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UAV Aerial Imaging Applications for Post-Disaster Assessment, Environmental Management and Infrastructure Development

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***Abstract*—This paper discusses the use of a low-cost unmanned aerial vehicle (UAV)-based remote sensing system for different applications, namely post-disaster assessment, environmental management and monitoring of infrastructure development. A collaborative research consortium was established to promote the acquisition, post processing, analysis and sharing of UAV-based aerial imagery. A streamlined workflow - flight planning and data acquisition, post-processing, data delivery and collaborative sharing - was created in order to deliver acquired images and orthorectified maps to various stakeholders within this consortium. Various use case examples of UAV aerial imagery work are still in ongoing development. Initial experience shows that the combination of aerial surveys, ground observations and collaborative sharing with domain experts results in richer information content and a more effective decision support system.**

I. Introduction

The rapid development of unmanned aerial vehicle (UAV) technology has enabled greater use of UAVs as remote sensing platforms to complement satellite and manned aerial remote sensing systems. UAVs have emerged [1] as portable, scalable, high-resolution imaging platforms that augment satellite imagery, which may have observation gaps due to atmospheric phenomena (e.g. cloud cover) and limited coverage over a certain region due to its orbit around the Earth [2]. It has also become an effective tool for targeted remote sensing operations in areas that are inaccessible to conventional manned aerial platforms due to logistic and human constraints.

Many studies have been published on the use of aerial imagery for different applications, such as estimating riparian zone impacts [3], vegetation mapping [4], damage assessment after a disaster [5], such as a strong typhoon [6], [7], [8], monitoring of wetland ecosystems [9] and coastal management [10]. In addition, the development of smaller and more cost-effective UAV platforms has made certain commercial applications more feasible [11]. Some examples of UAV applications include characterization of rice paddies [12], inspection of industrial facilities [13], river detection and tracking [14], traffic monitoring [15] and disaster management [16]. These show the benefits of having a "bird's eye view" of research sites and illustrate the potential of UAVs as essential tools for acquiring aerial imagery.

Although use of UAV technology has cost and operational advantages compared to the satellite and standard aviation alternatives, the cost to own and operate a UAV can still be prohibitive, especially for developing countries. A non-profit organization called conservationdrones.org has been active in building low-cost (i.e. less than USD2000) UAV data gathering capacity for environmental conservation in developing countries as well as raising awareness on the conservation challenges in those regions. Their ongoing efforts have demostrated that it is possible to use UAVs for conservation in a more cost-effective way [17].

This paper presents various applications of low-cost UAV aerial imagery in the domains of post-disaster assessment and recovery, environmental management and infrastructure

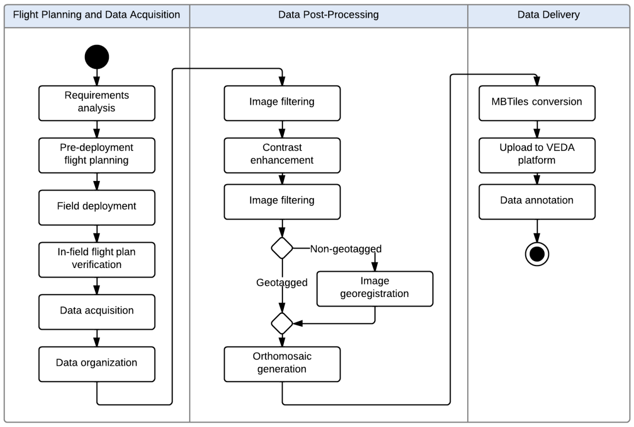


Fig. 1. UML activity diagram repesentation of the aerial imaging workflow diagram for UAV-based mapping. The workflow depicts the processes in each of the three stages of flight planning and data acquisition, data post-processing and data delivery. Each stage may be performed concurrently by working on different datasets similar to a process pipeline. The workflow consists of both human and machine processes.

