANNED AERIAL VEHICLES

2.1 Introduction

The term unmanned aerial vehicle refers to an aircraft without an on-board human pilot. UAVs can be remote controlled aircraft (e.g. flown by a pilot at a ground station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems.

Unmanned Aerial Vehicles have seen unprecedented levels of growth in military and civilian application domains (Valavanis 2007). In the last five years only, the total quantity of UAVs has more than doubled, and so is the quantity of producers and developers. In the same period, the number of civilian applications has increased three folds, while research applications grew two folds (UAV International 2010). The increased demand for UAVs is typically attributed to the low manufacturing and operational costs, flexibility of the platforms to accommodate the consumer's particular needs and the elimination of the risk to pilots' lives in difficult missions (Sarris 2001).

The continuous trend in the miniaturisation of electronics enables the production of smaller UAVs while simultaneously equipping them with cameras and other sensors to support aerial geo-data collection (Lemmens 2011). With low cost, small, and lightweight integrated GNSS and inertial navigation systems, UAVs can be navigated with decimetre accuracy and the acquired orientation parameters can reduce the number of ground control points needed for post-processing (Eisenbeiß 2004).

2.2 UAVs' Mapping Applications

Unmanned vehicles are being increasingly used for several areas of civilian and industrial applications and have the potential to be used in many more (Sarris 2001; Skaloud et al. 2006; Valavanis 2007). UAVs can take a cost effective role in homeland security in the tasks of surveillance, border patrol, and law enforcement. They are also being used in industrial and agricultural applications (such as crops spraying), facility management and construction (e.g, open-pit mines, powerlines, and transportation infrastructure).

UAVs are also of advantage to geoinformatics applications, such as cartography, corridor mapping, hydrologic monitoring, urban planning, fly-through, and archaeological mapping. Additionally, UAVs equipped with the appropriate payloads would have a tremendous impact on measuring parameters required for scientific researches of any nature (environmental, near-shore and marine, atmospheric, pollution etc) as they provide access to phenomena of interest far closer than previously possible. However, in most of such cases, the objects of interest are typically spread over a small area or narrow corridors (Skaloud et al. 2006).

As relevant to disaster and emergency management, unmanned aircraft are uniquely capable of penetrating areas which may be too dangerous for piloted craft such as the hurricane regions and volcano areas. UAV platforms with cameras can provide real time mapping and monitoring in other hazardous situations such as earthquakes, landslides, erosion, mud flows, floods, and fire detection, as well as real-time link for the search and rescue operations.

2.3 Categorization of UAV Systems

The variability of platforms presents unique challenges in categorizing the full range of available UAVs. The most commonly used is the range and altitude criteria. Based on these criteria, Table 1 lists the types of UAV relevant to this study, with additional information on the weight of the payload and endurance. Beyond these five categories lie several other classes with ranges (> 100km), altitudes (> 3km), and speeds that are more relevant to military strategic interests (UAV International 2010). Another classification of UAVs separates them into unpowered (e.g., glider, kite) and powered ones, along with lighter than air (balloon, airship) and heavier than air (Eisenbeiß 2009).

Table 1. Extract of UAV Categories (UAV International 2010)

UAV Categories	Range (km)	Flight Altitude (m)	Endurance (hours)	Mass (kg)
Nano (η)	< 1	100	< 1	< 0.025
Micro (μ)	<10	250	1	<5
Mini	<10	150/300	<2	< 30
Close Range	10-30	3000	2-4	150
Short Range	30-70	3000	3-6	200

Since kites, blimps and similar platforms are affected by wind and thus can't be easily controlled (Lemmens 2011), this study will focus only on the group of the powered and heavier than air UAVs. This group can be further classified based on airframe types, being of flexible wing, fixed wing, or rotary wing. A fixed-wing UAV requires a runway to take-off and land but it is stable and can carry a payload of up to several kilograms. A rotary aircraft (rotorcraft, helicopter) takes off and lands vertically (vertical take-off and landing, VTOL) and offers flexible manoeuvring and hovering capability (Lemmens 2011; Valavanis 2007).

