Photogrammetry and Point Cloud Modeling with the Incorporation of Micro-Drones for Web Mapping Applications

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Abstract — *Drones and Micro-Drones have played a major role in homeland security and various divisions of the Department of Defense. Needless to say, this technology has passed from military hands to the average citizen. Some may use this as a recreational pastime, others as a hobby. However, with major advances in photogrammetry software this technology has proven to be a vital instrument in the geospatial field. This investigation includes a comparative analysis of three photogrammetric software's: Agisoft Photoscan, Pix4D and VisualSFM. They were utilized to create sparse and dense point cloud comparisons; these models were visually inspected and assessed given a set of images. Upon completion of the experiment, a webpage interface was created to provide a detailed perspective of these models and their functionality.*

Key Terms — *Drone Mapping, Pix4D, Photogrammetry, Photoscan, VisualSFM, Web Mapping, Web Mapping and Point Cloud.*

INTRODUCTION

With the advent of hobby drones, many improvements have been made in the Geospatial field. Geospatial Science is always in the need for more current temporal data; however this data is required to meet certain quality standards. In the proper hands, images acquired by drones can greatly benefit the geospatial community, by partially lowering the cost, and significantly aiding the study being performed. Nevertheless, the field of Unmanned Aerial Systems (UAS) remains a slippery slope; with Federal Aviation Administration (FAA), regulations still in question, most of the regulations pertaining to micro-drones (UAS under 4.4 pounds) remain unclear. Herein lies a major component of this study. A micro-drone, in this case a Parrot Bebop, weighing in at 0.88 lbs is utilized for the acquisition of the images along a bike trail in the municipality of Isabela P.R. Federal guidelines are more obscure for this class of micro-drones, however special precautions were observed when acquiring said images. These precautions included: observing when the lowest amount of pedestrian traffic was in the area as to not endanger pedestrians due to a malfunctioning aircraft, and a two person team as to ensure the safety of passerby's as well as to maintain situational awareness.

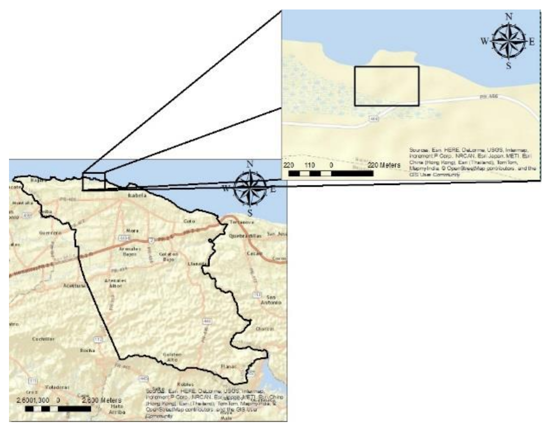

Figure 1
Study Area Section D

Figure 1 depicts the area where this study is performed, zoning in on an area of approximately 0.03 Km^2. A relatively small area, this as a precautionary measure to avoid bombarding the programs and significantly circumventing extensive wait time due to the rigorous procedures being performed, as these are known to be extensive and time consuming. Once the optimum software analysis was established, a webpage was created with a referenced 3D model of a section of the bike trail known as *"Paseo Mabodamaca"*. This webpage interface included a 150 meter analysis of the surrounding area of the entire bike path to include Environmental Safety Index (ESI), rest areas or gazebos and videos of the area. These steps were created to immerse the user in the local area by enriching their experience.

This study will be divided into three stages:

1. Experimentation Process, for establishing the optimum Point Cloud software.
   - Point Cloud Methodology
   - Point Cloud Results
2. Modeling the target area; a section of "Paseo Mabodamaca".
   - Modeling Methodology
   - Modeling Results
3. Web Development, as a final step for displaying the 3D model.

Theoretical Framework

Geospatial Science and Technology refers to the science and technology used for visualization, measurement, and analysis of features or phenomena that occur on the Earth. This can be applied to a vast array of disciplines and may greatly benefit these in numerous ways. According to the National Oceanic and Atmospheric Administration (NOAA), photogrammetry refers to the process of taking measurements from photographs. In this study, both geospatial science and photogrammetry were applied for a final webpage interface which can grant users the ability to manipulate spatial features in and around said bike trail.

