Mersin Photogrammetry Journal

https://dergipark.org.tr/en/pub/mephoj

e-ISSN 2687-654X

Deploying UAS Directly Inside the Active Crater of Turrialba for Photogrammetry Data Collection Designed for Active Volcano Monitoring

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Cite this study: Godfrey, I., Sibaja Brenes, J., Avard, G., Martínez, M. & Meghraoui K. (2025). Deploying UAS Directly Inside the Active Crater of Turrialba for Photogrammetry Data Collection Designed for Active Volcano Monitoring. Mersin Photogrammetry Journal, 7 (1), 37-42.

https://doi.org/10.53093/mephoj.1499133

Keywords
Volcanic Degassing
Photogrammetry
Infrared Digital Modeling
Hazard Mitigation
Public Safety

Research Article

Received:11.06.2024
Revised: 19.06.2025
Accepted:21.06.2025
Published:30.06.2025

Abstract

Modern UAS or drones are quickly advancing when it comes to the collection of high-resolution images which are georeferenced and can be used to create a high resolution 3-D model ofcomplex topography. Researchers in the field are making quick progress with new algorithms and analytical applications. These drones are being used in the field of volcanology in quite a useful manner as active volcano craters are one of the more challenging and complex areas to access. UAS have now assisted several departments of Universidad Nacional with data collection, analytics and optimization practices. In May of 2023 with the assistance of the Atmospheric Chemistry Laboratory of Universidad Nacional LAQAT-UNA and the Volcanic and Seismic Observatory of Costa Rica OVSICORI-UNA showed that our efforts using UAS at active volcanoes was greatly beneficial and the collective efforts proved the usefulness of deploying UAS around active degassing volcanoes such as the Turrialba Volcano in Costa Rica. Researchers in several departments at Universidad Nacional are keen on collaborating with others in international institutions for data fusion and synergy, to work together on gathering information on how to create better UAS hardware and payload components,and to cooperate for a better understanding of user needs, regulations and requirements for the safe operation of UAS. UAS allow for collection of accurate images which keep the researchers and remote pilots safe and out of the danger zone. UAS assist with the rapid accumulation of data, they can be pre- programmed for a specific type of UAS flight mission designed for a certain objective of gathering images for complex terrain or topography. The system can be used around active volcano craters, it can monitor mountains and cliffs subject to cracking, erosion and rock falls. Different extreme and complex environments can be documented and digitalized using this same method such as glacier zones and other sophisticated regions with difficult to access areas. *All remote flights were using the SINAC Special Use UAS Research Permit – SINAC-ACC-PI-LC-037-2021*

1. Introduction

Topographical modeling of dangerous often difficult to reach land features has become one of the most popular and most lucrative US applications. The generation of digital models representing extreme environments by using orthomosaic mapping methods has become especially useful in volcanic nations like Costa Rica.

It is important that these unmanned aerial vehicles are used as a base for the identification, documentation, preservation and future work which can be done in the future[1]. Modern measurement technologies such as UAVs should be used in studies. [2-10].The main objective for the May field work at the Turrialba Volcano National Park was to obtain the images required for the digital model of the active crater and to useUAS to take high resolution detailed images of the crater interior. We used UAS to monitor the topography, gather degassing data and collected

images sufficient to create an interactive environmental monitoring model of the West Crater.

2. Method

Several drones were used at the summit including a DJI Matrice-600 Pro, DJI Mavic Mini 2, DJI Mavic 3 Thermal and an Evo Lite + UAS from Autel Robotics. We used these UAS for photogrammetry first as it was the most important application. 90° camera view with a straight down orientation was used and the flights were flown manually. Using the images as actual valuable data sets for monitoring the active crater of Turrialba. There was a 80% front and back overlap and a 60% side overlap for the data set collected.