Another categorization offered by Eisenbeiß (2009) was based on system performance. Accordingly, UAVs were classified into Open source and Manual controlled systems (OM-class), Micro and Mini systems (M-class), and Large payload UAVs (L-class). The OM-class is comprised of mostly non-commercialized systems with particularly low production costs for the hardware and poor navigation performance, the M-class is characterized by short range, low altitude commercial systems which have payload capacities below 5kg while the L-class comprises of large scale UAVs capable of medium to high altitude flights bearing large payloads greater than 5kg with high performance navigation and georeferencing sensors. Table 2 characterises UAVs from the perspective of the navigation sensors, and the quality of geo-referencing and spatial data collection (Eisenbeiß 2009).

Table 2. UAVs in terms of to flight performance and navigation (Eisenbeiß 2009)

Sensors	Georeferencing	Real-time Capability	Application Requirement	UAV Category
No GPS/INS	Post	0	Low accuracy	OM-class
GPS and consumer-grade INS	Post/direct	+	Moderate accuracy [dm-m]	M- & L-class
DGPS/ navigation- and tactical-grade INS	Post/direct	++	High accuracy [cm]	M- & L-class

(0: lowest value, +: middle value, ++: best value)

3. CHOOSING UAV SYSTEM

3.1. Proposed Criteria for a Suitable System

Several studies have proposed different criteria for choosing UAV with imaging capabilities. However, they all agree that the main requirements for a suitable UAV are high resolution, accuracy, low cost, and portability (Lemmens 2011; Skaloud et al. 2006). Other studies added other operational consideration such as the size and weight of payload; stability and vibration; number of people needed for launch and control; level of piloting skills; flight time; range; minimum airspeed; minimum size of takeoff and landing area; and safety (Lemmens 2011). One may also add that data processing has to be largely automated and there should be no need for ground control points (Lemmens 2011).

Further to the above general considerations, an aerial mapping system designed for responding to natural disasters in the region must not only be technically appropriate but must also be cost appropriate to ensure its usefulness and sustainability as a geoinformatics tool. As such, the ideal UAV platform considered for reliable mapping and response to natural disasters in the Caribbean must satisfy the following characteristics in order to adequately account for the socio-economic and technical unsuitability of traditional aerial mapping systems for disaster mapping in SIDS.

- *The system should be readily available and easily deployable* – requiring minimum time and resources for set up and launch of the system.
- *The system should be easily transportable* – this will facilitate use in multiple locations as some of the island states are archipelagic and can also facilitate cooperation in acquisition and operation of the systems between states.
- *Limited operator skills* – as the system is intended for civilian use it is expected that the UAV will require basic piloting skills from the human controller.
- *Autopilot and Way Point Navigation* – the system should be able to carry out detailed flight planning and autopiloted navigation and image acquisition of the mapping area as well as navigation to particular waypoints.

- *The payload should be modular* – facilitating the use of multiple sensors, with a minimum payload of 500g. This will allow the system to not only be used for photographic imaging but would allow for use between disasters for other analysis or research.
- *The system should have extensive range* – allowing for the variability of disaster mapping the system should be able to handle both low altitude detailed mapping and medium altitude flight.
- *The system should provide links to a global coordinate system* – the system should be able to provide coordinate information in global and local coordinates independently of ground control stations as the integrity and visibility of these may suffer after a natural disaster.
- *The system should be cost effective* – capital costs should be generally low (approximately US$ 35,000) allowing its adoption by government and private agencies responsible for disaster mapping while operation costs should allow for continued and constant use of the system.
- *The system should build capacity* – enhancing the skills and knowledge of operators, technicians and institutions by providing increased opportunities for aerial mapping applications and research through the availability of directly acquired and task specific datasets.