The study was conducted in three stages, stage one consisted of the experimentation conducted for geospatial modeling 3D features utilizing the three photogammetric software's. These software's were: Agisoft PhotoScan, Pix4D and VisualSFM. A small area was modeled to examine which software faired best.

Stage two consisted of modeling a section of a bike trail. The focus feature in question is a pedestrian trail located on the northern coast of Isabela, P.R. This trail is approximately four miles long and traverses numerous floral and faunal habitats. Through the use of aerial imagery gathered by a micro-drone a set of images was compiled and processed.

Stage three consisted of the web development aspect of the study. The main criteria for this stage was to create a user-friendly webpage interface. A domain was purchased and hosted through GoDaddy.com. Two webpage mapping libraries were utilized for the creation of the interface; mapbox.com and leafletjs.com.

Photogrammetry and Modeling

Photogrammetry has been used in a wide array of disciplines from archeology, in an effort to conserve and record artifact placement, to create a detailed visual record of the excavation at many points, while also gathering quantifiable 3D data to track the removal of soil from the site [1]. In this instance archeologist utilize PhotoScan and Autodesk 123 Catch to visually create a 3D model, and ArcGIS ArcMap to intergrade these visually rich models with descriptive data. Up to the creation of surface models to be utilized in, Smooth Particle Hydrodynamics was used to model the surface runoff in the Iberian Peninsula during its heavy rainstorms [2]. In both cases, Unmanned Ariel Vehicles (UAV's) colloquially referred to as "drones", have played a significant role in creating 3D modeling of the surface. In these cases, both researchers have utilized the photogrammetric spatial modeling software; Agisoft Photoscan. Agisoft Photoscan is currently one of the uppermost software that is capable of rendering a 3D model to a high level of accuracy [3]. However, with the ever evolving advances in software engineering, newer developers are bridging the gap and creating an ever more competitive field. Such is the case with the Swiss company Pix4D. Founded in 2011 after more than ten years of leading scientific research, Pix4D has become the main provider and industry standard for professional UAV processing software [4]. Lastly VisualSFM [5] in combination with Clustering Views for Multi-view Stereo (CMVS) [6] and Patch-based Multi-view Stereo Software (PMVS) [7], the merger of these binaries provides users with open source software capable of rendering sparse and dense point clouds. This with Meshlab, another open source program, the rendition of 3D models can be accomplished. Stage one will make a comparative analysis on all three programs; Agisoft Photoscan and Pix4D and VisualSFM.

Hardware

The Parrot Company was founded in 1994 by Henri Seydoux, Parrot creates, develops and markets advanced technology wireless products for consumers and professionals [8]. This company has also created a line of micro-drones capable of recording in high definition as well as high quality still images, case in point, the Parrot Bebop. The Bebop drone weighs in at 400g with its battery, a 1,200 mAh lithium polymer capable of 11 minutes of flight time. It also has a Quad core graphics processing unit, Parrot P7 dual-core CPU Cortex 9 operating Linux and 8mb flash memory. This micro-drone uses Wi-Fi antennas: MIMO dual-band with 2 double-sets of dipole antennas for 2.4 and 5 GHz to communicate with its controller which can be a cellular devices (with a compatible accelerometer and gyroscope), as well as the tablets such as the IPad or Samsung Galaxy Tab amongst others. By creating its own Wi-Fi connection, it has a distance of approximately 250m with a sending power of 21dBm, however there is an optional feature called a skycontroller (also created by the Parrot Company), which allows the drone to communicate with its controller for up to 2km. This micro-drone utilizes 4 Brushless out-runner motors, capable of propelling this lightweight quadcopter to 13 m/s or 29 mph. It has an integrated 14 mega pixel camera, with a 180° circular fisheye lens with 3-axes digital video stabilizer. Its photographic parameters are 1920x1080 (video) and 4096x3072 (still photography). The Bebop is integrated with a GPS and GLONASS.

Although the Bebop can be controlled with a wide array of smartphones and tablets, this proved to be, in my opinion, a less than optimal form of flight control. This due to its functionality with the gyroscopic feature of the mobile device; that is to say it utilized the devices' gyroscope to control the pitch and roll axes. Therefore, the need for a more suitable form of control arose. The need for better control was quelled by and Nvidia Shield Portable. Although this device has an integrated motion sensor (3-axisgyro and 3-axis accelerometer), it utilized two joysticks as an interface for controlling the micro-drone. These controlled full functionality of the bebop drone as well as provided a five inch 1280x720 multi-touch HD display allowing for first person view of the drone.