2.1. The Degassing Turrialba Volcano

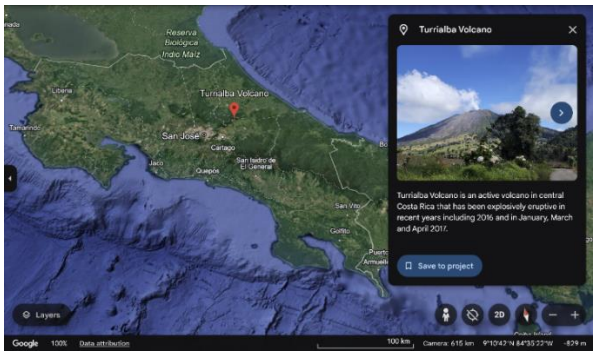

Figure 1. Google Earth Representation of the Turrialba Volcano Location -The Study Area Map

Figure 2. The Actively Degassing West Crater of the Turrialba Volcano, May 12th 2023, 8am.

Figure 3. The AERMOD Plot Overview Illistrating the Atmospheric Pollution Releasing from the Turrialba Volcano, May 12th 2023, 8am.

2.2. High Risk UAS Flights in a Volcanic Atmosphere

The summit area of the Turrialba Volcano can be one of the more complicated areas for UAS flightsin Costa Rica. Although often difficult atmospheric conditions are present, its these fault zone regions and the modeling of the surface features here that researchers and geologists find most beneficial. [11]

Several research institutions in New Zealand have been deploying drones for volcanic monitoringwith great success. Publications from 2016 show several different payload sensors being used in conjunction with UAS by the School of Environment; University of Auckland which were used to capture images which were not only geo referenced but also temperature calibrated thermal orthophotos. This method was used around the geothermal fields and has now become a routine part of the university research of gathering aerial photos for the generation of Digital Elevation Model's (DEM). [12]

In the research publication titled; "*UAS Based tracking of the Santaguida Lava Dome, Guatemala*"; scientists from the German Research Center for Geosciences and Boise State University deployed aspecialized UAS to monitor the lava dome of the Santaguida Lava Dome in Guatemala. Since lava domes were some of the most dangerous and difficult aspects of the volcanic eruption to capture, we decided to adapt several of the UAS remote pilot strategies outlined in this research to capture the most useful data on geomorphology and volcanic structure before deploying our UAS directly into the active West Crater of the Turrialba Volcano in Costa Rica. [13]

Figure 4. UAS View of the West Crater Floor Fumarole Turrialba Volcano May 2023

Figure 5. The AERMOD Plot Illistrating the Atmospheric Pollution Releasing from the Turrialba Volcano, May 12th 2023, 8am.

2.2.1. Geomorphology Inside the Active Crater

There was a very small light green puddle that was observed and photographed using the UAS inside the active crater of the Turrialba Volcano. In May of 2023 the small puddle of water inside the active West Crater appeared to be the only body of accumulated water at the volcano summit.

UAS have proven to be both economical and beneficial to serving data collection around difficult to access areas such as volcano craters. The West crater of the Turrialba volcano is in fact impossible to enter, and the UAS was the only feasible solution to obtain up close images, video and photogrammetry measurements for digitalizing and visualizing the area. Deploying UAS like this around active volcanoes is quickly becoming an essential part of volcanic surveillance.

Due to the change in pre-eruptive behavior associated with volcanoes that have been previously recorded via permanently stationed monitoring networks, researchers have previously found that afluctuation in gas flux and thermal energy release can be associated with a new eruptive phase. Monitoring for thermal energy release, size of fumaroles and associated temperature and levels ofdegassing are all important parameters to track for a complete volcanic surveillance program. [14]

Figure 6. The Atmospheric Pollution Source Inside the West Crater Releasing SO_2 and H_2S from the Turrialba Volcano, May 12th 2023, 8am.

Figure 7. The Atmospheric Pollution Sources Along the West Wall of the Crater Releasing SO_2 and H_2S from the Fumaroles May 12th 2023, 8am.

Researchers from Aerodynamic Laboratory, Sáo Carlos Engineering School, University of Sáo Paulo,Brazil are focusing efforts on how economically priced UAS can be tuned to preform ideal volcanic surveillance via a transmission system which relays real time environmental data from the area being surveyed back to the laboratory. Here researchers are specifically interested in data which will assist in the early warning detection system and more accurately forecast volcanic eruptions. One of the key benefits noted by this group was UAS keep scientists and remote pilots out of the danger zones and areas of direct impact around volcanic eruptions. [15]

In the case of the Turrialba volcano In May of 2023 lessons were taken from several university teams focused on geosciences and remote sensing, the lessons and complications they explained in their publications were taken into extreme consideration while preparing for these UAS photogrammetry missions at the summit of the Turrialba Volcano. [16]

3. Results

The initial goal was accomplished during the very first flight at the Turrialba summit. With one UAS flight on May 17th, 2023, with good atmospheric conditions the flight designed to gather the RGB data for the digital model of the active West Crater was conducted. The images were taken from the drone which was a Mavic 3 Thermal, and the digital model was created from the images. It's the RGBdigital model that is actually the foundation for digitalizing and visualizing complex topography, before any scientific data can be incorporated.

