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SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

SMALL UNMANNED AIRCRAFT (SUA) PILOT PROJECT

DECEMBER, 2015

THE UNIVERSITY OF RHODE ISLAND GRADUATE SCHOOL OF OCEANOGRAPHY | CRC COASTAL RESOURCES CENTER

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Acronyms

CAA	Civil Aviation Authority
CCM	University of Cape Coast Center for Coastal Management
DFAS	UCC Department of Fisheries and Aquatic Science
DSAS	Digital Shoreline Analysis System
DSM	Digital Surface Model
FLIR	Forward Looking Infrared
FON	Friends of the Nation
GIS	Geographic Information System
GPS	Global Positioning System
HM	Hen Mpoano
LiDAR	Light Detection and Ranging
MPA	Marine Protected Area
MP&C	Mission Planning and Control
NGO	Non-Governmental Organization
QA/QC	Quality Assurance/ Quality Control
RGB	Red Green Blue
SFMP	Sustainable Fisheries Management Project
SLR	Sea Level Rise
SNV	SNV Netherlands Development Organization
TCPD	Town and Country Planning Department
UAV	Unmanned Aerial Vehicle
UCC	University of Cape Coast
UCC Geo	University of Cape Coast Department of Geography
UNDP GEF	United Nations Development Program/ Global Environmental Facility
URI	University of Rhode Island
USA	United States of America
USGS	U.S. Geological Survey
USAID	United States Agency for International Development

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PART A – PROJECT DESCRIPTION

Introduction

Advances in technology over the last decade have made Unmanned Aerial Vehicles (UAVs), and the imagery they capture, a valuable tool for environmental research and scientific analysis. With a wide array of sensors currently available, systems can be tailored to specific needs including localized base mapping, elevation modeling, vegetation analysis or health, wetland delineation and coastal monitoring. UAV systems fill an important niche for researchers, filling the void between course satellite imagery and traditional, expensive aerial surveys. With rapid deployment and low flight ceilings, these systems are not hampered by clouds or weather, and provide a cost-effective means of acquiring accurate, on-demand digital data.

The popularity of these systems stems from the level of flexibility these units provide. Being highly mobile and easy to deploy, UAV systems allow researchers to survey specific areas at

Figure 1: Pilot UAV study areas along the western coastline of Ghana.

regular intervals to establish baseline conditions and monitor/quantify change. Core functionality is derived from the georeferenced, high-resolution color images these systems capture (< 5cm ground sample distance) and the speed with which output products can be generated. Typical data products include digital ortho-photo mosaics and elevation/surface models which are easily brought into a Geographic Information System (GIS) for visualization, data extraction and further analysis.

Demonstration Projects

To highlight the utility of UAV imagery for evaluating the health and preparedness of coastal ecosystems and infrastructure, a series of pilot studies (Figure 1) were conducted for priority areas identified through the USAID-funded Sustainable Fisheries Management Project (SFMP):

- Mapping the fisheries value chain and economic development along the waterfront (Axim)
- Shoreline change and vulnerability of coastal infrastructure (Sanwoma)
- Wetland delineation and encroachment monitoring (Iture)

The purpose of these pilots was to demonstrate to project partners how a UAV platform operates, the quality of the imagery than can be captured and the value these products hold for deriving additional data that can feed the policy and decision-making processes.

Site Descriptions

Sanwoma

Sanwoma is a small fishing village located within the Ellembelle district of Ghana's Western Region. Located at the mouth of the estuary where the Ankobra river meets the sea, residents struggle to maintain their homes and livelihoods as they cope with the effects of riverine flooding and coastal erosion. The community faces daily inundation as river waters rise with the tide, and along the beach, coastal erosion rates are some of the highest in Ghana. The effects from climate change are likely exacerbating these issues and placing the community in an extremely vulnerable and precarious position.

Iture Wetland Complex

The Iture wetlands are part of the Kakum River estuary and are located in the Ghana's Central Region within the Cape Coast Metropolitan Assembly district. This wetland ecosystem is biologically diverse and contains all five species of mangroves present in Ghana. Primary stressors to the system are mangrove cutting and garbage dumping which continue to degrade the environment. The Iture mangroves have been identified as a good candidate for restoration and are in need of an accurate survey to record baseline conditions for future change monitoring.

Lower-Axim Landing site

Axim lies within the Nzema East district and is the largest grouping of fish landing sites in Ghana's Western Region. The area is highly developed and faces pressures from an eroding coast, failing shoreline infrastructure and poor sanitary conditions throughout the landing area. With little room for expansion, the Axim waterfront is in desperate need of redesign through sound community planning. Aerial imagery will provide district planners with the big-picture view needed to assess on-the-ground conditions and develop alternatives to improve health and safety conditions throughout the landing area.

UAV Permitting Process

This effort sought full compliance with Ghanaian Law regarding UAV operations as outlined by their Civil Aviation Authority (CAA). The CAA is the official permitting agency and all applications for flight must receive their approval before a permit will be granted. The permit application process is composed of the following steps:

1. Submission of a UAV flight request that includes:
    a. Purpose of the flights
    b. Location and dates of operation
    c. List of government offices or institutions involved and how the proposed operations will benefit these groups
    d. Type and specification of equipment to be used

e. Map of proposed operating areas
f. Non-refundable $1,000 USD permit fee

2. Submission of a Flight Operations Manual following CAA protocol that describes all components of safe equipment operation.
3. Provide proof of liability insurance during the operations period
4. Demonstrated flight capability of the lead UAV pilot

In return, the CAA issues a provisional approval letter and forwards the request to the Ghana National Security Office for final approval. Copies of the permit application, flight operations manual and CAA provisional approval letter are contained in Appendices 1-3.

PART B – EQUIPMENT AND IMAGERY CAPTURE

UAV System Description

Unmanned aerial vehicles designed for mapping or data capture differ from their recreational counterparts in that the actual drone is but one of four distinct components of an aerial survey platform.

The Aircraft

UAV bodies consist of a sensor platform and some means of lifting and propelling that sensor package over the ground. The are many styles of aircraft bodies, but the two most common classes are “fixed wing” or “rotary wing” (Figure 2). Fixed wing aircraft most closely resemble traditional model aircraft; generally having two wings and a single propeller. The primary strengths of these systems include typical flight times of 1-2 hours and higher operating speeds, which directly translate into more area covered per individual flight. Limitations of fixed wing platforms include the inability to hover in place and larger launch/land areas required for operation. However, the need for more space is mitigated by the increased flight times, allowing the operator to select an appropriate ground control area and fly some distance to the actual survey location.

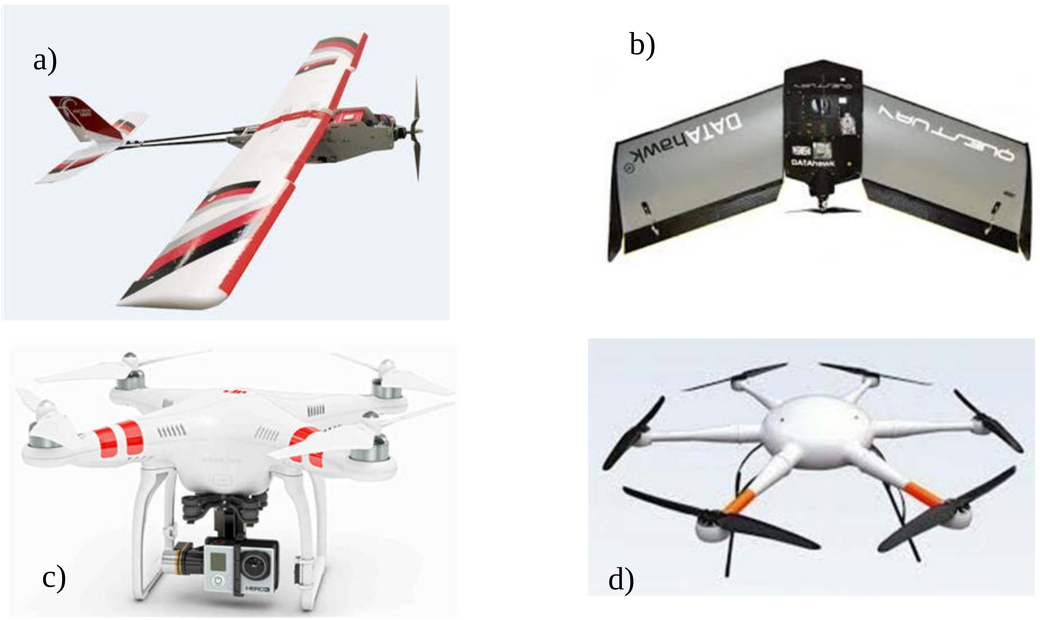

Figure 2 Common UAV body designs for both fixed wing and rotary wing aircraft. a) Precision Hawk Lancaster; b) Quest Data Hawk; c) DJI Phantom 2 Vision+; and d) HiWing HW-X210

Rotary wing systems can have 1 (helicopter) to 4 (quadcopter) or more propellers. These systems launch or land vertically and require much less space for ground control operations. In addition, these aircraft have the ability to hover in place making them an ideal platform for inspecting equipment and infrastructure, such as power transmission lines and oil platforms. The largest drawback to rotary wing platforms are the brief 20-60 minute flight times which impact operations in two ways. First, the operator must launch the aircraft in very close proximity to the aerial survey location since there is a limited battery capacity to transit to/from the area of interest. In difficult terrain or congested environments this can directly limit options for locating ground operations. Second, more flights are required to capture the same amount of imagery a fixed wing aircraft could collect in a single flight, necessitating additional batteries and in-field charging capabilities. With a full suite of sensors available for either body style, in the end, there is no right or wrong aircraft design. Each have their strengths and weaknesses and mission needs will ultimately dictate which system is preferable.