Modeling Software

Advances in photogrammetry and computer software are facilitating the creation of three dimensional modeling; however there are major companies that hold the proverbial reigns as far as industry standards in 3D modeling. These companies utilize algorithms to create a point cloud rendering of a 3D feature, using still photography as its means of extrapolating data. Which is to say consistent points between photographs, this point is then plotted on a plane and a false coordinate system is the applied. This point is then referenced in a three dimensional environment, and has an X, Y and Z position in virtual space. The process is repeated several times and a sparse point cloud cluster is created.

Cloud Rendering Software

One of the vanguard cloud rendering software is Pix4D. This company utilizes a series of proprietary algorithms to create a dense point cloud; this point cloud data is utilized for various processes in the program as its versatility is illustrated in its final product, which can create Digital Surface Models (DSM), Digital Elevation Models (DEM) and a 3D textured mesh amongst others. This versatility is only available through its professional edition which entails a monetary fee. However, there is an option available free of charge; Pix4D Discovery Mapper. Discovery Mapper allows users to create point cloud data but will not create a DSM nor an orthomosaic generation.

Secondly, Agisoft Photoscan was utilized to create a point cloud data set. This program comes in two main forms a standard edition and a professional edition. This is a program with a broad range of commercial use and is also capable of creating DSM as well as orthomosaics much like Pix4D. However this feature is only available with the professional edition.

Lastly, VisualSFM is an open source program capable of creating sparse cloud data, utilizing structure from motion (SFM). VisualSFM is the product of Changchang Wu of The University of Washington, along with the additions of secondary binaries such as CMVS/PMVS, can create dense cloud datasets. This program is a light weight portable application and open source.

Web Development Software

Stage three or web development stage consist of identifying which parameters needed to be established as to streamline web interaction. Adobe Muse is a web design software created by Adobe Systems, this software allows users to generate visually aesthetic webpages and ease-of-use interface. The program provided the main templates for the backbone of the webpage. However, the emphasis of the webpage is an area which highlights the web mapping aspect. This section was developed with the libraries found in mapbox.com in collaboration with leafletjs.com and manipulated with online integrated development environment (IDE), titled ShiftEdit. ShiftEdit is a web-based IDE. It includes syntax highlighting, tabs and built-in (S) FTP support. This software provides the versatility of programming from a cloud service and does not require the need for a physical drives to store data.

Along with software and as a quintessential need for web development, is the necessity of embedding images. In this case markers located on a web map will identify with an image, video or animation of the feature identified by the marker. Four cloud services were utilized these were:

1. Imgur, for two dimensional photographic images.
2. Google views, for panoramic and google sphere animation.
3. Sketchfab, for 3D animation and interaction.
4. YouTube, for GoPro and Bebop videos.

POINT CLOUD METHODOLOGY

The methodology consisted of a set of 59 images capture by the Bebop micro-drone along the northern cost of Isabela P.R. This area was chosen because of its remoteness to pedestrian traffic. Along with its terrain features, as this area is a sand beach allowing for a forgiving landing if the quadcopter suffered from a malfunction in midair or a mishap due to pilot error. The micro-drone is flown over an area of approximately 0.03 Km^2, this will provide the drone with adequate images to run a point cloud rendering with each program as it is recommended at least 50 images captured by the passive visual sensor located on the micro-drone. The flight consisted of approximately c in altitude at low speed, this is done because, this specific model of micro-drone is still incompatible with autonomous flight, therefore must be controlled manually and set to an automatic timer for the acquisition of images. The timer is set to its minimal value, which is 7 seconds.

Processing

Processing consisted of downloading all the images from the micro-drone to a personal computer and importing these images into the three corresponding program. Each program executed a sparse point cloud and a dense point cloud. Pix4D requires minimal entry as a feature of this software is the automatic tie point recognition. It consisted of locating a tie point which can be located in 3 images and is computed in the initial processing. All additional options were:

- Image scale at which images are computed: Original image size.
- Optimized parameters: optimize externals and all internals
- Image scale: half image size
- Point density: optimal
- Minimum number of matches: 3

All other options were set to default. This concluded image analysis process and resulted in a point cloud.

Secondly, Agisoft Photoscan was initiated and images were uploaded. PhotoScan requires images to be aligned before it can process the data. All processes in PhotoScan should be manually assigned. The following steps were conducted in keeping with its manual.