Not only can the UAS method be used for digitalizing and visualizing the extreme environment of anactive volcano crater, but additional geological parameters can be measured such as inclination of volcanic flanks and crater walls. These are parameters used in conjunction with crater radius and depth measurements which are all viable data points used for tracking and monitoring an active volcano crater. Each of these parameters can be tracked with UAS. The data sets collected with these drones can be gathered from safe distances and can be used in digital visualization platforms for information sharing and quicker decision making, making the UAS method especially beneficial to governments and decision makers during times of eruptive activity.

When considering fieldwork around active degassing volcanoes, UAS reduces risks to human healthand can be a more economical solution compared with using small, manned aircraft like the Cessna172 or Hughes 396C helicopter frequently used by the USGS in the USA. Drones have been used to great effect in monitoring geo-hazards from safe distances. Drones have been used to quantify ask fallout after eruptions, as well as quantify lava deposits, and these drones are now complimenting various additional applications for a variety of research departments assisting a wide range of institution types. [17]

4. Discussion

Clusters of small yellow sulfuric crystals were found in the fumarole vent areas on the western crater wall. The small areas of yellow and white crystal formations were more clearly visible when we were able to observe the craters interior via a small drone. Much of the crystal formation was found around the degassing vents on the western crater wall. There were no such formations seen on the crater floor where the second area of fumaroles was found.

Figure 8. Drone Image from Inside the West Crater Showing Formations of Yellow Sulfuric Crystals

Figure 9. Drone Image from Inside the West Crater Releasing SO_2 and H_2S Forming Clusters of Yellow Sulfuric Crystals

Figure 10. Drone Image from Inside the West Crater Releasing SO_2 and H_2S Forming Clusters of Small Yellow Sulfuric Crystals

There was some minor degassing seen coming from the western crater wall and the crater floor as the previous drone flights had concluded.

Due to overall drier conditions the water vapor was significantly less intrusive to the UAS flight path and the RGB images were able to be collected on the first flight within the first 30 minutes. The degassing observed coming from the active West Crater of the Turrialba Volcano was developed into an AERMOD plot by LAQAT-UNA to visualize the volcanic plume and disbursement of atmospheric pollution in the study area.

Figure 11. Drone Image from Inside the West Crater

Showing the Crater Floor with Complete Clarity, May 12th, 2023.

Figure 12. Drone Image from Inside the West Crater Showing the Crater Floor with Complete Clarity, May 12th, 2023.

5. Conclusion

UAS can now monitor atmospheric pollution, take samples from hyper acidic lakes, and contribute to enhance mapping and modeling of extreme environments with complex topography through image digitalization. Some of these areas such as UNESCO sites have never been modeled before due to extreme difficulty in accessibility and obvious risk factors to human health and the financial risks associated with the drone itself.

UAS photogrammetry offers a solution to creating digital models of these areas. UAS for photogrammetry can be used for the volcanic surveillance programs in many nations in emerging economies. Drones have been used to great affect around extremely active and often erupting volcanic areas such as Mount Sinabung in Indonesia. [18]

Figure 13. Drone Image from Above the West Crater for Digital Model Referencing

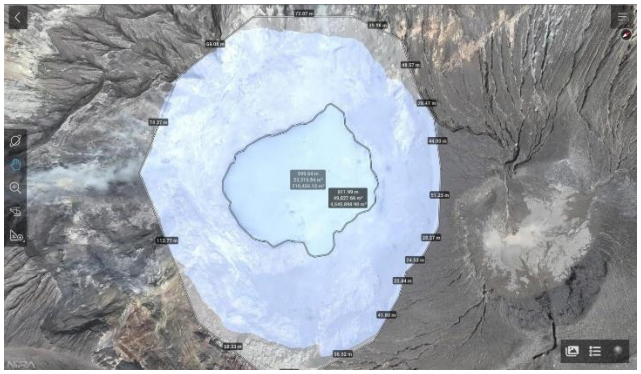

Figure 13. Digital 3-D Model of the West Crater of the Turrialba Volcano in Costa Rica

The West Crater rim radius was 811.9 meters, the total surface area covered by the crater rim radius was 49,827.66m^2 and the amount of estimated volume from the crater floor to the crater rimwas 4,540,898.90 m^3.