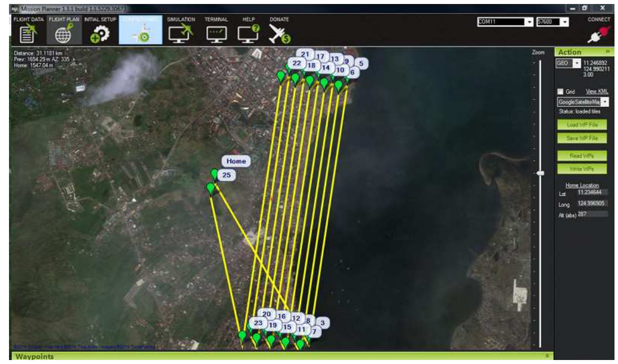


Fig. 2. UAV flight plan of the coastal section of Tacloban city, Leyte generated using APM Mission Planner. The plan involved flying a small UAV 200 meters above ground level. The raster scan pattern indicated by the yellow line was designed to take images with 80% overlap and 75% side overlap. The waypoints indicating a change in direction of the UAV are shown as green markers.

development in the Philippines. An aerial imagery consortium was established to develop a close collaboration between UAV specialists and domain experts in various fields, such as agriculture and disaster science. The consortium consists of members from industry, local government and the academe. An aerial imaging workflow was implemented in order to facilitate the processing and sharing of acquired data among participating members of this consortium.

II. Aerial Imaging Workflow

The aerial imaging workflow describes an end-to-end method for generation and dissemination of post-processed images. It was developed in order to streamline acquisition, processing and delivery of UAV aerial imaging data to stakeholders within the UAV aerial imagery consortium. It also serves as a guide for continous process improvement. Due to the rapid development of UAV technology and aerial imaging tools, integration of newer systems and methodologies is an ongoing engineering challenge. Thus, the workflow will continuously be updated, with the goal of automating more activities in order to increase processing speed, reduce cost and minimize human error.

The workflow, shown in Fig. 1, describes three primary stages: flight planning and data acquisition, data post-processing and data delivery. Each stage is described in more detail in the following subsections.

A. *Flight Planning and Data Acquisition*

This stage involves gathering of aerial images from the area of interest using a UAV remote-sensing platform.

There are several processes involved in this stage. First, the requirements of the mission need to be analyzed and defined in order to determine flight parameters as well as the areas of interest. Second, an initial set of flight plans, in the form of Google Earth KML files and waypoint files, are created. Fig. 2 shows a sample flight plan together with flight log data. Waypoints for the UAV autonomous flight are created using ground control station (GCS) software such as the APM Mission Planner[1]. Third, a UAV field team is deployed to the area of interest. Once in the field, the team verifies the flight plans before the UAV is flown by performing a pre-flight survey. The survey may be done through ground observations of the area, use of local knowledge or short range aerial observations with a rotary UAV to identify launch/recovery sites and terrain characteristics. This may lead to adjustment in the flight plans. After the flight plans have been verified, the UAV is deployed for data acquisition. Lastly, once all the data has been collected, it is organized and prepared for post-processing.

In this stage, the expected outputs are a set of aerial images and flight logs containing GPS coordinates and inertial measurement information (i.e. yaw, pitch, roll) needed for the creation of orthorectified digital maps.

In order to ensure the cost-effectiveness and quality of data acquisition, the appropriate UAV platform and optical payload need to be chosen.

1) UAV Platform: In our initial imaging campaigns, we used a Micropilot MP-Vision UAV for data acquisition[2]. However, due to increased cost of maintenance and significant skill requirements of setting up the MP-Vision, a custom UAV platform was developed.

The custom UAV uses semi-professional and hobby-grade components combined with open-source software (see Fig. 3). The UAV's airframe is the Super SkySurfer fixed-wing EPO foam frame.[3]. Autonomous flight is achieved through the ArduPilot Mega (APM) autopilot system[4], consisting of an Arduino-based microprocessor board, airspeed

[1]http://ardupilot.com/downloads/?did=82
[1]http://www.google.com/earth/
[2]http://www.micropilot.com/products-mp-visione.htm
[3]http://www.rc4y.com/super-skysurfer-24m-epo-wingspan-sailplane-glider-kit-only-send-via-ems-p-523.html
[4]http://store.3drobotics.com/products/apm-2-6-kit-1

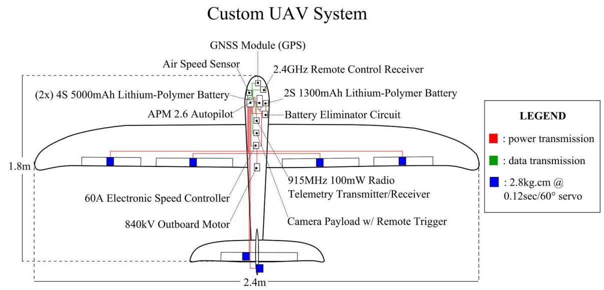


Fig. 3. System diagram of custom UAV. One of the design goals was to keep the UAV modular for ease of assembly and disassembly during deployments.

sensor, pressure and temperature sensor, GPS module, triple-axis gyro and other sensors. The firmware for navigation and control is open-source. The autopilot is connected to the electronic speed controller (ESC) of the propeller motor and the servos that operate the plane's flight control surfaces. A GPS module is also linked to the autopilot for autonomous navigation and position estimation of the UAV in the GCS.