- Align Photos
  - Accuracy: Medium
  - Pair Selection: Generic
- Optimize Alignment: All Values Default
- Build Dense Cloud: Medium
- Build Mesh
  - Surface type: Arbitrary
- Build Texture
  - Mapping Mode: Adaptive Orthophoto

Lastly VisualSFM was initiated and images were selected. Due to the lightweight nature of this program fewer steps are required and there are no special parameters to be configured. The process in creating a point cloud consists of:

- Compute Missing Matches
- Compute 3D Reconstruction
- Run CMVS/PMVS

Post Processing

These point clouds were further examined through the use of Meshlab, an open source program for point cloud and modeling datasets. Although this process was only utilized to examine the output and in no way modified the data as this is an examination of the raw data calculated by the respective application.

POINT CLOUD RESULTS

The resulting point cloud renderings were imported into Meshlab as two separate classes; class one: sparse cloud and class two: dense cloud. All renderings were compared visually and points tabulated.

Sparse Cloud

Upon initial inspection of sparse clouds VisualSFM and PhotoScan appear comparable as seen in Figure 2 and Figure 3, PhotoScan and VisualSFM respectively. VisualSFM rendered 5,589 points in its sparse cloud rendition, while PhotoScan created 3,446. In which case, VisualSFM created 2,143 more points than PhotoScan. Pix4D does not provide the exportation of sparse cloud, therefore cannot be tabulated in this section.

Figure 2
Agisoft Photoscan Sparse Cloud

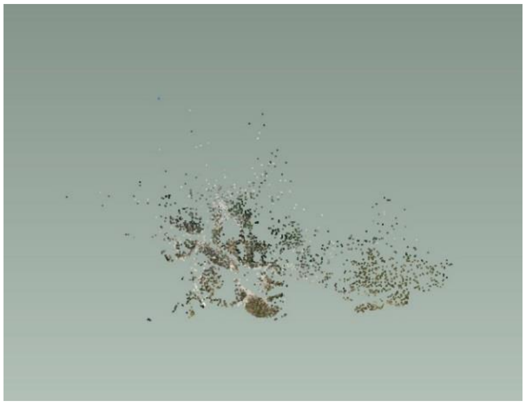

Figure 3
VisualSFM Sparse Cloud

Dense Cloud

Dense cloud renderings from all three programs are presented as all programs allow the exportation of dense clouds. The first dense cloud rendering was presented by Pix4D. This rendering contains a total of 89,697 points, this rendering took 56m:55s. However, upon visual inspection some of these points were placed in the sky and not on the surface as expected, this can be seen in figure 4. The next program to be analyzed was PhotoScan, this provided the best image rendering. A total of 3,898,028 points were rendered with the majority of these placed in the target area, as can be observed in figure 5. This rendering had an image resolution of

0.0962234 m/pix and a point density of 108.004 points per square meter. Lastly, with the fewest points rendered was VisualSFM, this with a total of 116,376 points rendered; however the vast majority of these points were within the target area, as can be observed in figure 6. Although some of these were allocated in the sky, most were placed on the surface.

On a side note: the information attained in this analysis was performed by the generation of a report for each respecting software. For this reason some data is presented for one software and absent other data; which may prove instrumental in the quality assurance aspect.

