Effective post-disaster reconnaissance using unmanned aerial vehicles for emergency response, recovery and research

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H.A. Follas

Opus International Consultants Ltd, Auckland

D.L Stewart

Opus International Consultants Ltd, Wellington

J. Lester

Opus International Consultants Ltd, Christchurch

ABSTRACT: Natural disaster emergency response requires quick reconnaissance, while ensuring the safety of personnel. The use of Unmanned Aerial Vehicles enables effective rapid assessment of damage following hazard events, without putting people at risk.

Following the Christchurch Earthquakes, a fixed wing UAV was deployed by Opus to obtain high quality imagery of slopes on the Port Hills in Christchurch, and was shared with organisations involved in post-disaster response associated with the risk from rock fall and landslides. A quadcopter UAV and remote controlled robots were also used to obtain close up imagery within the badly damaged Catholic Basilica to allow condition assessment. Fixed wing and quadcopter UAVs were also deployed following storm events in the Nelson-Tasman districts in December 2011, and in Wanganui / Wellington districts in May / June 2015, to inspect and photograph landslides and retaining walls affected.

UAVs can also be used to obtain videos and georeferenced imagery which allows rapid creation of 3D models of sites that were previously practically inaccessible, and this was applied following the Wanganui / Wellington storms. Such use is also invaluable to quickly collect valuable post-disaster information for later research, while the evidence is still intact (e.g. landslides, liquefaction, lateral spreading), and without affecting emergency response.

This paper presents case studies from the use of UAV's over the past 10 years to facilitate enhanced site and infrastructure characterisation in a post-disaster emergency response phase, to provide confidence in the assessment of post-disaster risk and to facilitate quick recovery.

1 INTRODUCTION

The use of remotely operated aircraft (UAV's/drones) and robotic vehicles to assist emergency response has grown rapidly in the past few years, largely through the rapid advancement and availability of affordable technology, but also due to the ease of site access, the ability to rapidly capture data and positive health and safety benefits the technology offers without negatively impacting the ongoing emergency response.

Many UAVs incorporate gimbal stabilised photography and high definition video capture with GPS geolocation of imagery. Relatively large areas can be rapidly captured and modelled accurately by post processing imagery utilising 'structure from motion' photogrammetric software. Software outputs typically include detailed Ortho-corrected photo mosaic imagery and accurate 3D models of structures or the surrounding terrain. These outputs can also be used for many CAD and GIS applications. Through these combined outputs, UAVs provide a means of immediate assessment of damage to structures / remedial actions.

Rathje and Franke (2015) discuss the increasing use of remote sensing techniques including UAVs for earthquake disaster reconnaissance, and collection of data for research and learning from disasters.

Continued rapid advances in the technology are anticipated with developments such as UAV's that can fly in all weather, the use of new sensors on UAV's such as LiDAR (such technologies are discussed by Olsen and Gillons 2015), and more reliable and capable remote controlled robotic vehicles.

The current paper provides a summary of our findings regarding the usefulness and applications for UAV's in various phases of emergency response, based on a number of years of experience both developing and using available technologies following earthquake and storm events.

2 UAV TECHNOLOGY IMPLEMENTED

2.1 UAV inspections between 2007 and 2010

Opus has used Unmanned Aerial Vehicle (UAV) technology in the Auckland Region from 2007. Initially this was using a frangible foam 'Easystar' electric powered glider type fixed-wing radio controlled model aircraft carrying a remotely triggered Pentax 12 Mega Pixel compact digital camera (Fig.1). The 'Easystar' was largely based upon a hobbyist radio control training plane, with a 1.4m wingspan and being hand launched could remain airborne for up to 30 minutes and operate up to 600m away from the operator and remain in visual control range. The camera was remotely triggered by an infra-red controller and could be positioned to take either oblique or vertical imagery of subject material. The aircraft was initially developed and utilised for use by the Opus Auckland Civil Engineering Team for remote access to difficult sites, slip inspections, progress aerial site photography and providing promotional aerial photos for clients and company flyers etc. While the 'Easystar' was launched and flown in left-hand circuits around the subject, most of the photography was 'guesswork' undertaken without any downlink or telemetry.

Figure 1 - The "Easystar" fixed-wing radio controlled aerial camera aircraft with camera setup for vertical images (left) and obliques (right). The UAV was developed in-house by one of the authors of this paper.