3.2 Short-Listing Suitable UAV Systems

UAVs are the fastest growing sector in the aerospace market and there exist over 1240 commercially available UAVs manufactured by over 500 companies (Tatham 2009; UAV International 2010). This study however focuses on suitable platforms for low cost photogrammetric applications and systems which can perform autonomous or easily navigable flight operation. Some of the suitable commercial UAVs available are presented in Table 4 and are hereby classified based on the three previously stated classifications. The open source systems, OM-class, such as Mikrokopter, UAVP and Paparazzi are highly modular components and though a full UAV system can be produced they require considerable effort in the construction of the platform and programming of the onboard flight system which is beyond the scope of this study.

The M- and L- class UAVs provide the highest potential for low-cost mapping. Most of the models listed in Table 3 can be considered as full Unmanned Aerial Systems (UAS) as the suppliers can provide not only the UAV platform, but ground control stations, software, autopilot functionality, navigation sensors and a range of imaging payload. These particular systems are designed specifically for imaging applications; however, there exist a broad range of UAVs designed for other uses which are capable of being outfitted for imaging applications.

Table 3. Subset of commercial UAV systems

PRODUCT NAME	COMPANY	PRICE USD $	CLASS	TYPE	CLASSIFICATION	PAYLOAD CAPACITY	GPS/INS	AUTONOMY (mins)
DraganFlyer X4	Dragan Fly Innovations inc	8,495	M	Rotary	Quadrator	250g	INS	20
DraganFlyer X6	Dragan Fly Innovations inc	19,995	M	Rotary	Multi-rotors	500g	GPS/INS	20
DraganFlyer X8	Dragan Fly Innovations inc	32,165	M	Rotary	Multi-rotors	1000g	GPS/INS	20
Draganfly Tango	Dragan Fly Innovations inc	20,490	M	Fixed Wing	Propeller	1140g	GPS/INS	50
CropCam	MicroPilot	6,999	M	Fixed Wing	Propeller	145g	GPS/INS	20-55
MP-Vision	MicroPilot	9,500	M	Fixed Wing	Propeller	145g	GPS/INS	20-55
LP960	Lehmann Aviation	8,990	M	Fixed Wing	Glider	-	GPS/INS	-
LH2000	Lehmann Aviation	7,990	M	Rotary	Quadrator	-	GPS/INS	-
MD4-200	Microdrones (UK) Ltd	29,000	M	Rotary	Quadrator	250g	GPS/INS	-
MD4-1000	Microdrones (UK) Ltd	37,195	M	Rotary	Quadrator	1000g	GPS/INS	60
PIXY 26.40	Uav Aerial Photography	8,290	L	Flexible wing	Powered Paraglider	4kg	GPS	60
PIXY 29.40	Uav Aerial Photography	9,673	L	Flexible wing	Powered Paraglider	6kg	GPS	60
PIXY Vision	Uav Aerial Photography	13,825	L	Flexible wing	Powered Paraglider	6kg	GPS	60
PIXY - UAV	Uav Aerial Photography	19,499	L	Flexible wing	Powered Paraglider	6kg	GPS	60

4. CONCLUSION

Earth observation and GIS techniques can significantly contribute to improving the 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, the traditional use of satellite and aerial images for this task in the Caribbean have been challenged by technical and financial issues, in addition to a persisting cloud cover specific to tropical environments.

UAVs are becoming increasingly popular as photogrammetric platforms for civilian use due to their relatively low cost, ease of operation and the emergence of low cost navigation and imaging sensors capable of performances comparable to higher priced sensors. The operational nature and cost factors make this potentially an applicable technology to build a low cost mapping system upon, in light of the requirements for Caribbean SIDS. They can therefore, represent a viable alternative solution over other mapping systems for disaster mapping and management activities. Further applications for unmanned aircraft can be explored once these solutions have been developed. The main problems still to be addressed are the vibration of the system, the payload capability and the integration of all sensors. Added to that, is the requirement for a legal/administrative accommodation within national airspace.

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