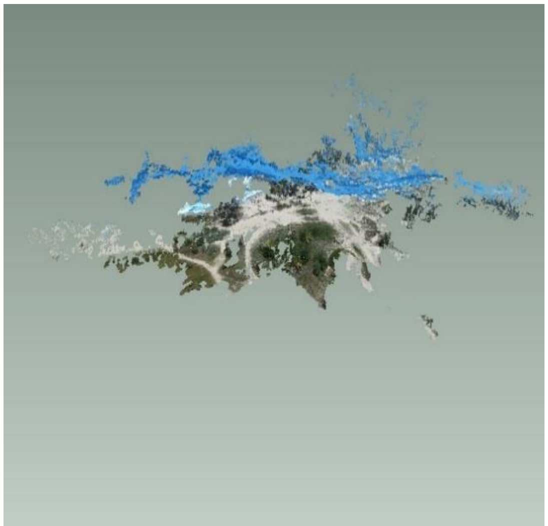

Figure 4
Pix4D Dense Cloud

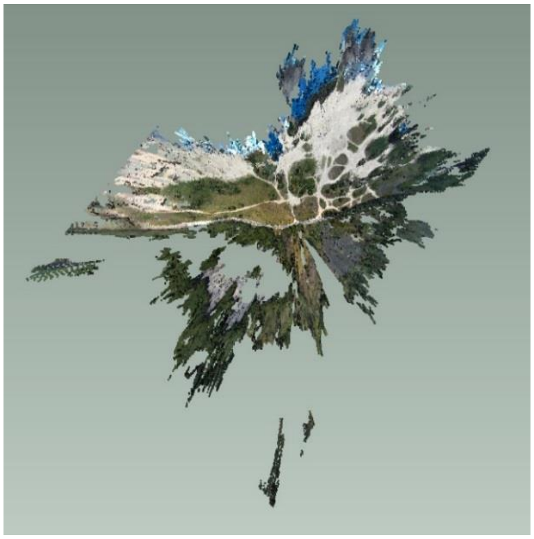

Figure 5
Agisoft Photoscan Dense Cloud

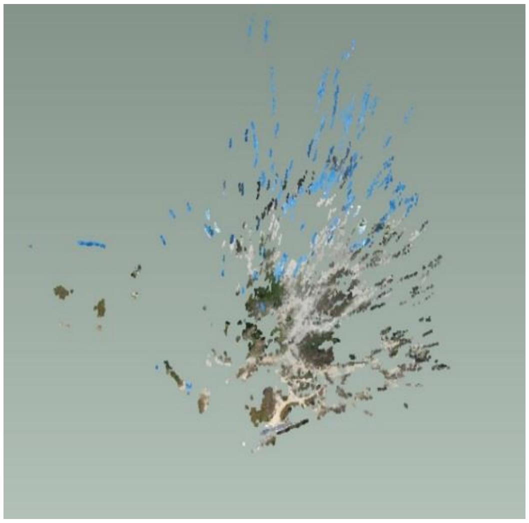

Figure 6
VisualSFM Dense Cloud

A comparison can be made between Pix4D and VisualSFM, despite obtaining fewer calibrated images, the renderings for this model obtained a higher point density therefore a more complete model of the target area was obtained. This led to almost four million points rendered. In addition, it obtained the lowest geolocation error with 5.715426 as opposed to 19.78941 by Pix4D and not available for VisualSFM. Table 1 demonstrates these respective values, excluding Pix4D which did not make this feature available for exportation.

Table 1
Vertices

Software	Sparse Cloud	Dense Cloud
Pix4D	N/A	89,697
PhotoScan	3,446	3,898,028
Visual SFM	5,589	116,376

Table 2
Calibrated Images

Software	Calibrated	Total	Ratio
Pix4D	35	58	60.3%
PhotoScan	58	58	100%
Visual SFM	49	58	84%

Table 3
Geolocation Error

Software	X	Y	Z	Total
Pix4D	8.75	7.87	3.15	19.78
PhotoScan	3.48	4.32	1.34	9.14
Visual SFM	N/A	N/A	N/A	N/A

MODELING METHODOLOGY

Once the procedure to identify the optimum modeling software had been successfully proven, a larger modeling project was established. This was to divide sections of the bike trail and acquire more images using the drone to achieve a larger target area, as seen in figure 7. This area was cordoned off into four sections numbered alphabetically Sections A-D and mapped through the modeling software until a complete model was achieved.

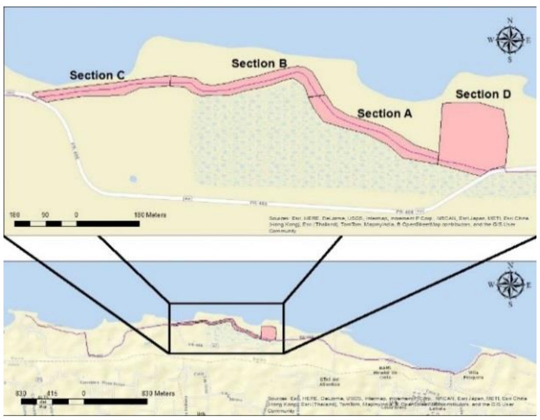

Figure 7
Pix4D Dense Cloud

These sections were flown individually and due to battery life and recharging cycle (approximately 1 hour per battery) took a total of 4 days to gather all the data necessary, however these were not all consecutive due to less than favorable weather conditions.