The UAV airframe was modified in order to custom fit various components, such as the autopilot, GPS module, airspeed sensor, camera payload, motor and batteries. Also, the servos were placed near the control surfaces to ensure modularity during assembly and disassembly of the UAV.

Communication between the UAV and GCS is done through radio telemetry. The UAV can be set to manual mode using an RC controller to enable a human pilot to assume control of the UAV. Normally, the UAV will be set to autonomous navigation mode, where it will follow a predefined set of waypoints for a particular mission. However, manual control is often employed during take-off and landing for added safety.

The GCS is loaded with the APM Mission Planner software, which perform a number of functions. First, it can generate waypoints for the UAV to follow while in autonomous mode. Second, it is used to calibrate UAV control surfaces and autopilot settings for particular missions. Lastly, it is used to monitor and control the UAV during flight.

Development of the custom UAV underwent several design builds based on field experience. Each UAV build was used in actual mapping missions. Any lessons learned during deployment of the current build was used to improve on the succeeding build. The latest system architecture is depicted in Fig. 3.

Based on observations from actual mapping flights, the custom UAV has an endurance of about 30-50 minutes, depending on payload weight and wind conditions, and is able to survey an area of up to 4 sq. km.

The custom UAV has several advantages over its commercial counterpart. Without payload, the cost to assemble the custom UAV costs approximately USD2000 while the current version of the MP-Vision is priced at USD9500[5]. Also, from field experience, the custom UAV turned out to be easier to assemble, repair, maintain, modify and use. This allowed faster deployability of the UAV. In addition, since the autopilot firmware is open-source, with a large community of developers supporting it, it became easier to identify and address issues and obtain software updates.

The disadvantage of using the custom UAV was that it was more prone to hardware and software errors, either due to assembly of parts, wiring of electronics or bugs in the software code. It can fly away due to loss of GPS synchronization, since for the firmware versions that were used, there was no known preprogrammed failsafe mechanism that would allow it to return to a predesignated emergency location. Despite these, use of the custom UAV turned out to be more feasible and cost effective than use of a commercial-grade UAV.

Both the MP-Vision and custom UAVs were used in aerial mapping missions. However, during latter campaigns, use of MP-Vision was minimized and served as a backup in case the custom UAV encountered any problems.

2) UAV Payload: Three different camera payloads were used for data acquisition - Panasonic Lumix LX3[6], Canon S100[7], and GoPro Hero 3[8].

The Lumix LX3 was initially preferred over the Canon S100 for aerial mapping missions due to better image quality. The camera shutter was actuated by a servo that is controlled by the autopilot. However, this mechanical trigger would often fail, leading to false captures where the flight log would register a camera trigger, but the camera itself did not capture the image.

The Canon S100 is a GPS-enabled camera that could be programmed to take time-interval shots using Canon Hack Development Kit (CHDK)[9] firmware modification. Eliminating mechanical triggering, which is prone to failure, made capturing of images more reliable.

Both the Lumix LX3 and Canon S100 were used for mapping missions, where the autopilot is programmed to trigger the cameras at pre-defined distance intervals in order to ensure consistent overlap of images for orthorectification and stitching. The GoPro Hero 3 was used in missions requiring video reconnaissance.

B. Data Post-Processing

The aerial images collected from the flight planning and data acquisition stage need to be processed in order to produce usable information. Data processing is not performed in real-time. The data from the UAV, consisting of the flight log and media (images and/or video), are downloaded to the GCS upon landing. The data is post-processed in the lab workstations when the UAV field team returns from the mission.

The workflow at this stage focuses on the creation of an orthomosaic - an orthorectified, georeferenced and stitched

[5]http://www.micropilot.com/products-mp-visione.htm

[6]http://shop.panasonic.com/shop/model/DMC-LX3K
[7]http://www.canon.com
[8]http://gopro.com/cameras
[9]http://chdk.wikia.com/wiki/CHDK

map derived from aerial images and GPS and IMU (inertial measurement unit values, particularly yaw, pitch and roll) information.

The transformation of aerial images into orthomosaics involves the following steps. First, the dataset of aerial images are manually filtered to remove take-off/landing, blurry and oblique (i.e. non-level flight) images. Second, using commercial image editing software, contrast enhancement is applied to images that are either overexposed or underexposed. Third, the resulting images are georeferenced. Lastly, an orthomosaic is generated from the geotagged images.