Sensor Systems

UAVs rely on remote sensing technologies to capture and record information about the areas in which they operate. While this ability to record data without physically making contact with an object or environment has traditionally been accomplished with satellites or large aircraft, the rapid miniaturization of these same tools now make them viable technologies for UAV surveying. Though a complete description of the various sensor types is beyond the scope of this document, Table 1 lists the common classes of sensor packages available and the primary uses for each. As with the airframe, design sensor choice will be driven by project goals. In general, true color and multispectral sensors will be the most affordable and will provide the greatest flexibility for the majority of environmental planning and monitoring applications.

Table 1 Common UAV sensor packages and typical applications for each.

Sensor Type	Primary Use
True Color Camera (RGB)	Base Mapping; Surveying
Multispectral	Agriculture; Vegetation Health
Hyperspectral	Vegetation Mapping; Species Identification
Light Detection and Ranging (LiDAR)	Elevation Mapping
Forward Looking Infrared (FLIR)	Mapping Thermal/Heat Signatures

Mission Planning and Control

The mission planning and control (MP&C) software is a critical component of an aerial mapping system and is generally included by the manufacturer as part of any UAV package intended for aerial surveying. The primary goal of conducting aerial surveying operations is the creation of a seamless, georeferenced, high-resolution orthomosaic created from the tens (10’s) to thousands (1000’s) of individual images captured by the UAV sensors. Once reconstructed, the imagery can be used as a base map for simple visualization or ingested into a Geographic Information System (GIS) for further data extraction and analysis.

In order to develop an accurate reconstruction, it is paramount that individual images are captured at regular intervals along the flight path and there is adequate overlap to facilitate accurate mosaicking during post-processing. In general, overlap of approximately 80% along track and 60% between tracks are required to correctly match adjacent images during mosaicking. Proper mission planning allows the operator to evaluate multiple sampling strategies by modifying all of the flight and image collection parameters, including the size and shape of the flight path, flight altitude and speed and the desired amount of image overlap (Figure 3). All of these variables have a direct impact on flight times and final image quality so it is important to develop a sound survey plan prior to actually beginning the image collection process.

During flight the MP&C connects to the Global Positioning System (GPS) satellite network for accurate position information allowing the software to control the UAV during the survey. The software follows the pre-determined mission plan and automatically triggers the sensor at regular intervals for data collection. Throughout the autonomous control process important information regarding UAV status is relayed to the operator on the ground including the aircraft's location, count of GPS satellites used to fix the aircraft's position, number of images collected and the remaining battery life. If problems are detected at any point during autonomous flight the operator can regain manual control of the UAV to correct the issue or land the vehicle. Prior to flight the software is used to design a survey plan which includes the area of collection, flight altitude, and required amount of overlap between images.

Figure 3 User interface for the Pix4D Capture App, a UAV Mission Planning and Control (MP&C) utility.

Image Post-Processing and Mosaicking

The American Society for Photogrametry and Remote Sensing (ASPRS) defines photogrammetry as *". . . the art, science, and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena."* The sub-discipline stereophotogrammetry is employed to estimate the three-dimensional position of an object based on measurements collected from two or more photographic images with different vantage points. Taken together, these areas of study provide the foundation for all post-processing of UAV imagery and are what allow hundreds of individual images to be "stitched" together into a seamless, spatially correct mosaic.

Modern image processing software has largely automated the mosaicking and orthorectification process for data captured via UAV and there are several third-party software manufacturers that provide the necessary tools. Figure 4 diagrams the complete post-processing workflow, however there are six major steps involved when converting individual UAV images into a seamless mosaic :

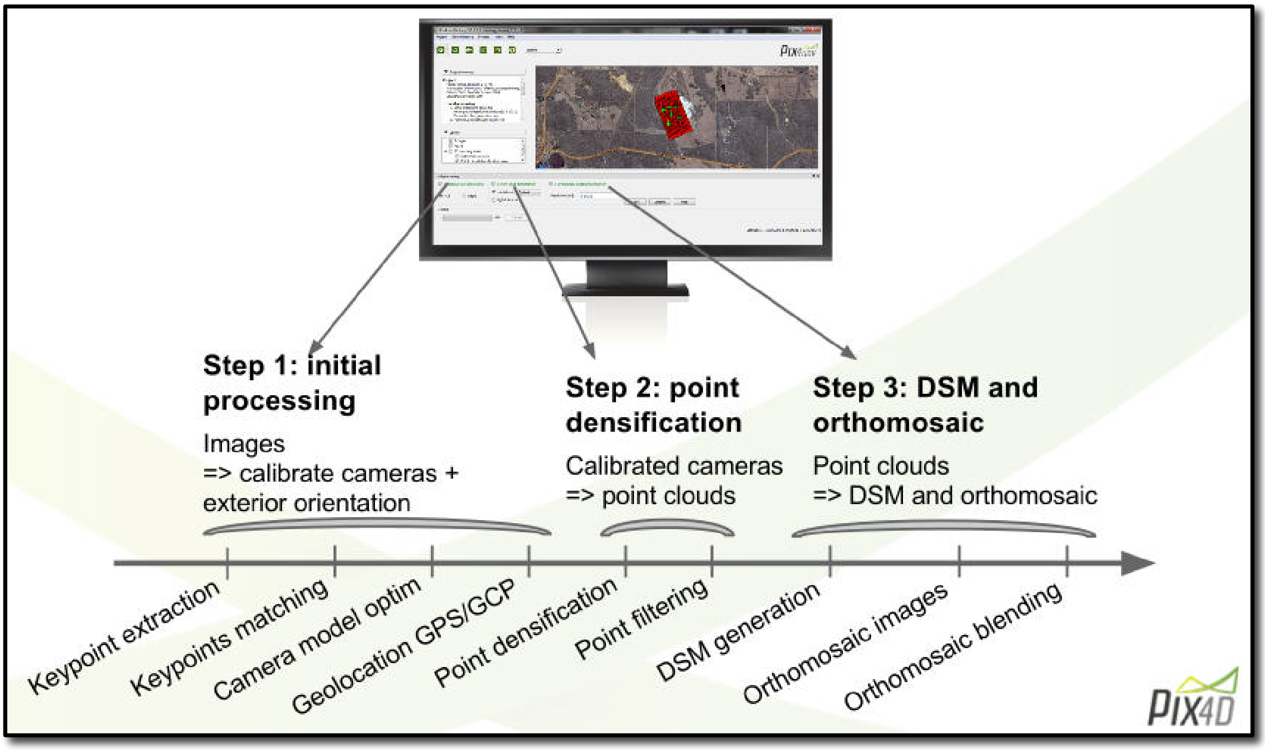

Figure 4 General and detailed workflows for post-processing UAV imagery. Source: Pix4D®.

1. Identify keypoints within each image –
   Keypoints are simply areas in the image with unique spectral characteristics that are easy to identify and target for matching. Building edges, shadow lines and areas of high contrast all could be used as keypoints. It is not uncommon for the software to identify up to 60,000 unique keypoints per single image.
2. Find matching points between images –
   The software will cycle through all of the available keypoints for an image and attempt to match with keypoints from adjacent images. With good imagery, the original 60,000 keypoints are reduced to an average of 3,000 matched pairs

per image. This matching process is dependent upon images having the correct amount of overlap; too little overlap and it's not possible to accurately join an image with its neighbors.

3. <u>Remove distortion caused by the camera lens</u> –
Wide-angle lenses common on UAV cameras introduce a type of optical distortion known as "fisheye" that must be corrected prior to mosaicking. With fisheye, objects in the center of the frame appear normal but objects along the margins are distorted so that straight lines appear curved (Figure 5).
4. <u>Orient each camera and generate a 3-D point cloud using triangulation</u> –
The software reads the imager header files to obtain the camera orientation (yaw, pitch, roll) for each image and uses this information to generate a georeferenced point for all of the matched keypoints. Figure 6 displays the triangulation process where a feature common to each image is identified and a line is drawn from the camera location to the point of interest. The point of intersection for these lines represents the position of the feature in geographic space ("Photogrametry", n.d.). Once finished with the keypoints, this process is repeated for any other objects that can be identified across multiple images and is known as point densification.