Once all the necessary data was acquired, these images were processed with Agisoft PhotoScan, and sparse and dense clouds were rendered. PhotoScan allows projects to be divided into groups called chunks, the sections previously mentioned, are imported into PhotoScan and grouped as chunks. These chunks are created to ease the modeling procedure by allowing individual chunks to be processed, therefore eliminating the need to process all the images at once. The processes applied to these chunks were the same as previously mentioned for the experimentation process however, two extra steps are implemented. First, with the dense cloud model a mesh is rendered. The parameters established were:

- Surface Type: Arbitrary
- Source Data: Dense Cloud
- Face Count: Medium

All other parameters were left as its default values.

Secondly, a texture of the newly rendered mesh is created with the following parameter:

- Mapping Mode: Adaptive Orthophoto
- Texture from: All Photos
- Blending mode: Mosaic

All other parameters were left as its default values. When all the chunks have their respective 3D models and textures created, the last step was the alignment of these models and their merger. The alignment parameters established were:

- Method: Point Based.

All other parameters were left as its default values. The merger parameters established were:

- Merge Dense Cloud: Yes
- Merge Models: Yes.

All other parameters were left as its default values.

MODELING RESULTS

Section A with a length of approximately 400m, was the section with the most images acquired with a total of 114; this in part due to the lineal nature of this section with a wide open canopy that provided an unobstructed view of the surface terrain. Section B was a section with a slight bend and tall foliage surrounding the area. It measured 480m although this section was larger than the previous one, the surrounding vegetation made it nearly impossible to capture quality images acceptable for the modeling procedure. This section constitutes a total of 75 images. Section C was also an area with challenging features, this area continued with high vegetation seen in section B, however the area eventually cleared which made it possible to acquire images. This section had a total of 68 images. Section D covered the initial experimentation procedure and was later added as a chunk with 59 images.

WEB DEVELOPMENT

Utilizing GoDaddy.com the domain efrainanieves.com was purchased and was hosted through cPanel. The web design aspect was created with Adobe Muse which helped shape the bulk of the webpage, this design was divided into five pages:

- Page 1, Home page.
- Page 2, Bike Path.
- Page 3, 3D Mapping.
- Page 4, Photo Gallery.
- Page 5, Contact Us.

Page 1 or the Home page consist of background information of *"Paseo Mabodamaca"* along with procedures and an outline for the experimentation process. This includes the preprocessing, processing and post-processing. Information on hardware and software utilized, including information on the micro-drone, software and approximate time in field.

Page 2 or Bike Path is the emphasis of this webpage. In this page, a selection of eight java script plugins were utilized from the leafletjs and mapbox libraries. These are:

1. Leaflet Providers, provides support for displaying different basemaps from different sources not just mapbox.
2. Control Layer, this plugin controlled which layers were on by default and which layers can be manually turned on and off.
   a. The basemaps are:
      i. Satellite (Esri World Imagery).
      ii. Streets (Mapbox)
      iii. Topographic (Thunderforest Outdoors).
   b. Layers
      i. Gazebo
      ii. Isabela
      iii. Paseo Mabodamaca
      iv. 3D
      v. Video & Panorama
      vi. Benthic
      vii. Invertebrate
      viii. Reptiles
      ix. Marine Mammals
      x. Wetlands
3. Slideshow gallery in a marker tooltip. This feature provides an image embedded using Imgur cloud server, along with a brief description. The images displayed in the tooltip were images captured of the rest stops or gazebos. This showed what a given rest stop provided in reference to overhead shelter and benches amongst others.
4. Control Locate. This feature permits a real-time position on the web interface automatically panning to the user's current location.
5. Legend. The legend establishes by color region areas identified by the ESI, in a 150m proximity.
6. Zoom Home. Establishes a default zoom and coordinate location, aiding the panning feature.
7. File Layer. This allows users to upload and project their own GeoJSON, GPX or KML.
8. Location Share. Allow users to send and receive a marker with a message.
9. Full screen, enable the map to be in full screen mode.
10. Omnivore, Loads & converts CSV, KML, GPX, TopoJSON, WKT formats for Leaflet.