For images that are already georeferenced (i.e. embedded with GPS coordinates), such as those taken with the Canon S100, the georeferencing step may be omitted. For non-georeferenced images, georeferencing is done by a custom Python script that generates a CSV file containing the mapping between images and GPS/IMU information. In this case, the images are not embedded with GPS coordinates.

Orthomosaic rendering is done using the Pix4Dmapper photomapping software developed by Pix4D [10]. The program can use either geotagged or non-geotagged images. For non-geotagged images, the software accepts other inputs such as the CSV file generated by the custom Python script to georeference each image and generate the photomosaic. Pix4D also outputs a report containing information about the output, such as total area covered and ground resolution. A sample orthomosaic is shown in Fig. 4.

Quantum GIS[11], an open-source GIS software, was used for annotating and viewing the photomosaics, which can sometimes be too large to be viewed using common photo viewing software.

Additional image processing algorithms, such as feature extraction and classification, can be applied to either the individual aerial images or the generated photomosaic. This additional step is specific to the application domain in which the images are used.

C. Data Delivery

Because orthomosaics generally have large file sizes (e.g around 300MB for a 2 sq. km. render), it would be cumbersome to transfer them via portable storage devices or personal cloud storage systems. Also, having multiple copies of the same map would not be ideal, since the map could be modified at a later time, forcing everyone who needs the map to update their copies. A better way would be to upload the map on a common web-based platform, which stakeholders can access and any modifications on the map would be available to them.

A web-based geographic information systems (GIS) platform was created in order to facilitate sharing of aerial maps. The platform, named VEDA, allows viewing of rendered maps and adding metadata. The key advantage of using this platform is that the aerial imagery data is located in one place and can be accessed from any computer with a modern Internet browser.

Before orthomosaics can be uploaded to the VEDA platform, they need to be converted into an approprate format supported by the platform. The current format used is MBTiles developed by Mapbox [12]. The MBTiles format specifies how to partition a map image into smaller image tiles for web access. Once uploaded, the orthomosaic map can then be annotated with additional information, such as markers for points of interest. Fig. 5 shows the layout of a rendered orthomosaic in VEDA.

III. UAV Applications

The following subsections describe use of the low-cost UAV aerial imaging system for various mission-critical work in the Philippines.

The Civil Aviation Authority of the Philippines (CAAP), which is the national aviation authority of the Philippines and is responsible for implementing policies on civil aviation, does not yet have a formal ruling on the use of small, lightweight (i.e. less than 20kg) autonomous unmanned aircraft for civilian applications. However, in the UAV aerial imaging missions, permission from the local government units (LGUs) was first obtained before flying.

The UAV field team operated mostly in rural areas and wilderness, which reduced the human risk factor in case of aircraft failure. Also, as a safety guideline, the UAV was not flown within 3 miles from an active airport.

A. Damage Estimation After Typhoon Haiyan

Typhoon Haiyan, one of the most powerful typhoons ever recorded at landfall [18], caused massive casualties and damages to industries in the Samar and Leyte islands (as well as other areas in the Visayas region) of the Philippines. Initial aerial imagery work was conducted in Tacloban City a few weeks after the storm hit. The goal was to get an initial overview of the damages wrought by the typhoon. About three months after the disaster, aerial mapping missions were initiated in order to support relocation and rehabilitation efforts of areas near the coastline (see Fig. 5).

Aside from assessing damages to buildings and infrastructure, UAV aerial imaging for assessment of damage to agricultural industries in the region is also an important application and an ongoing concern for LGUs implementing recovery plans. The coconut industry, in particular, which plays a vital role in the Philippine economy [19], was severely impacted due to millions of coconut trees being damaged or flattened [20] after the storm hit. In order to get an accurate assessment of the damage wrought by the typhoon, and to make a decision on the scale of recovery assistance from national government, aerial imagery coupled with a ground survey is a potentially promising approach.