The first practical usage of the 'Easystar' for emergency response aerial support came during August 2008. Severe winter storms and extremely heavy rainfall reactivated an old deep seated block slide on Turei Hill in Kawakawa Bay. The slip threatened the closure of the coastal road and cutting off communications to a number of east coast communities. The 'Easystar' was utilised at the city council's request to provide rapid response visual survey of the extent of cracking and movement of the slump block. A number of reconnaissance surveys were undertaken over a number of weeks, photos were taken were then mosaicked and compared with previous imagery. The imagery was subsequently disseminated to local community groups and multiple media outlets.

2.2 Use of multi-copter UAVs

From July 2014, as more advanced UAV technology became commercially available, Opus began to implement UAV technology across New Zealand and standardising on the DJI Phantom quadcopter UAVs (Fig.2). The technology incorporated in the Phantom, driven by a tablet based application incorporates gimbal stabilised 12 or 14 Mega Pixel photography or high definition video capture.

While it is essentially an entry-level UAV, the ability of the Phantom to take-off vertically, hover in a GPS assisted stationary position (not affected by wind drift) combined with live image and video capture (some of the Phantoms can live-stream video via YouTube) have revolutionised the ability to quickly, safely assess and visualise inspections of hard to access unstable terrain and structures etc.

The Phantom can also be operated in an autonomous mode, flying to pre-programmed waypoints or flying along gridlines for detailed surveying. Typical flight times are between 15-20minutes.

Figure 2 - DJI Phantom multi-copter in use for inspection of railway slip damage 50km north of Wanganui

2.3 Pix4D Mapper and surveying disaster sites with UAVs

We have implemented the use of motion photogrammetric software Pix4D Mapper in conjunction with our UAV operations. Structure from motion software has revolutionised photogrammetry as it can automatically process imagery acquired by UAV, aircraft or ground based platforms purely on image content. Pix4D enables the conversion of images into highly precise, customisable data for a wide range of applications including for GIS and CAD (Fig.3).

For rapid or emergency response applications, the use of UAVs and Pix4D in conjunction with good survey control has given the ability to immediately capture the site conditions at the time and produce an accurate 3D terrain model that can be compared with subsequent captures. What this means is that accurate base plans can be created for field staff, volumes and areas of affected sites can be accurately calculated and compared with previous flights and outputs can be utilised for designing engineered remedial works.

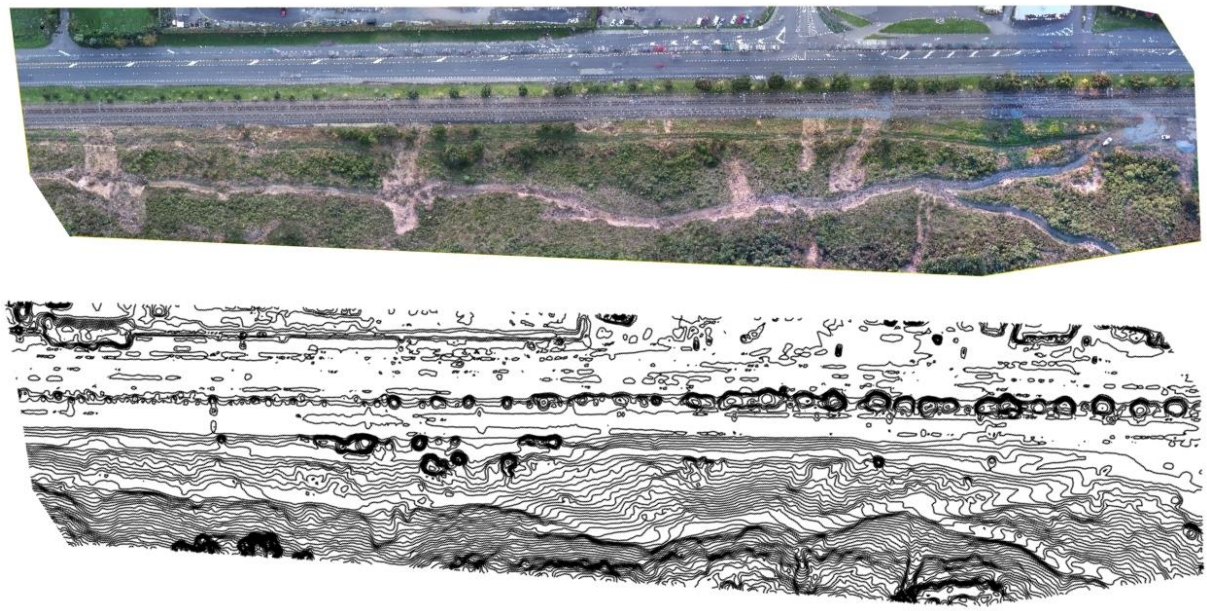

Figure 3 - Ortho-mosaic image output by Pix4D of debris flows near Paraparaumu and 1m contour plan of same site from post-processing UAV imagery with Pix4D.