These plugins were utilized in a separate HTML window made in Adobe Muse, to create the web mapping aspect. This window measures 1155 pixels wide by 510 pixels high and displayed a red vector line identifying the 4 mile long *"Paseo Mabodamaca". S*ix red markers styled by mapbox standalone markers (Maki) with the campsite logo which closest resembles a rest stop. In addition, green markers were used to identify 3D modeling with the star logo and finally a blue marker which identify videos. These videos were captured with a GoPro Hero 3+ or the Bebop Drone.

This page also includes Environmental Safety Index data used in the projection of the layers pertaining to each layer. It also includes a link in which users may download the metadata in a pdf format.

Page 3 or 3D mapping includes a side-by-side image of the 3D model rendered by PhotoScan and a Google Earth window of the target area.

Page 4 or Photo Gallery incorporates images utilized in the modeling process and images acquired while on the mapping procedure.

Page 5 or Contact Us includes a brief message as well as a short form with fields: Name, Email and Message in which information can be filled out and the feedback is received by the developer.

All tabular information was inputted into three Google Sheets Documents. The reason for creating three spreadsheets was to be able to control the layer through the layer control plugin. This feature controls the layers given an individual file, hence the need. These Google Sheets can be modified on the fly, so to speak, once in the field data can be edited through a mobile device with no knowledge of any programming aspect. These spreadsheets were divided into its respective categories satisfying the need for each individual marker group. Once formatted with the proper column and row requirements these were filled with spatial information to include latitude and longitude, marker color, marker description, a brief description of the feature, and the embedded code from its respective cloud storage (Imgur, Google Views, YouTube and Sketchfab). Google allows these spreadsheets to be published to the web and with the use of a .php code which translates the spreadsheet information to a GeoJSON format. Once this is translated, the GeoJSON is to be displayed as point features in the web map.

CONCLUSION

In conclusion the program with the best point cloud rendering performance for this specific form of modeling was Agisoft PhotoScan. This performed exceptionally well, calibrating 100% of the images loaded and rendering a large point cloud dataset. Therefore, this program performs exceptionally well and is a reliable form of rendering point cloud models.

Once the optimum modeling software was established, all images were loaded into Agisoft PhotoScan and a 3D model was created. The program rendered a high degree of spatial modeling and proved to be a valuable asset for the final product which was the web interface. Some sections of the target area failed to be modeled, these were areas which had high vegetation and according to the software manufacturer, this makes it nearly impossible to model utilizing low flying drones. This was the only drawback encountered in the modeling process, all other processes performed with high marks.

The web mapping application for this study ultimately is of an expository nature and can be used to obtain a greater appreciation of drone modeling in conjunction with web mapping. This field will undoubtedly grow, due to the insatiable need for current temporal data; making hobby drones no longer a novelty item but an irreplaceable tool found in many geospatial scientist toolbox.

REFERENCES

[1] A. Hill, Y. Rowan and M. M. Kersel, "Mapping with Aerial Photographs : Recording the Past, the Present, and the Invisible," in *Near Eastern Archaeology*, Third Edition, 2014, pp. 182–187.

[2] A. Barreiro, J. M. Domínguez, A. J. C. Crespo, H. González-Jorge, D. Roca and M. Gómez-Gesteira, "Integration of UAV Photogrammetry and SPH Modelling of Fluids to Study Runoff on Real Terrains" PLoS ONE 9(11): e111031. doi:10.1371/journal.pone.0111031, 2014.

[3] Agisoft. *PhotoScan About* [Online]. Available: http://www.agisoft.com/about/. [Accessed: January 9, 2015].

[4] Pix4D, *About Us* [Online]. Available: https://pix4d.com/about-us/. [Accessed: January 27, 2015].

[5] C. Wu. *VisualSFM: A Visual Structure from Motion System* [Online]. Available: http://ccwu.me/vsfm/doc.html. [Accessed: February 6, 2015].

[6] Y. Furukawa. *Clustering Views for Multi-view Stereo (CMVS)* [Online]. Available: http://www.di.ens.fr/cmvs/. [Accessed: February 19, 2015].

[7] J. P. Yasutaka Furukawa. *Patch-based Multi-view Stereo Software (PMVS)* [Online]. Available: http://www.di.ens.fr/pmvs/. [Accessed: February 24, 2015].

[8] PR, N. *Parrot MiniDrones* [Online]. Available: http://search.ebscohost.com/login.aspx?direct=true&db=bwh&AN=201401090409PR.NEWS.TODWIRE.LE-20140109-0010&site=ehost-live. [Accessed: February 19, 2015].