The UAV aerial imaging team has flown many missions over areas in Eastern Visayas that are devoted to coconut

[10] http://pix4d.com/products/

[11] http://www.qgis.org/en/site/

[12] https://www.mapbox.com/developers/mbtiles/

[14] http://www.openstreetmap.org/

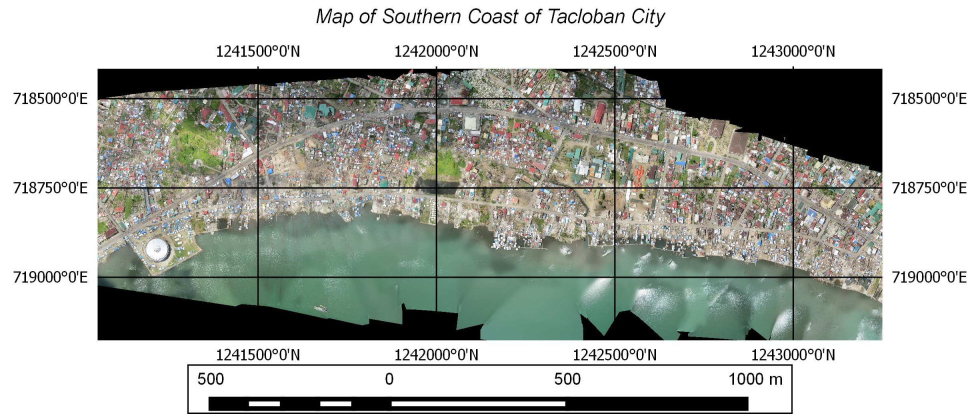


Fig. 4. Orthomosaic image of the southern cost of Tacloban City rendered using Pix4D software. The image is rotated 90 degrees clockwise so that the north side is at the right of the page. A grid with GPS coordinates generated using Quantum GIS is overlayed for positional reference. The image has an average ground sampling distance (GSD) of 5.13cm, and covers an area of 1.69 sq. km. A total of two flights and 785 images were used to create the orthomosaic. A scale bar with 500-meter intervals is provided for reference.

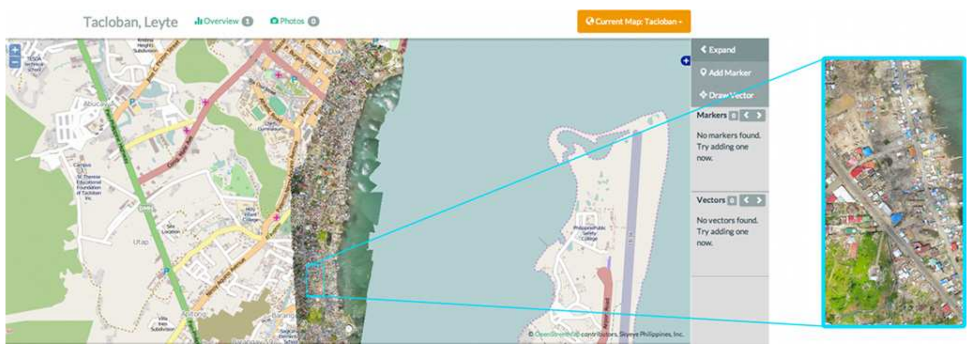


Fig. 5. Screenshot of VEDA webpage showing a Pix4D-generated orthomosaic of a coastal section of Tacloban City, Leyte overlayed on an OpenStreetMap[14] base layer (left). Aside from viewing map layers, the VEDA platform allows users to add markers and vector drawings over the maps; attach photos to markers, maps and vectors; integrate with other systems using an external API and generate custom project reports using a modifiable form. A closer look at a section near the southern coast of the city is shown on the right.

stands prior to Typhoon Haiyan. Initially, mapping missions were done for monitoring of infrastructure development in the municipality of Javier, Leyte (see Section III-E). However, the images collected also proved to be useful in developing applications for managing coconut plantations.

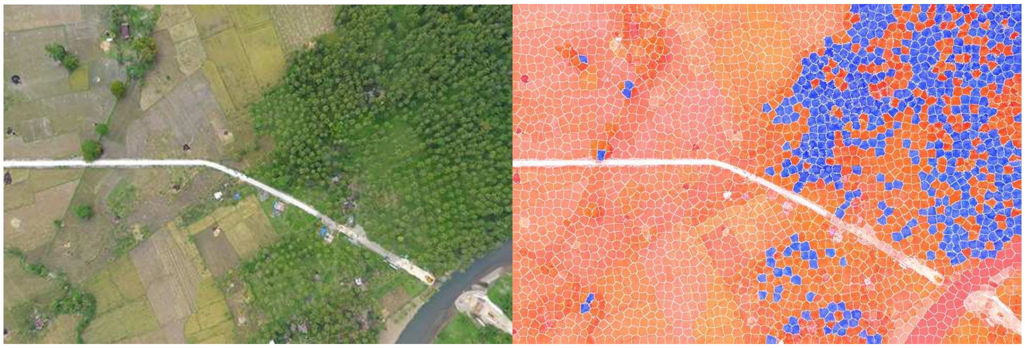
Image processing techniques are being developed to aid in distinguishing coconut trees from wild forest and vegetation for land use assessment and carbon source and sink estimates. One technique involved use of superpixel classification [21], wherein the image pixels are divided into homogeneous regions (i.e. collection of similar pixels) called superpixels which serve as the basic unit for classification. To determine the region associated with each pixel, the algorithm first divides the image into regions of equal dimensions and produces a seed point for each region based on the highest gradient intensity value. Afterwards, it undergoes an iterative process based on localized k-means wherein a pixel would be labeled based on the closest seed of its adjacent regions. The closeness is based on distance metric on its feature descriptor. Features are then extracted from each region and labeled to produce a model for classification.