Figure 5 An example of a raw UAV image (left) showing the effects of fisheye distortion caused by the wide angle lens, and the same image after the distortion has been removed (right) during post processing.

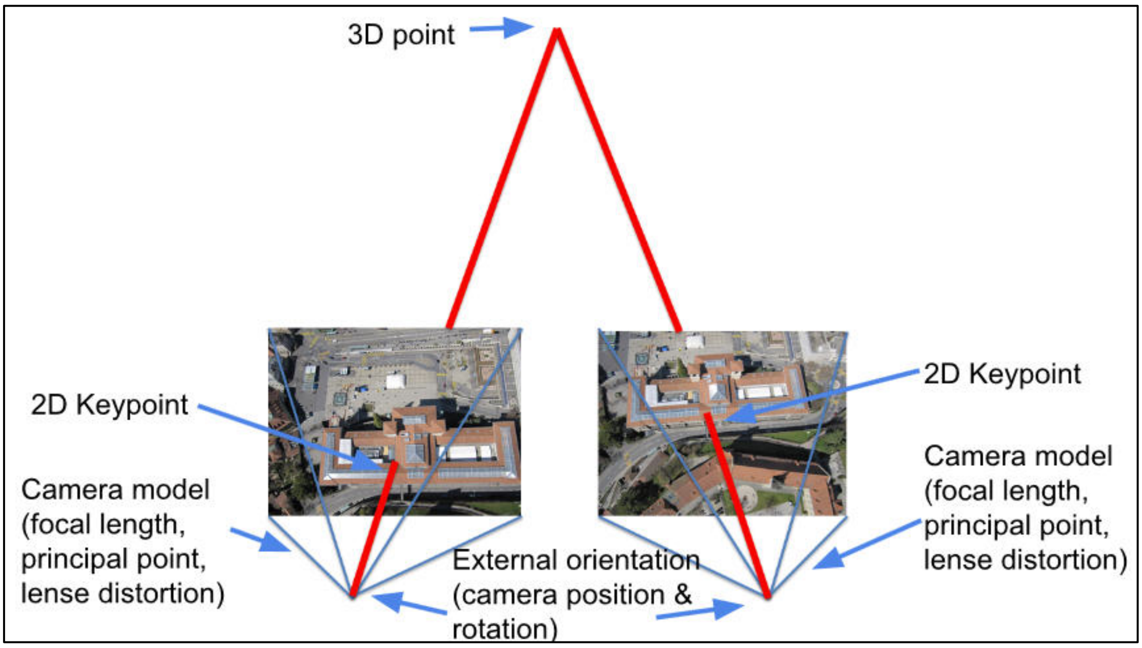

Figure 6 Stereophotogrammetry can be used to find the geographic position of an object common to both photos through triangulation. Source: Pix4D®.

5. Create a Digital Surface Model (DSM) –
   Using interpolation, the 3-D points are converted into a continuous, Digital Surface Model or DSM. Unlike a Digital Elevation Model (DEM) that displays only "bare earth" terrain elevations, a DSM contains terrain elevations in addition to buildings, trees and any other objects recorded by the UAV during flight.
6. Generate orthorectified image mosaic –
   An orthophoto is an aerial photograph that has been geometrically corrected to account for topographic relief, lens distortion, and camera tilt. Unlike an uncorrected aerial photograph, an orthophotograph has a uniform scale and can provide accurate measurements of true distance ("Othhophoto", n.d.). This correction process is applied to each image before a final blending of adjacent images into a seamless orthomosaic.

PART C – IMAGE COLLECTION AND PROCESSING

The UAV platform used for this work was a DJI Phantom2 Vision+; a rotary wing aircraft with a 14 megapixel true color camera and a maximum flight time of approximately 20 minutes. A full listing of the Phantom's technical specifications are listed in Appendix 4. The Pix4D Capture App was used for MP&C and was specifically designed to work with the Phantom aircraft and camera. All image post-processing and ortho mosaicking was completed using the Pix4Dmapper Pro® software.

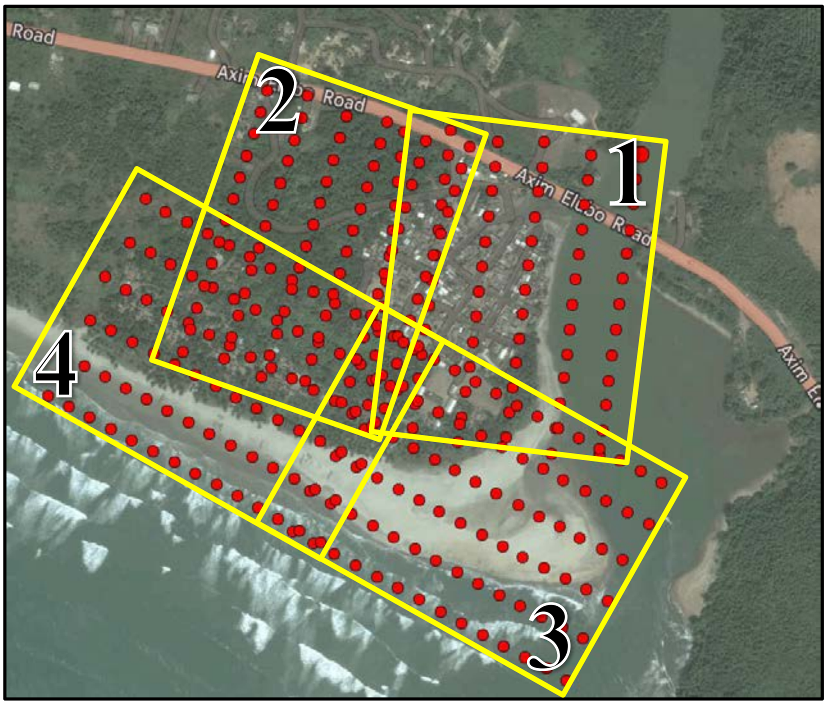

Figure 7 Mission planning for the Sanwoma study area showing individual flight layouts and amount of overlap between missions

Mission Planning

For each study location, the desired area of coverage was larger than what could be gathered from a single flight. The Pix4D Capture App was used to manually construct a series of overlapping mission grids appropriate for each situation. At each site, the size and shape of each flight pattern was determined by balancing site accessibility and the availability of launch/land points with maximum aircraft flight time. In all cases images were collected at 100m above ground level with approximately 80% overlap between images along the flight path. This resulted in a final image resolution of approximately 5cm. Figure 7 provides an example showing the Sanwoma study site and the approximate layout of each flight grid. Just as having the appropriate level of overlap is important between images of a single flight, multiple missions must also have adequate overlap so that all images from a study site can be tied together during post-processing.

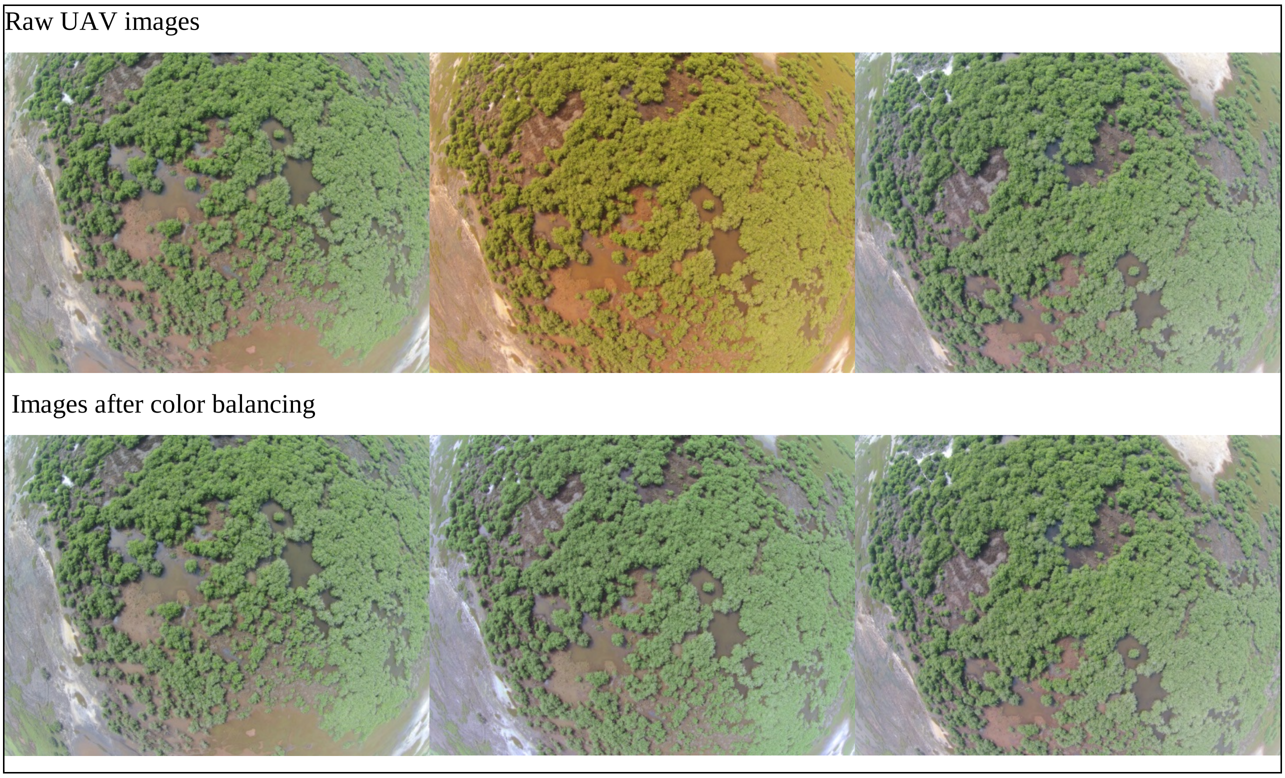

Figure 8 Three consecutive mangrove images along flight path before (Row 1) and after (Row 2) color balancing