3 EMERGENCY RESPONSE AND UAV AND ROBOT DEPLOYMENT: CANTERBURY EARTHQUAKES 2010 AND 2011

3.1 Canterbury Earthquakes 2010 and 2011

The 2010 Canterbury earthquake (also known as the Darfield earthquake) struck with a magnitude of 7.1 on 4th September 2010. Numerous damaging aftershocks followed, the strongest of which occurred on 22 February 2011 was a magnitude 6.3 shock known as the Christchurch Earthquake. Because this aftershock was centred very close to Christchurch, it was much more destructive and resulted in the deaths of 185 people. This event had a maximum PGA of 2.2g, the largest ever recorded in New Zealand. Liquefaction damage on low lying terrain was widespread and significant areas of rock fall and residual rock fall risk created significant risk to life and property in the Port Hills area of Christchurch.

3.2 'Easystar' UAV inspections, Rock Bluffs in Port Hills, Post February 2011 Earthquake

Following the February 2011 earthquake, and after considerable consultation with the emergency response management, we deployed the 'Easystar' UAV on the 8th of March to obtain high quality imagery of areas of ground damage on very steep and high bluffs in the Port Hills area of Christchurch. These bluffs were vulnerable to rock fall and landslides both during the quake and post-quake aftershocks. The 'Easystar' was operated from safe, remote locations and utilised to photograph and help identify the various rock fall sources and patterns to help assess the residual rock fall risk to property, roads and personnel working on remedial efforts (refer Figs 4 & 5). The imagery captured was particularly useful to help determine safe access routes where site access was deemed risky for access on foot and for abseiling teams. The imagery was shared with a range of organisations involved in post-disaster response for visualisation and forward planning.

Figure 4 - 'Easystar' imagery of earthquake effects in the Port Hills. Boulder strewn slopes and road damage near Mt. Cavendish Gondola

Figure 5 - Cliff line cracking near Sumner Heads, this eventually failed in later aftershocks.

3.3 Remote Condition assessment of the Catholic Basilica using quadcopter UAV and Robot

In addition to the Port Hills UAV work, two further types of remote viewing tools were used by the Opus team to obtain remote close up imagery within the Catholic Basilica to allow a basic condition assessment of the building's structure.

The Catholic Cathedral of the Blessed Sacrament is a Category 1 Listed heritage building built in 1905, and designed in a neo-classical style. The building constructed mainly of limestone, suffered significant damage in the February 22 earthquake including collapse of the two towers and partial collapse of the main dome. With the state of the building being uncertain and continuing aftershocks, access to the building was considered hazardous. A decision to preserve or demolish the main dome was required, but difficult without knowing the state of the internal structure supporting the main dome. The decision was made to use remote means to try and view the interior of the building.

Initially we attempted using a consumer grade ('off the shelf') Parrot AR Drone UAV (Refer Figs 5 & 6). This was operated with minimal training using an iPad 'base station', it was flown through a broken window to capture imagery showing the internal condition. The imagery was sufficient to enable an overview of the structural integrity to be established, but greater resolution was desired to enable an informed decision to be made.

Figures 5 & 6 - Parot AR Drone (left) and image capture from inside the Cathedral of the Blessed Sacrament (right) showing the damage to the structure around the sanctuary and the good condition of the nave columns.

Opus then approached the New Zealand Army who offered the use of their iRobot 510Packbot UGV and trained operators to carry out a detailed internal inspection with a higher resolution camera (Refer Figs 7 & 8). The iRobot had video recording capability and the main camera had a resolution of 14 megapixels and a 35x optical zoom enabling specific close-up images to be taken at leisure. It also had an unobstructed 360 degree hemisphere of view.

Figures 7 & 8 - NZ Army iRobot Packbot entering the cathedral (left) and captured imagery showing degradation of the pier structure supporting the dome arch (right).

This information showed degradation of the structure between the two sets of images captured, and provided sufficient detailed imagery of the structure to enable the decision to deconstruct the main dome. All this was achieved without putting human life at risk in a dangerous building with the constant threat of aftershocks.