For this use case, SIFT-based features were used on the center point of each superpixel to classify coconut trees from other image features. Fig. 6 shows the results of the initial test run where areas containing coconut trees have been segmented.

The image processing techniques being developed to distinguish specific crops such as coconuts from other vegation and wild forest will provide LGUs with data to address their land use concerns. Similar techniques could also be used for crop damage assessment after a disaster such as Typhoon Haiyan, where for example standing coconut trees could be distinguished from fallen ones in order to determine capacity to produce coconut-based products. In addition, aerial imagery augmented with ground observations would provide a richer source of information than either one could provide alone.

B. Fault Line Detection After Bohol Earthquake

A 7.2-magnitude earthquake occurred on October 15, 2013 in the island of Bohol, Philippines [22]. In the aftermath of the seismic event, a new fault system had emerged. Geologists from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and disaster response teams were



(a) (b)

Fig. 6. Sample aerial image of coconut trees taken in Javier, Leyte (Fig. 6a). Superpixel classification algorithm performed on the aerial image (Fig. 6b). The blue superpixels shown in Fig. 6b indicate areas containing coconut trees. Classification accuracy of superpixels containing coconuts, which was computed using ground truth, was found to be at 91% using k=15 nearest neighbors. Increasing k did not result in an increase in accuracy.

deployed to map and analyze the new fault system, which was estimated to be about 100 km long.

A three-man UAV team was sent to Bohol after the earthquake to perform an aerial survey of the new fault line in support of a quick response team (QRT) of geologists from PHIVOLCS. Their mission was to map the extent of the fault line as identified by the QRT. In an initial campaign, about 8km were surveyed and what appeared to be a 3km surface fracture was found. Based on ground observations, the height of the fracture was typically around 3-4 meters (up to 6 meters in some locations). Aside from aerial mapping, it turned out that the UAV team was able to assist the QRT in providing aerial reconnaissance, which enabled the latter to more quickly locate the extent of the fault line for analysis.

An aerial survey of a new fault line is viable when performed right after an earthquake. The advantage of using UAV-based aerial imagery is that the images were collected quickly for analysis. Having the UAV field team together with the QRT of geologists made communication easier and allowed for more targeted acquisition of data.

To assist with seismic fault line detection, image processing techniques were used to extract the fault line features from aerial images.

The aerial image is subjected to a conventional image enhancement process to distinguish and extract fault line features automatically. Transforming the original image to its corresponding HSV color model provides more valuable information than its RGB colorspace. From observation, the fault line is most easily distinguishable in the saturation channel. The saturation channel is segmented into five levels of contrasts wherein the least contrast region would contain the fault itself. Finally, image binarization and morphological operations are applied to the classified region where the fault is, to further extract and isolate the fault line. Fig. 7 shows the results of the image enhancement process.

C. Lake Resource Management

The Seven Lakes of San Pablo in the province of Laguna was named as one of the worlds most threatened lakes recently [23] and a holistic view of the water resource is needed to guide rehabilitation and preservation efforts. In line with this, an aquaculture and lake resource management system was deployed in Lake Palakpakin, one of the Seven Lakes [24]. Aside from taking water quality measurements via wireless sensor networks, a key component of the system is providing updated aerial imagery of the lake. A number of things can be studied and quantified using this approach: turbidity, algae blooms, formation of flow blockages such as from water hyacinths and fish pen layouts, compliance with environmental directives of fishpen coverage of lakes among other things. Identification of land use around the lakes and development trajectories will also assist long-term infrastructure and zoning plans.