Color Balancing Raw Imagery

After each flight, images were transferred from the aircraft to a laptop computer for quality checks and to safeguard the images should the UAV accidently be lost during a subsequent mission. During the quality control (QA/QC) process it was noted that the color balance between individual photos along the flight track could differ greatly depending on the amount of blue light recorded by the camera sensor. Too little light in the blue spectrum and the images retained a distinctly yellow tone that was very different from the surrounding photos. These off-color images surfaced randomly and appear to be directly related to the camera used by the Phantom 2 Vision+ platform. Since it was impossible to predict in the field what factor(s) were contributing to the off colors, it was determined that re-flying effected missions had a low probability of correcting the issue. Rather, the team chose to apply selective color correction during post-processing using the *Match Color* adjustment tool within the Adobe Photoshop CS® software package. As can be seen in Figure 8, this option provided an effective means of removing color deficiencies prior to final mosaicking.

Generating Mosaics

For each study area, images for individual flights were collected and processed as a single unit using the Pix4Dmapper Pro® (v2.0.104) software (Table 2). During processing, a Quality Report (Figure 9) was generated after each processing step that would highlight any potential problems detected either with the data or processing outputs. Examples of information contained in the report include the average number of keypoints identified per image, the number of points matched between images and whether the software was able to effectively correct for image distortion. Prior to final mosaicking the quality reports were reviewed and used to modify mosaicking parameters, if necessary, to ensure the best quality results. Copies of the quality reports for each study area are contained in Appendix 5. As a final step, each of the image mosaics were exported from Pix4D as georeferenced TIFF images that were directly ingested into the ArcGIS® 10.3.x software package for further analysis.

Table 2 Input and output summary for the image mosaicking process

Location	Flight Height	Number Flights	Number Images	Mosaic Resolution
Sanwoma	100m	4	324	5cm
Axim	100m	6	609	5cm
Iture	100m	7	823	5cm

Quality Report

Generated with Pix4Dmapper Pro version 2.0.104

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	Iture_Combined
Processed	2016-02-01 12:42:23
Average Ground Sampling Distance (GSD)	4.94 cm / 1.94 in
Area Covered	1.4692 km^2 / 146.921 ha / 0.5676 sq. mi. / 363.236 acres
Time for Initial Processing (without report)	03h:25m:54s

Quality Check

Images	median of 39319 keypoints per image
Dataset	822 out of 823 images calibrated (99%), all images enabled
Camera Optimization	0.74% relative difference between initial and optimized internal camera parameters
Matching	median of 2307.94 matches per calibrated image
Georeferencing	yes, no 3D GCP

Preview

Figure 9 Partial image quality report produced by Pix4D. These reports flag any potential issues with the data or processing allowing changes to be made prior to final mosaicking

PART D – METHODS AND FINDINGS

Sanwoma

The project emphasis for Sanwoma was to evaluate the role UAV imagery could play in identifying and quantifying threats to coastal communities. In Sanwoma, the imagery was used to aid vulnerability mapping efforts and evaluate the community's susceptibility to shoreline erosion and riverine flooding.

Erosion/Accretion rates for the immediate coastline were computed using the Digital Shoreline Analysis System (DSAS®) developed by the U.S. Geological Survey (USGS) (Thieler et al. 2009). Run as an extension from within ArcGIS®, this software constructs a series of transect lines perpendicular to the beach face and computes a rate-of-change between multiple shoreline positions. Shoreline location was determined by manually digitizing the most recent high tide line or "wet line" on both the existing 2005 orthophotos and the 2015 UAV mosaic. Because it was impossible to know the exact stage of the tide cycle at which the images were captured, the wet line provided the most consistent feature that could be identified in each set of imagery. An arbitrary baseline was created which served as the reference "0" point for measurements, and DSAS was used to generate a series of perpendicular transects at 50m intervals and compute rates of change over the 10-year period (Figures 10 and 11).

Along the open coast, erosion rates between 2005 and 2015 vary from approximately -1.6 m/yr at the western boundary of the community to over -4 m/yr as one moves east towards the river mouth. These rates align well with erosion estimates for the Ghanaian coast put forth by Ghana's Hydrological Services Department and in published literature (Appeaning-Addo, K. 2009; Boateng, 2012). Immediately inside the river's mouth accretion is the dominant process due to the strong longshore current driven by the prevailing southwesterly winds. Shoreline gains in this location range from 3 m/yr to 130 m/yr, though this area remains unstable and undevelopable. Coastal storms, longshore currents and riverine flow volume all have a direct impact on the durability of the deposited sands, and it is unlikely that these new low-lying deposits will transform into anything more than a temporary environment.

In addition to vulnerabilities from coastal erosion, the community experiences daily flooding due to the confluence of tides and riverine flow. Barring significant weather events, flood waters due not enter the community from the ocean through overtopping of the dunes, but rather through the low-lying canoe landing site along the river. Although there is no small-scale topographic data available for much of Ghana, the high-resolution Digital Surface Model (DSM) created as part of the image mosaicking process (Figure 12) provided the foundation for visualizing flood impacts. Elevation values for the water level were obtained by inspecting the imagery mosaic and identifying areas that were wet and had obviously been submerged during the last high tide. Coupled with field observations made during the UAV flights, the DSM was interrogated in several locations and the values averaged to arrive at a base flood height. Using a standard "bath tub" approach, an inundation surface was generated by filling the DSM to the estimated daily flood level (Figure 13). Due to Sanwoma's existing vulnerability to flooding and low topographic relief, the potential effects from Sea Level Rise (SLR) are also a concern for the long-term sustainability of this community. Mean sea level is rising approximately 3 mm/yr in Ghana and modeled predictions indicate that water levels could rise approximately 36 cm by 2100 (Sagoe-Addy and Addo, 2013). To visualize how SLR might affect the daily flooding of the community, inundation modeling was repeated with an additional 40 cm added on top of the base water level.

Sanwoma Discussion

The UAV mosaic provided the means to visualize two prominent threats to the community in a manner not possible with existing imagery or data. Having up-to-date aerial photography meant that not only could current erosion rates could be estimated, but the dynamic nature of the location could be visualized. Coastal erosion is clearly an issue for the community and this will likely worsen in the future as sea level rise aggravates the problem by exposing more shore to the physical processes that cause erosion. While the receding coast may not have a direct impact on the community now, as can be clearly seen in the imagery, Sanwoma is rapidly losing the undeveloped buffer area along the coast that has historically provided a level of protection for the community and the infrastructure within. Erosion impacts will be most apparent in the west where over 40m of coastline have been lost over the last ten years and where more frequent overtopping of the dunes by waves will threaten the non-permanent villagers living there.

The surface model developed as part of the mosaic workflow also provided a new means to visualize and quantify flooding impacts Sanwoma. It's no secret that high waters cause daily issues for the community, but the DSM affords much greater detail in visualizing the scope of the problem and identifying who is most affected. Combined with the imagery, the DSM open new doors for planning efforts and can be used for siting important infrastructure, limiting development in hazardous areas, assessing flood mitigation options and making future flood exposure predictions.

Iture Wetlands

The wetland complex at Iture was specifically selected as a study site to evaluate the efficacy of UAV imagery to quantify mangrove stand size, identify areas of cutting and aid replanting efforts. Different from larger mangrove stands within the Ankobra and Pra estuaries, the mangroves at Iture are a compact package that could be completely surveyed using a small UAV with limited flight times. The challenge, however, was that the DJI Phantom camera was not designed for vegetation survey work and only records traditional 3-band (Red, Blue, Green or RGB) color images not intended for these types of analyses. While it is possible to manually digitize mangrove stands directly from color imagery, this is laborious and time consuming work. It was hoped that alternate methods could be employed that would automate the delineation process and reduce overall processing time.

Unlike ordinary color photographs, multispectral images capture information in both the visible and non-visible portions of the electromagnetic spectrum (Figure 14). For vegetation or agricultural studies, it is common to utilize imagery having one or more additional bands of information within the infrared portion of the spectrum to aid in identifying vegetation class (wetland or upland) and/or assessing vegetation health. Lacking this information in the Iture mosaic, a hybrid method of mangrove identification was explored that coupled spectral grouping with manual classification techniques.