4 NELSON-TASMAN DISTRICTS, DECEMBER 2011 STORM

4.1 December 2011 Event

In mid-December, 2011, two days of torrential rain, resulted in a 1 in 500 year rainfall for Takaka and a one in 250 year event in Nelson (Tasman District Council, 2012). A state of emergency was declared, with extensive flooding and slippage from waterlogged hillsides, resulting in large numbers of road closures and damaged properties. Hundreds of people were evacuated from their homes. Regions were cut off for several days and many destinations in Tasman Bay were cut off for months.

4.2 'Easystar' UAV inspections

From 21st December, the 'Easystar' UAV was deployed in Nelson and Tasman District following the storm event, and provided the various emergency response teams with an immediate perspective view of the terrain and the extent of damage to help facilitate remedial works. Inspection of the extensive SH6 Rocks Road Cliff along the waterfront at Nelson utilised cranes and abseiling to view the ground damage on the cliff (Stewart and Brahaharan, 2013). The use of cranes in this case requires full road closure (Fig.9). In contrast the 'Easystar' reconnaissance of SH6 'Rocks Road' had negligible impact on operations, and provided valuable imagery for development of long term protection measures for this key route.

Figure 9 - Contrasting techniques for reconnaissance of 'Rocks Road' slips in December 2011. The crane usage (left) required a full road closure while flying images with the UAV (right) required almost negligible disruption.

5 UAV INSPECTIONS IN WANGANUI/WELLINGTON AREAS FOLLOWING MAY 2015 STORMS

The storm affected the southern part of the North Island, and in parts of the Kapiti Coast was the heaviest seen for more than 50 years, with peak rainfall exceeding monthly averages in a single day.

In May 2015, the Phantom UAV was deployed to the Wanganui and Wellington Districts to assist with the assessment of unstable terrain created by the deluge of rain and associated flooding. Two example sites are discussed below.

Aranui Bluff is located on a tight bend along Whangaehu Valley Road (18 km north of Mangamahu, Wanganui District). A rock slide at the bluff destroyed the traffic barrier and removed a considerable section of the road shoulder (Figs 10&11). Boulder and rock debris which had fallen from part way up the 110 m high bluff, had sufficient momentum to cross the river. Remedial solutions to safely remove remaining debris and to reconstruct/reopen the road was challenging, as it was difficult to even obtain a basic survey of conditions at this very steep precipitous site. Utilisation of the UAV enabled the capture of continuous georeferenced imagery of the site (with sufficient survey control points captured on the ground), with post processing with Pix4D providing an accurate digital terrain model in hours rather than days.

Figures 10 &11 - Pix4D model of Aranui Bluff (110m high) and rock slide (left) and photo of gaping joints in rock face 80m up face with the road below (right).

This provided designers accurate profiles of the existing site conditions (Fig.10). High Definition video shot of the exposed rock face by the UAV was also subsequently used by abseilers to ascertain the safest descent routes for assessing the face.

The Paekakariki coastal road section of state highway 1 (SH1) and the adjacent North Island Main Trunk (NIMT) railway line, north of Wellington, were closed due to a large debris flow which originated in the steep hills above (Figs 12 &13). The source and likelihood of further debris flows at the site, were not able to be identified immediately prior to clearance of debris and reopening. Utilising live video feed, the Phantom UAV was flown up some of the quite inaccessible stream valleys and successfully identified the source of debris which blocked the rail and road during the storm.

Figure 12 - Remnants of a debris flow which came downstream (top) and blocked rail and road. UAV was flown from shore platform (foreground).

Figure 13 - Close-up of May 2015 debris flow source enabled: talus and debris undermined by rapidly flowing and swollen stream originating in steep country (right).

6 UAV INSPECTIONS IN WANGANUI AND TARANAKI REGIONS, JUNE 2015

A significant storm event in June 2015 resulted in extensive flooding and land sliding in the Wanganui and Taranaki regions. Helicopter inspections were used for immediate response by authorities such as KiwiRail and Wanganui City Council. UAVs were subsequently used by Opus in the following weeks

for these organisations to provide data to characterise the extent of damage and to facilitate assessment and design of remedial solutions.

The 4 km long section of railway immediately north of Wanganui known as the Westmere Bank was subject to numerous landslips both above and below the railway line. Due to the long sections of railway to be assessed, a fixed wing UAV (Fig.14 inset) was used to capture imagery of this section and also a 2 km section of damaged Council road. From the photos taken, Ortho-mosaic strips were generated within 24 to 48 hrs of the flight allowing 1:1000 scale base maps to be created and used to enable field reconnaissance and characterisation of the landslides (Fig.14). Landslides and site features were clearly visible on the Ortho-photo base maps which enabled rapid and accurate recording of site damage.