A mission plan with altitude of 365 meters was used to map the extent of Lake Palakpakin, which had a lake surface area of one kilometer, and was then repeated monthly or quarterly depending on weather conditions. The mapping mission started in July 2011 and is still ongoing in order to monitor temporal changes of the lake. Also, with the help of our partners in the deployment site, fish pens in the resulting maps were labeled with their respective owners, as shown in Fig. 8. This helped in tracking unregistered units. Local government units and members of the Fisheries and Aquatic Resources Management Councils (FARMCs) expressed their satisfaction with the aerial imagery work, which gave them the necessary decision support to have a better understanding of the lake. It allowed them to work together and brainstorm on plans to improve water flow in the lakes via rearrangement of fish pens and determine future steps to promote eco-tourism in the area.

D. River Monitoring

The Aklan River System is part of the highly important Aklan River Forest Reserve, which serves several municipalities along its banks, including the tourist-heavy municipality of Kalibo. In its upland, it contains large tracts of virgin forest still co-existing with communities as well as agricultural and industrial activity along its river banks right down to the rivers mouth next to Kalibo International

(a) (b)

Fig. 7. Original aerial image (Fig. 7a) compared with the enhanced image (7b) of a section of the fault line discovered after the Bohol Earthquake. The fault line (highlighted red) is depicted as a vertical line near the center of the image in Fig. 7b. Some misclassified red pixels also appear in the right portion of the enhanced image.

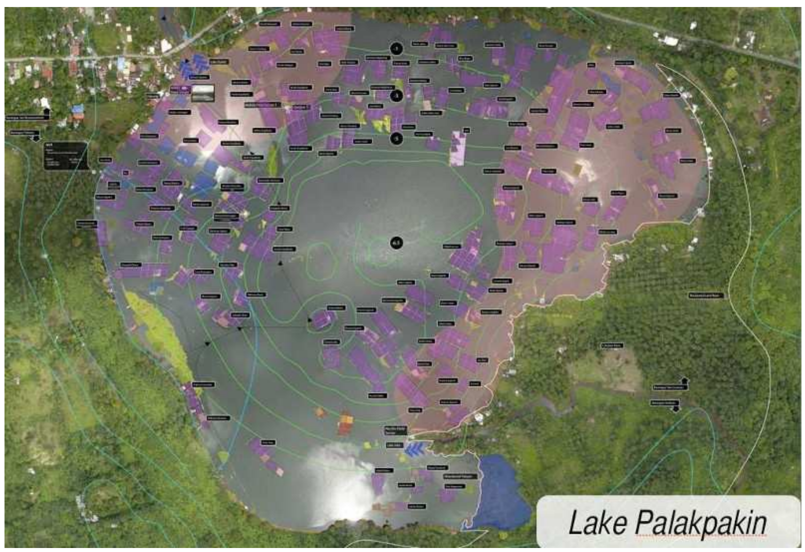


Fig. 8. Orthomosaic render of Lake Palakpakin with annotated information on fishpens. Based from local knowledge, 9 out of 43 hectares of the lake are covered with fishpens, resulting in about 20.93% coverage. This is significantly higher than the fishpen carrying capacity of the lake, which is at 10%. However, based on fishpen analysis of the aerial image of the lake, the coverage was found to be approximately 5.96 hectares, resulting in 13.86% coverage. This shows how the aerial map could be used to determine if the reported fishpen coverage is accurate and would help to enforce the carrying capacity limit.

Airport. Aquaculture activity is also ongoing, with a nursery of native fishes nurtured beside the river.

Aerial images were obtained along sections of the river in order to better understand the erosion and river sedimentation and to provide insight on the hydro-physico-chemical characteristics of the river system in order to develop river control infrastructure. Fig. 9 shows the aerial mapping layout of the entire river, as well as an orthomosaic image of a section of the river. Mapping of the river is still an ongoing mission.