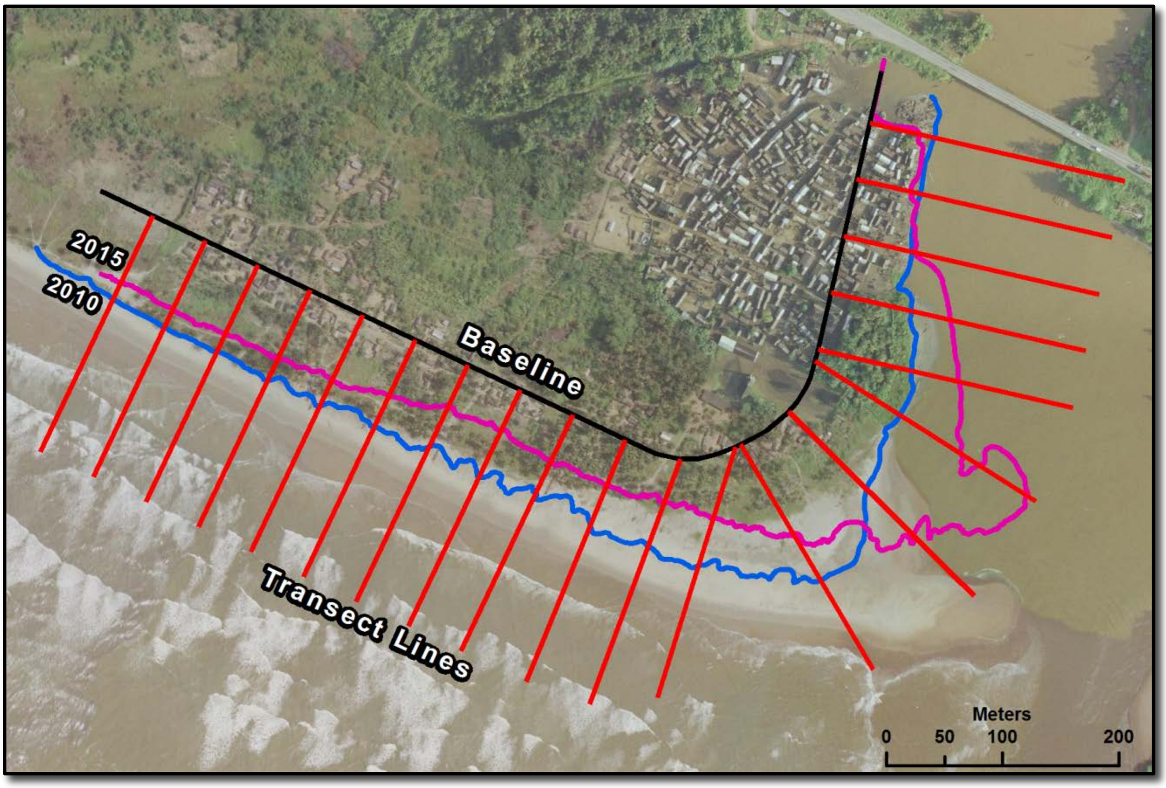

Figure 10 DSAS outputs for the shoreline change analysis at Sanwoma, Ghana. Shown are the average yearly change rates in meters, with the 10-year cumulative shoreline change envelope in parentheses. Negative rates signify erosion; positive values indicate accretion

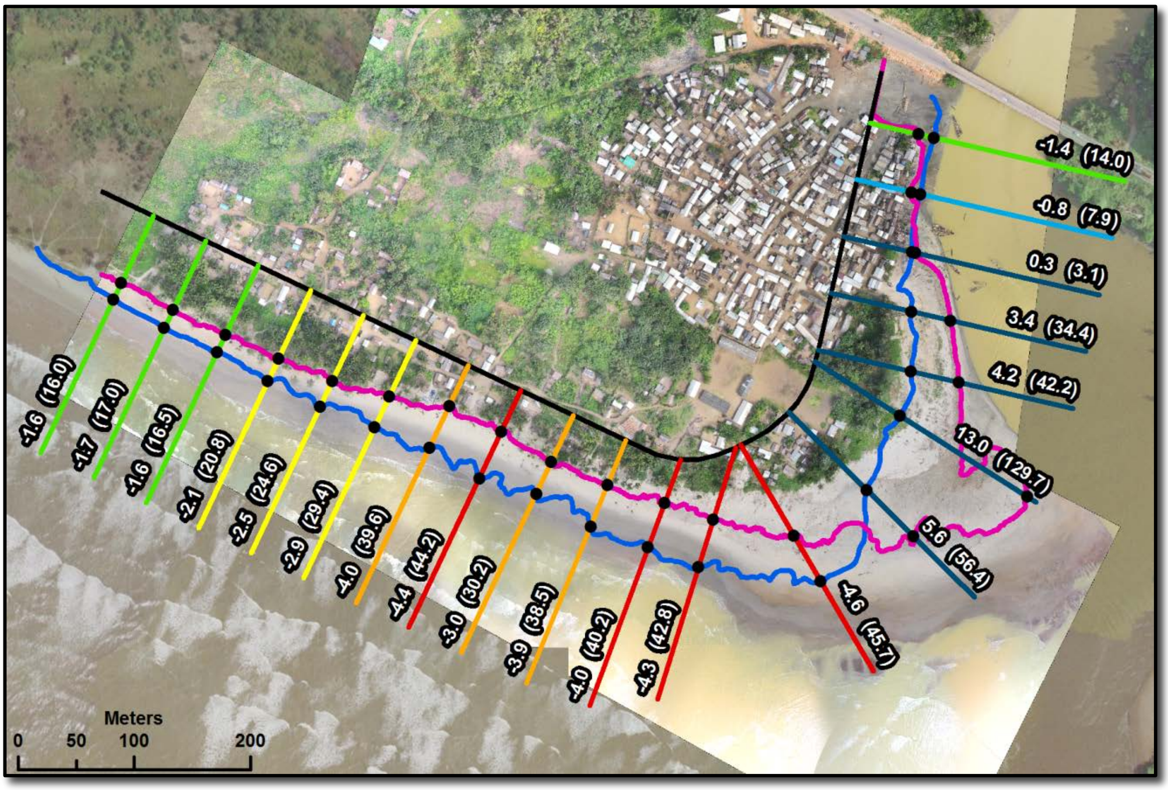

Figure 11 Inputs for the shoreline change analysis at Sanwoma, Ghana. Displayed are the manually digitized shoreline positions from 2010 (blue) and 2015 (pink), along with the reference baseline and shore transects used by DSAS to compute the change metrics

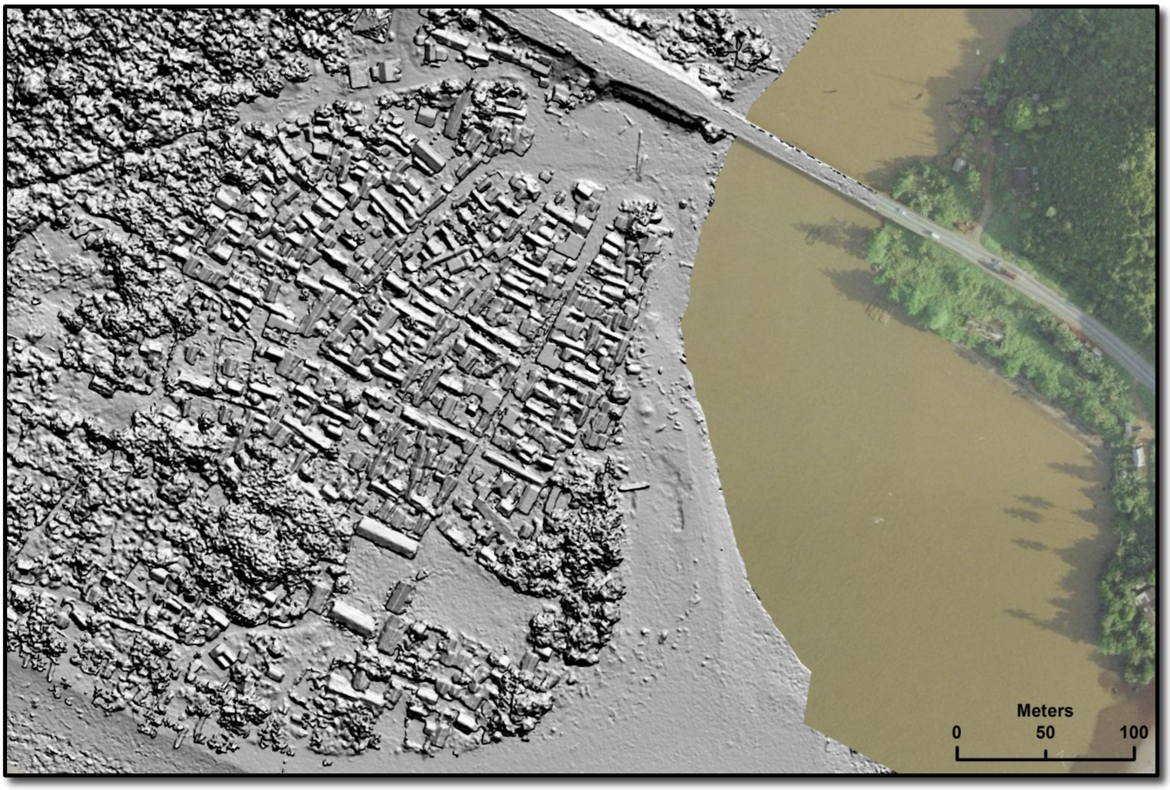

Figure 12 Digital Surface Model (DSM) for Sanwoma that was generated as part of the image mosaicking process. Under normal weather conditions flood waters enter the community daily through the canoe landing area just south of the highway bridge