The crater floor had an estimated radius of 599.64 meters to 719.56 meters depending on where the line was drawn. The fluctuations in the radius measurement are a result of where the line is drawn which is not always perfectly visible due to rock falls and small avalanches of rock from withcertain sections of the active crater. The total surface area covered by the crater floor was

23,319.84 m^2, and the system even estimated the altitude differentiation giving us the variation in depth on the crater floor alone was estimated at 23.22 meters in fluctuations. It's estimated these fluctuations on the crater floor are due to rockfalls and material falling from the crater walls. All results were processed and visualized on the Nira app and the various measurements were saved for future analysis.

UAS photogrammetry can be used to digitalize various regions with complex topography. This UASapplication has gained particular attention in the field of volcanology for surveying active volcano craters. The continued process of using this UAS method for image collection and digitalization for visualization can be used every two months, which will allow for digital tracking of the volcanic evolution of the active area. UAS photogrammetry has previously been used by volcanologists in Italy, New Zealand and in Costa Rica. Certain new payload sensors are now being flown in addition to previously installed ones increasing data collection potential via UAS and contributing to data processing synergy. [1921.22]

The UAS photogrammetry application has been proven a successful way to track the progression oflandslides along highway belts in Costa Rica, the method has been used to track the landslide progress at the summit of the Irazú Volcano National Park where all the antennas are located, and UAS photogrammetry has been used to track the geomorphological progression of several active volcano craters in Costa Rica. It's these UAS photogrammetry flight missions around the active volcano craters that prove exceptionally useful as they can assist with estimations of progression of any cracking, height fluctuations, ejected material, crater morphology, and additional objectives as well. Also, the UAS flights frequently offer additional insight into additional areas of interest for future fieldwork for these researchers. New advancements in IR technology, UAS research and development and the general acceptance of the public will offer greater opportunities moving forward. Drones quickly become the ideal solution for strategically positioning remote sensing equipment into active volcano craters and eruption sites while keeping any researchers at safe distances from any areas of certain risks. [20]

The UAS application can be used to help track the inflation and deflation of active volcanoes, they can track and progressively monitor the geomorphology of active craters, and UAS can also be usedto model the pre and post eruption area for gathering information which can be used in the estimation of ejected material during eruptions such as the layer of accumulation of volcanic ash around the crater direct impact zone. Today modern UAS are being used in various environmental science departments for the collection of beneficial data which can be used in the advancement of their particular department. UAS are quickly filling gaps and offering economical solution to either compliment on what has been previously accomplished, but they are also breaking boundaries andsetting new objectives for monitoring extreme environments to solve pressing problems in climatemonitoring and visualization today.

Acknowledgement

All contributing authors would like to express their sincerest gratitude to the SINAC Park Rangers at the Poás Volcano National Park for the safety oversight, exclusive areas to launch and land our UAS fleet and the unwavering support from the various departments of Universidad Nacional along with the Government of Costa Rica for researching, understanding and preserving these beautiful and historical natural UNESCO sites for future generations. Thank you all very much!

Author contributions

Ian Godfrey: Photogrammetry flight planning and execution, processing of the 3-D digital model of the crater, **José Pablo Sibaja Brenes:** Atmospheric pollution data interpretation and the generation of AERMOD plots, **Geoffroy Avard**: Oversight of all activities in volcanic areas, safety guide on exclusive trails for national park site access, volcanic safety inside the park **María Martínez Cruz:** Collective data interpretation and communication of conclusive findings, **Khadija Meghraoui:** Geospatial analysis and data visualization interpretation

Conflicts of interest

The authors declare no conflicts of interest.

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