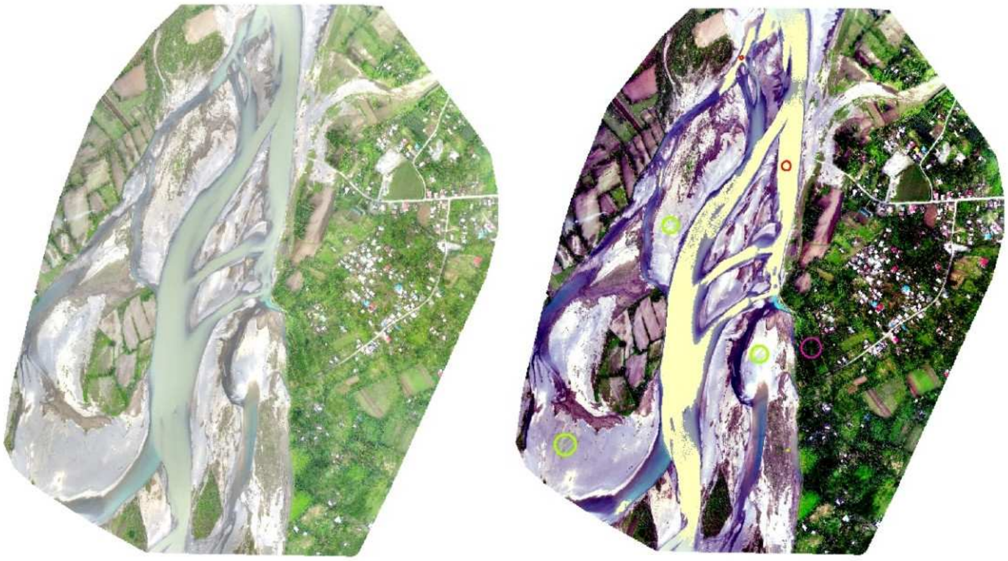
Similar to the Lake Palakpakin case, the Aklan River is also a shared resource with multiple stakeholders. Use of aerial maps provides powerful decision support that helps organize and unify efforts to manage the resource.

The Aklan regions agriculture sector is composed of rice, corn, coconut, peanuts and other fruit trees. These crops are identifiable using aerial imagery based on normal RGB and multi-spectral cameras. Using standard image processing techniques, it is possible to calculate vegetation indices, with ground truth obtained from Aklan State University (ASU) domain experts and local stakeholders.

In a pilot analysis of meandering fluvial processes, an orthomosaic image depicting a small 2 sq. km section of the Aklan River (Fig. 10) was processed using ArcGIS 10.2 software. Contrast enhancement and supervised classification techniques were used in the analysis. A small, arbitrarily-chosen training sample representing one percent of the total image (73,538 pixels) was used for sediment plume classification.

E. Infrastructure Development

Javier, Leyte is a 4th class municipality (i.e. one of the poorest municipalities in the Philippines) that is undergoing



(a) (b)

Fig. 10. Orthomosaic image of a section of Aklan River is shown in Fig. 10a. Fig. 10b shows the post-processed image after contrast enhancement and maximum likelihood classification techniques were performed. Red circle represents the plume training pixels. Light green circle represents aggregate training pixels. Magenta circle represents vegetation training pixels. The yellow region represents the generated plume classification area of 149,550 square meters.

(a)

(b)

Fig. 9. The total area that needs to be covered by aerial imagery (yellow region) is shown in Fig. 9a. The red region indicates an area that cannot be mapped yet due to close proximity to an airport. The cyan boundary indicates an area that has already been mapped. The mapped section is shown as an orthomosaic in Fig. 9b.

massive infrastructure development in the past two years from the time of this writing. The current administration is heading the construction of new paved roads, two bridges, a police station, municipal health clinics and flood control systems. It is expected that this massive and immediate difference in infrastructure would generate significant changes in the land-use scheme of the municipality.

An aerial survey was done in order to monitor the progress of a farm-to-market road and bridge in Javier, Leyte. Fig. 11 shows the progress done in the infrastructure. The aerial survey provided the LGUs with information to determine regions on which private tracks needed to be purchased and an estimate of how much forest needs cutting to secure environmental clearance. In addition, the imagery facilitated release of funding from budgetary agencies. The final imagery, shown in Fig. 11c, provided closure and proof of project completion.

IV. Conclusion and Future Work

The creation of an aerial imagery consortium has enabled collaborative work among different researchers involved in UAV technology, disaster science, environmental management and urban planning. The various applications discussed have shown that UAV aerial imagery provides domain experts and decision makers with data essential for analysis and effective action. However, the aerial imagery data need to be verified with ground truth in order to produce more accurate information. The aerial imaging workflow allowed for consistent output of aerial imagery data that could be shared more easily using the web-based platform, VEDA.

Future work by the consortium will focus on collecting more data for the current use cases, and searching for new applications. In addition, the aerial imaging framework will be further developed to automate more processes, such as image filtering and image contrast enhancement. Autonomous take-off and landing will be configured for the custom UAV in order to reduce the need for a skilled pilot. A catapult system will be created for the UAV to launch in areas with a small clearing and a parachute system will be added in order to reduce the risk of damage due to belly landings.

(a) (b) (c)

Fig. 11. Images taken over the course of two years in the development of a new road and bridge in Javier, Leyte. Fig. 11a shows an image of the area before the farm-to-market road and bridge began. Fig. 11b shows the completion of the road and finally the bridge Fig. 11c.

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