Figure 14 - Base map generated from fixed wing survey (Fixed wing UAV shown inset, top right) with geologist's slip observations drawn and overlaid.

Figure 15 - Ortho-photo of slip site generated from multi-copter imagery (launch site is shown in Fig.2 and is located on hazard free flat land at far right)

A Phantom multi-copter UAV was used during the reconnaissance to capture imagery at lower altitudes at specific sites within the Westmere Bank and a critical damage site 50 km north of Wanganui. This provided higher resolution ground models and video footage to enable better

definition of the extent and nature of slope instability (Fig.15). Production of cross sections from the multi-copter's 3D model(s) aided rapid assessment of the risk to the railway line. The use of the multi-copter UAV enabled more rapid assessment of the condition of the rail corridor to enable decisions to be made about reopening. These included UAV inspection of:

- Steep slopes below the railway line that would otherwise only have been visible by abseil and
- Extensive unstable areas above the railway line, which enabled clarification of the extent and mode of failure of land sliding.

7 SAFETY MEASURES IN THE USE OF UAV

It is important that UAVs are operated safely in gathering the valuable post-disaster or other site data. Prior to 1 August 2015, skilled but essentially untrained operators were able to use UAV's in many applications within public airspace (operating under the old CAA model aircraft Part 101 rules). More stringent CAA regulations introduced at that date require operators to gain permission from property owners and all people beneath the intended UAV flightpath prior to operating. Many authorities in New Zealand now require any UAV operators to be certified under the new Part 102 rules, as the new default 'minimum standard' for UAV operations.

8 DISCUSSION ON THE USE OF UAVS FOR POST-DISASTER RESPONSE

Low cost UAV's, (even converted model aircraft) can provide invaluable information on otherwise inaccessible sites (e.g. Christchurch Basilica). The appropriate use of UAV's and robotic vehicles for emergency response can provide major benefits in terms of safety of field staff, and due to their small size and typically short inspection duration usually have negligible impact on immediate response operations and subsequent operation of the facility.

While UAVs can provide fairly instantaneous coverage of the effects of a disaster site, but ironically sometimes it has taken days or in some cases weeks to convince authorities to understand and adopt the use of this technology. This illustrates the importance ensuring pre-planning to ensure that authorities are aware of the full capabilities and benefits of the UAV based data capture, and the safety measures that are in place. This will enable more effective use of the UAV technology to assist with the emergency response.

In terms of choosing appropriate UAV technology- fixed wing UAV's typically cover larger areas and therefore require fewer launch areas and shorter field time than Multi-rotor UAV's, but have a disadvantage in that they require large open spaces for landing/recovery. Multi-rotor UAV's are able to be held stationary and are ideal for close-up inspections of key features e.g. using high definition video or high density photography for production of detailed 3D models. Because of its small size, we have found that the Phantom UAVs lend themselves very well to inspections adjacent to live highways, providing suitable precautions are taken to minimise driver distraction while working at quite close quarters.

Systematic photography of a site enables subsequent production of 3D models. The 3D models facilitate rapid production of survey quality base map plans and cross sections on which assessment of current conditions can be quickly assessed. Survey control can be either inbuilt within the UAV (e.g. RTK GPS) or introduced by way of independently surveyed control points that are visible within the images. 3D model fly-through visualisations also provide a very useful tool to allow decision makers to understand the extent of damage and other constraints at the site (e.g. proximity of overhead services).

In some cases, the operator needs to be chosen for the specific task. In many cases a UAV operator specialising in a particular discipline e.g. geotechnical or structural engineering can expedite and optimise the data collection, by focussing on the key elements of potential concern. To expedite the value of the UAV outputs, these can be made available on a shared server or website. Plan outputs should be clearly labelled with a statement of accuracy/disclaimer to prevent inappropriate subsequent use.

9 CONCLUSION

UAV technology has been increasingly used for post-disaster recovery in New Zealand by the authors, and the case studies presented illustrate the value of this tool. The use of UAV technology greatly helps facilitate the rapid collection of post-disaster data for subsequent processing, assessment and research, particularly while the evidence is still intact. Collection and the rapid dissemination of imagery typically can aid emergency response. Subsequent repeat UAV imagery collection at these disaster sites can be used to accurately determine the changes that have occurred over time – which can be either deterioration of site conditions or from site mitigation activities e.g. remedial engineering works. The potential value of UAV technology and software applications for UAVs for emergency response is expected to keep increasing rapidly, in parallel with the rapid development of the technologies.

10 ACKNOWLEGMENTS

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