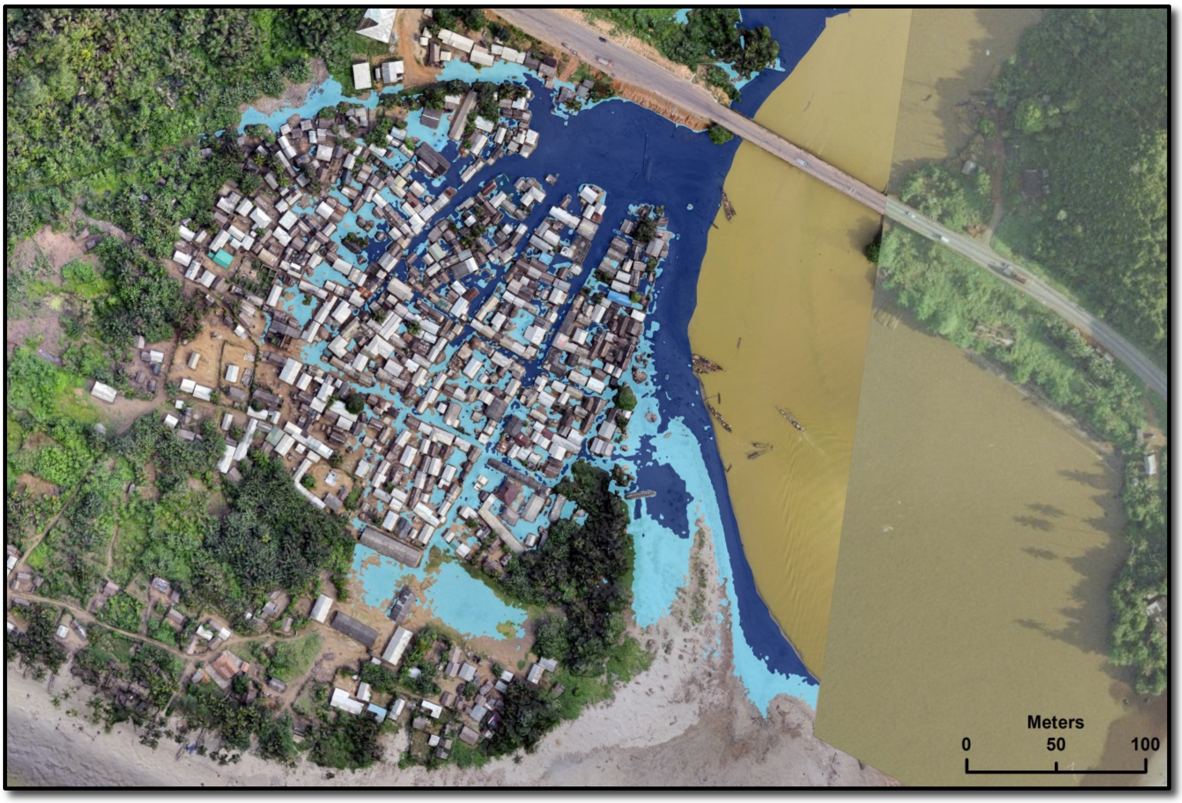

Figure 13 Estimated flood inundation levels for Sanwoma. Dark blue areas represent current daily flood conditions under normal circumstances; light blue areas highlight the probable extent of daily flooding with the addition of 0.4m of sea level rise

Ordinary color photographs only record information in the visible portion of the spectrum (RGB) while multispectral images for vegetation studies include additional bands of information in infrared portion of the spectrum. Source: MicaSense®.

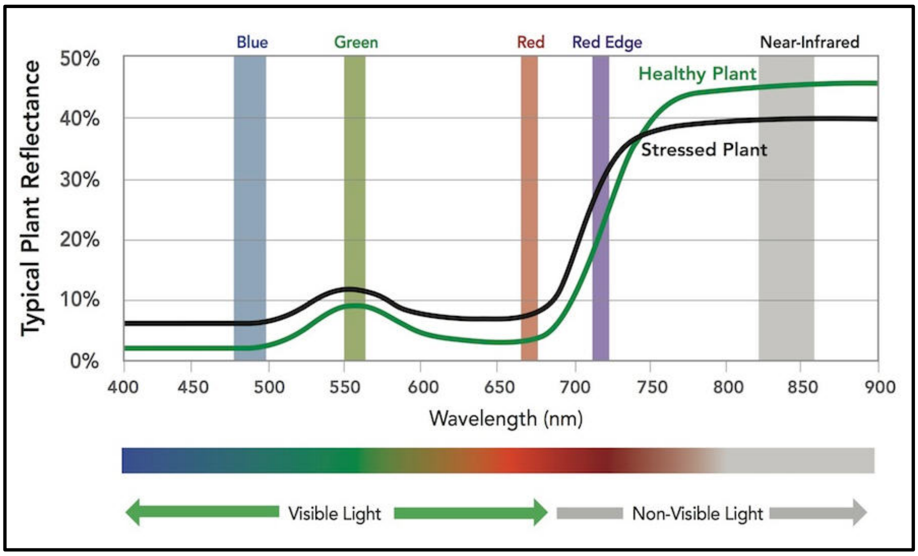

Figure 14 The electromagnetic spectrum as it relates to vegetation studies showing both the visible and non-visible portions.

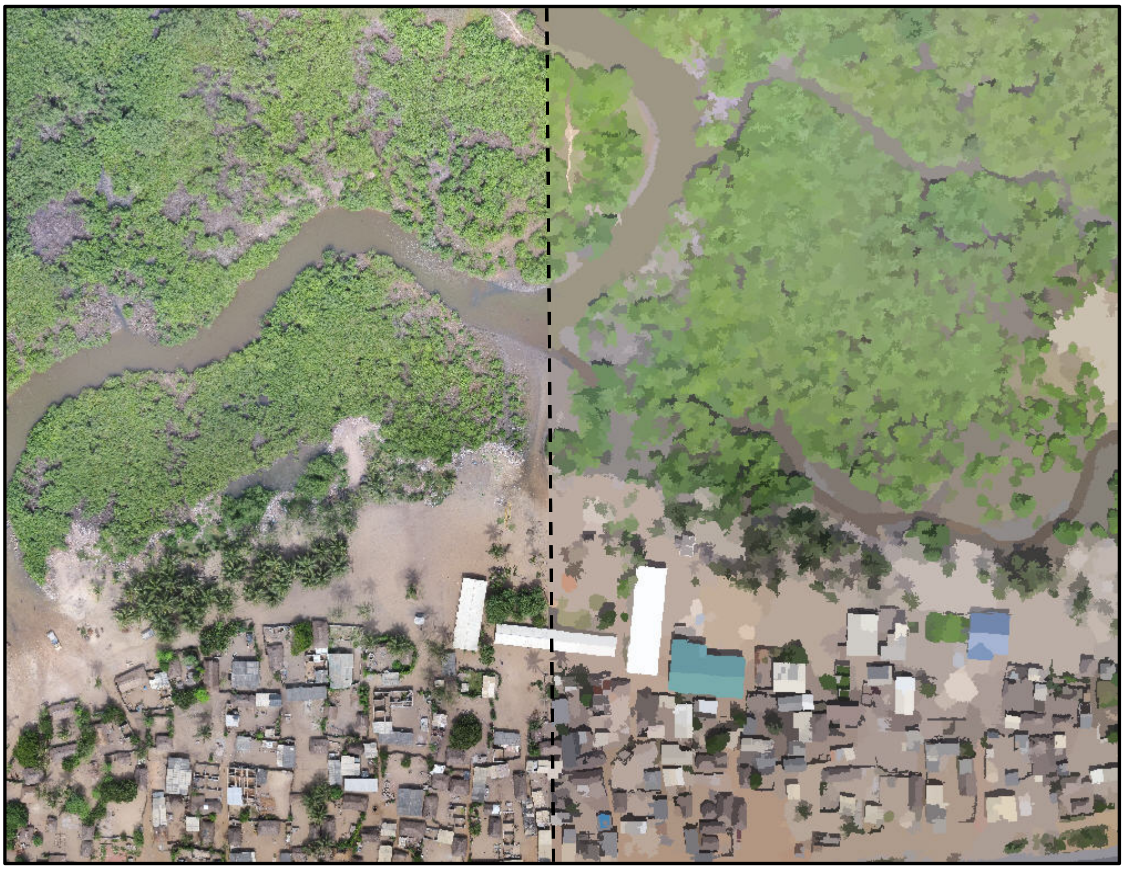

Figure 15 A subset of the Iture image mosaic displaying the original image (left) alongside the results from the image segmentation process (right).

With the release of ArcGIS 10.3, Esri® introduced a new suite of image processing tools for image segmentation and classification. The *Segment Mean Shift* tool, similar to an object-based classification, departs from conventional pixel-by-pixel image analysis and allows spectrally similar adjacent pixels to be grouped into much larger objects and manually placed into categories. This process, while not fully automated, provided a direct means of identifying mangrove areas despite the lack of multispectral data. Figure 15 provides a side-by-side comparison of the image before and after the segmentation tool was run.

After completing the segmentation, a generic classification scheme was created to define broad classes of information (i.e. healthy mangrove, dying or cut mangrove, open water, bare sand, other, etc.) and representative clusters of pixels were placed into each bin. The exact number and designation of each class was unimportant; they were simply groups of information that were readily identifiable in the imagery. These training samples were then used as the basis for the *Interactive Supervised Classification* which applied the spectral characteristics of each group to the entire mosaic, placing all of the pixel clusters into one of the available classes.

Figure 16 Iture wetland complex showing both healthy mangrove areas and locations where cutting has occurred.

Without the benefit of data from at least one infrared band, results from the segmented classification were quite poor as there was simply too much spectral similarity between objects of different groups – mangroves resemble grass flats, wet muddy areas appear similar to locations where mangrove are dead/dying or have been cut and turbid waters look much like wet sandy areas. Despite cross-class contamination, the segmentation did a very good job of placing all of the vegetation into a single group due to the strong reflectance of light in the green wavelength. Thus, while the mangrove class may have included extraneous information pertaining to grass flats, palm trees and private gardens, most all of the actual healthy mangrove clusters were included as well. Using this knowledge, the mangrove class was exported as a separate polygon layer and manually edited to delete all of the erroneous bundles of pixels that had been included. This workflow was repeated to isolate locations where mangrove cutting has occurred (Figure 16), and summary statistics were generated to tabulate the area covered by each. Through this process it was determined that the Iture wetland complex holds approximately 38.1 hectares of living mangroves, with 3.5 hectares showing obvious signs that the stand is dead, dying or has been cut.

Iture Discussion

The lack of multispectral imagery definitely added challenges to the mangrove delineation process, but regardless, the UAV mosaic proved extremely useful for quantifying mangrove stand size. What the imagery lacked in spectral capabilities, it made up for with its resolution that allowed mangrove patches to be clearly delineated both by the software algorithms and by eye.

As described by Kuenzer et al. (2011), aerial photography can play an important role in mangrove management and is particularly well suited for local studies aimed at mapping local ecosystems and monitoring change. Mangrove ecosystems are typically difficult to access making traditional field surveys very time-consuming and expensive. The main advantages of UAV imagery are the low acquisition costs, ready availability and high spatial resolution. As confirmed through this work, a principal disadvantage is that detection automation is usually not possible without at least 1-band of information in the infrared portion of the spectrum and strong visual interpretation skills are required.

It is clear from the imagery that cutting of the Iture mangroves has occurred in the past and continues to this day. While this work identified a small percentage (< 10%) of the Iture stand displaying definite signs of degradation, these numbers could increase significantly with additional ground surveys as there were large bare sections on the imagery where it was not possible to determine whether the main drivers were natural or anthropogenic. With regard to mangrove harvesting, two questions arise: 1) Is cutting is having a negative impact on the ecosystem?; and 2) Is cutting is being performed in a sustainable manner?

The Iture wetland complex is unique in that it possess very rich diversity containing all five of the mangrove species present in Ghana (deGraft-Johnson, 2010). From 2008 to 2010, the UNDP GEF Small Grants Program funded an effort in the Iture complex entitled "*Integrated Management of Iture Mangroves to Rehabilitate the Degraded Abakam-Elmina Coastal Wetlands and Ramsar Sites in the Central Region*". Pertinent to the funding decision was an assessment concluding the Iture mangrove ecosystem was moderately polluted, over stressed but an overall good candidate for restoration. In 2011 Sackey et al. awarded the Iture system a poor site rating suggesting the system was still experiencing severe stress due to cutting activities and garbage dumping. Current, high-resolution UAV imagery has the ability to fill an important void in ecological surveys and habitat vulnerability assessments by providing the necessary baseline data essential to ongoing monitoring efforts, performing change detection and identifying prime locations for replanting. Though not explored for this work, the underlying surface model from the mosaic also holds promise for assessing canopy height and estimating biomass; both important parameters in determining the carbon sequestration potential of the ecosystem.

Lower Axim Landing Site(s)

Lower Axim differed from the other two locations studied in that quantitative analyses were not part of the workplan, rather the goal was to provide a current, high-resolution canvas for community planning efforts led by the Ghana Town and Country Planning Department (TCPD). Part of the Ministry of Environment, Science and Technology, TCPD is charged with providing planning services to promote the responsible development of human settlements.

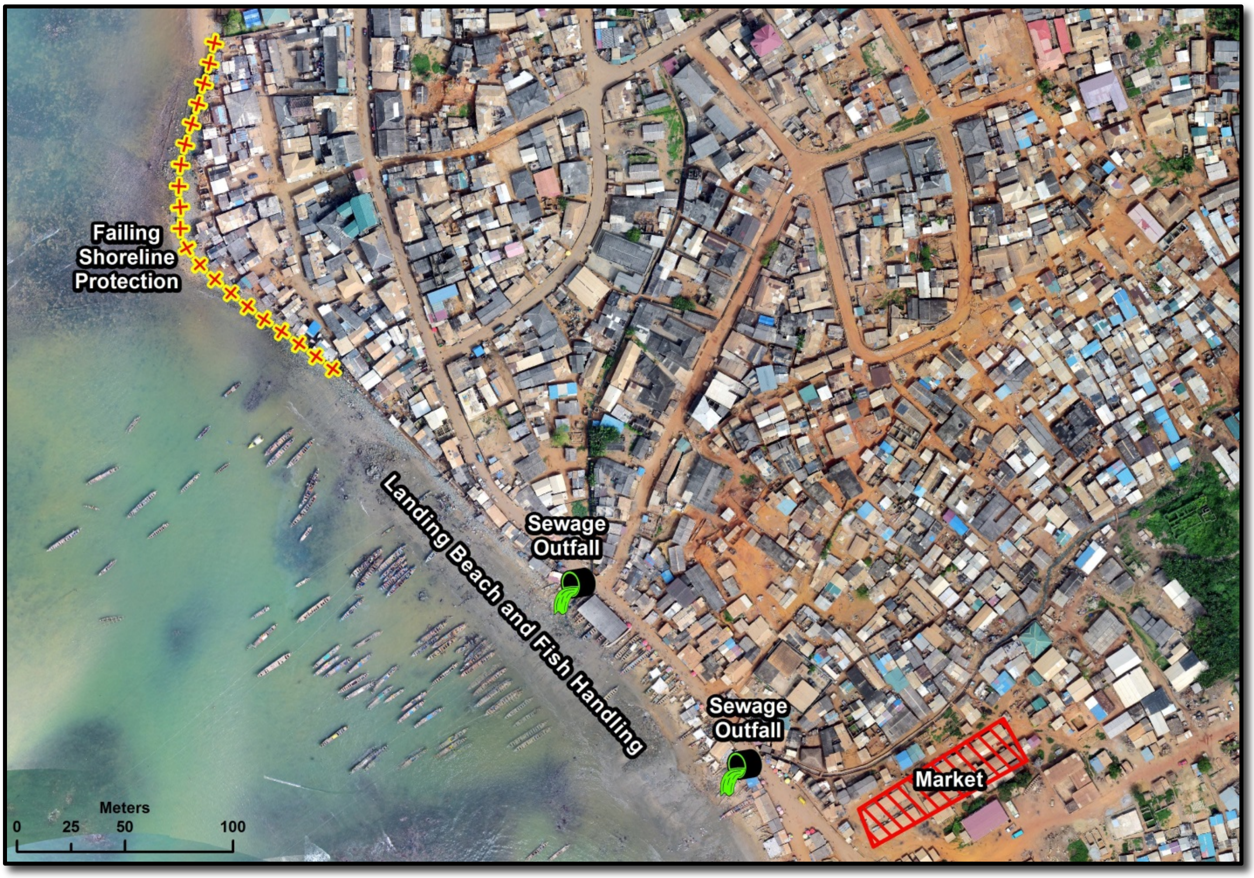

Figure 17 One of the canoe landing areas in Lower Axim showing the location of fish handling in relation to other health and safety issues which include poor sanitation and degraded shoreline protection.

As part of their work in the Western Region, TCPD and their technical contractors Spatial Solutions are in the process of mapping the fisheries value chain along the Lower Axim waterfront to evaluate strategies for the redevelopment and management of the canoe landing and fish handling areas. According to the 2013 Marine Canoe Frame survey, the multiple landing beaches of Upper and Lower Axim comprise the largest landing area in the Western Region with greater than 400 canoes and 4,000 fishermen.

From a planning perspective, Lower Axim is a challenging environment with dense development and limited expansion potential along the waterfront. Critical issues facing the community are ongoing shoreline erosion, failing shoreline protection infrastructure and poor sanitary conditions surrounding the landing area (Figure 17). Of immediate need to Spatial Solutions and TCPD was a high-resolution orthomosaic of the area that could be used to visualize existing conditions and test redevelopment designs.

PART E – SUMMARY

This project sought to evaluate emerging UAV technology and demonstrate its utility for providing high-resolution base imagery that supports a host of data collection, environmental/community planning and analytical research activities. With a suite of sensors available to meet different project needs, UAVs can play a critical role in mitigating a problem common in developing nations – the lack of current data to support effective decision-making.

Due in large part to the successes of this work, Year2 Q3 of the SFMP will see additional small UAV flights to capture imagery for priority locations and will directly support activities by SFMP implementing partners Friends of the Nation (FoN), Hen Mpoano (HM), SNV and Spatial Solutions/TCPD. Proposed survey locations include the landing sites at Old Shama and Elmina (fisheries infrastructure), the Anlo Beach communities (erosion, vulnerability and improved smoker siting), portions of the Pra wetland complex (mangrove monitoring and replanting) and the communities of Supomu Dunkwa and Beposo (TCPD community development).

As was done during the pilot study, upcoming work will extend beyond simple data collection and will include true capacity building activities for partner organizations. At the NGO level (FoN, HM, SNV) this will translate into direct assistance with extracting derivative data from the imagery, GIS database development and aid with geospatial analyses to support SFMP activities. For cooperating USAID partners (UCC Department of Geography; UCC Center for coastal Management; TCPD/Spatial Solutions) the focus will be on enhancing technical capabilities by including personnel from each organization in the data acquisition process and providing imagery to feed ongoing projects. Finally, at the institutional level (UCC) the aim will be to lay a foundation of internal experience and knowledge that the university can capitalize on to become a national leader in the application of UAV technology for environmental management and coastal planning.

For all of the successes, this pilot study also highlighted practical limitations with regard to the application of recreational UAVs for aerial surveying – the camera, mission planning and control and GPS positioning systems simply were not designed for this type of application which demands a higher level of precision than the average user requires. One means of overcoming these limitations that should be explored would be an organizational partnership to acquire a larger fixed-wing UAV platform designed specifically for aerial surveying. A system of this type would allow larger areas to be surveyed and would possess multispectral imaging capabilities to provide the greatest flexibility in meeting partner needs.

An example of this might be a collaborative effort between the USAID-funded Sustainable Fisheries Management Project (SFMP), and the University of Cape Coast's Center for Coastal Management (CCM) and Department of Geography (UCC Geo). The focus of this partnership would be on building institutional capacity to utilize new technology in the push for sustainable development and resource management. This arrangement is a win-win-win: as a nationally recognized spatial analysis laboratory, UCC Geo would receive training in cutting-edge technologies to support their work in resource management and environmental analysis; the CCM would receive similar training, and would work to improve the geospatial information base for Ghana's coastal region to aid spatial planning activities at the regional and district levels; and the SFMP, through their network of engaged project partners, would have the opportunity to showcase innovative methods that will improve the quality of project deliverables and serve as a catalyst for strengthening multidisciplinary, multi-organizational partnerships.

Without a doubt, advances in technology have made it much easier for researchers and project managers in developing nations to acquire the data they need to effect real change and to develop policies based on sound science. UAVs have a strong role to play in this, and as results from this pilot indicate, there is simply no other means of data collection that provides the same level of quality, flexibility and cost-effectiveness for small to medium scale efforts as UAV-acquired information.

PART F – REFERENCES

Akyeampong, S., K. Amador, and B. Nkrumah. 2013. Report on the 2013 Ghana Marine Canoe Frame Survey. Republic of Ghana, Ministry of Fisheries and Aquaculture Development, Fisheries Scientific Survey Division. Information Report #35. 76pp.

Appeaning-Addo, K. 2009. Detection of Coastal Erosion Hotspots in Accra, Ghana. *Journal of Sustainable Development in Africa*. 4(11):253-258.

Boateng, I. 2012. An Application of GIS and Coastal Geomorphology for Large Scale Assessment of Coastal Erosion and Management: A Case Study of Ghana. *J Coast Conserv*. 16:383-397.

deGraft-Johnson, K.A.A., J. Blay, F.K.E. Nunoo, and C.C. Amankwah. 2010. Biodiversity Threats Assessment of the Western Region of Ghana. The *Integrated Coastal and Fisheries Governance (ICFG) Initiative Ghana*.

Kuenzer, C., A. Bluemel, S. Gebhardt, T. Vo Quoc, and S. Dech. 2011. Remote Sensing of Mangrove Ecosystems: A Review. *Remote Sens.* 3:878-928.

Sackey I , W. M. Kpikpi, and A-W. M. Imoro. 2011. Ecological Studies in the Iture Estuary Mangrove Forest in Ghana. *Journal of The Ghana Science Association*. 13(2):37- 44.

Sagoe-Addy, K. and K.A. Addo. 2013. Effect of Predicted Sea Level Rise on Tourism Facilities Along Ghjana's Accra Coast. *J. Coast Conserv.* 17:155-166.

Thieler, E.R., E.A. Himmelstoss, J.L. Zichichi, and A. Ergul. 2009. Digital Shoreline Analysis System (DSAS) version 4.0— An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278.

Wikipedia contributors. Orthophoto. Wikipedia, The Free Encyclopedia. September 14, 2015, 10:31 UTC. Available at: https://en.wikipedia.org/w/index.php?title=Orthophoto&oldid=680967581. Accessed April 18, 2016.

Wikipedia contributors. Photogrammetry. Wikipedia, The Free Encyclopedia. April 8, 2016, 11:57 UTC. Available at: https://en.wikipedia.org/w/index.php?title=Photogrammetry&oldid=714220947. Accessed April 9, 2016.

PART G - APPENDICES

A1: UAV Permit Application
See Attached document

A2: Operations Manual
See Attached document

A3: CAA UAV Provisional Flight Approval
See Attached document

A4: DJI Phantom 2 Vision+ Specifications

Aircraft

Weight (Battery & Propellers Included)	1242g (2.8307lbs)
Diagonal Length (Motor-Motor Distance)	350mm (13.780in)
Max Flight Time	25mins
Max Ascent / Descent Speed	Ascent: 6m/s; Descent: 2m/s
Max Flight Speed	15m/s (Not Recommended)
Hover Accuracy (Ready To Fly)	• Vertical: 0.8m (2.6247ft) • Horizontal: 2.5m (8.2021ft)
Max Yaw Angular Velocity	200°/s
Max Tiltable Angle	35°
Supported Battery	DJI 5200mAh LiPo Battery

Gimbal

Control Accuracy	±0.03°
Controllable Range	Pitch : -90°—0°
Maximum Angular Speed	Pitch : 90°/s
Working Current	Static : 750mA; Dynamic : 900mA

Camera

Sensor Size	1/2.3″
Effective Pixels	14 Megapixels
Image Resolution	4384×3288
File Formats	• JPEG • RAW
Video Recording	• 1080p/1080i • 720p
Frame Rate	• 30 fps (1080) • 60 fps (1080/720)
Video Transmitting	• 640×640 (30fps) • 320×240 (15fps)
Recording FOV	110° / 85°
Operating Environment Temperature	0℃-40℃

Remote Control

Type	New version, left-dial
Features	Preinstalled smartphone holder
Operating Frequency	5.728 GHz－5.85 GHz
Communication Distance (Open Area)	• CE Compliance: 400m (1312.3ft) • FCC Compliance: 800m (2624.7ft)
Receiver Sensitivity (1%PER)	-93dBm
Transmitter Power	• CE Compliance: 25mW • FCC Compliance: 100mW
Working Voltage	120 mA@3.7V
Built-In LiPo Battery Working Current/Capacity	3.7V, 2000mAh
Left Dial	√ Control gimbal pitch movement
Throttle Lock	√ Lock the throttle stick
Trainer Port	√ Run simulation application to practice your flying skills

DJI 'Smart Battery'

Type	3S LiPo
Capacity	5200mAh, 11.1V
Charging Environment Range	0℃ to 40℃
Discharging Environment Range	-20℃ to 50℃

Range Extender

Operating Frequency	2412-2462MHz
Communication Distance (Open Area)	500-700m (1640.4-2296.6ft)
Transmitter Power	20dBm
Power Consumption	2W

A5: Image Mosaic Quality Reports

See Attached document