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Remote piloting UAS in extreme environments with challanging climatic conditions - An overview of modern UAS capabilities in the field of volcanology, geosciences, atmospheric chemistry and interplanetary exploration

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Abstract

Unmanned Aerial Systems have recently had advanced payloads configured by engineers for various atmospheric sampling experiments and have been proven a successful and innovative technology. Climatic stability in volcanic regions can change in less than one minute. And with that comes relative humidity fluctuations, 80% change in visibility conditions, wind speed change, wind direction change, enhancing wind gusts. It's the data collection on how UAS operate in these conditions that will eventually assist the development of UAS with the ability to conduct complex photogrammetry and atmospheric sampling flight missions of the Moon and Mars. For this reason, we created a short article on our findings on using UAS in some of the most extreme and complicated atmospheric environments.

Introduction

Monitoring volcanic degassing is an essential aspect of a complete surveillance program for volcano observatories. Advancements in UAS have assisted in the ability to take better gas readings via UAS which has significantly reduced risk for scientists' studding the volcanoes. The team of remote pilots with the Atmospheric Chemistry Laboratory of Universidad Nacional LAQAT-UNA has successfully operated drones in the Irazú, Poás Turrialba and Arenal active craters in Costa Rica. The foundation of UAS in volcanic degassing began with a drone survey of a volcano was conducted in 2016 and 2017; Researchers from Universidad Nacional collaborated on an international undertaking where advanced remote pilots flew drones at both the Turrialba Volcano in Costa Rica and the Masaya Volcano in Nicaragua. The flight mission objectives were to measure the degassing deriving from the active craters. At the time these two volcanoes were the largest time integrated source of CO_2 in all of Central America. During the 2016-2017 period when the research project was conducted both volcanic systems were actively degassing and showing increased signs of a potential eruption. Researchers and remote pilots managing this project noted that; Remote pilots operating in high altitude volcanic environments especially active systems had to be particularly concerned with the hardware because the devices are often subject to harsh field conditions [1].

Methods

Operating UAS in volcanic environments are much more complicated than altitudes of 0'4000 feet Above Ground Level (AGL). In UAS research conducted at the summit of the Irazú Volcano National Park in Costa Rica researchers started outlining what the exact challenges were for using UAS in high altitude tropical, volcanic environments. The Risk/Reward ratio for flying a drone was very significant. The ratio consists of weighing the value of the drone itself (not including the Remote Control batteries in the case) against the value of the data which can be obtained during that particular flight. It was concluded that remote pilots flying drones in volcanic regions should carry extra Micro SD cards in their drone case because valuable data may be obtained and the pilot may want to continue with more flight missions. By changing the Micro SD card, the data from the previous flight is guaranteed to be returning to the lab for processing. Sometimes valuable photos used to generate 3-D Digital Surface Model have been collected and the remaining flight missions are non-essential, in these situations it's important that the remote pilot remember to switch the Micro SD cards in-between flights.

Figure 1 – Main Active Crater of the Irazú Volcano National Park Costa Rica via UAS January 2020

When flying in volcanic craters there is not just the altitude in meters Above Ground Level or AGL like in the Part 107 remote pilot listening test. When piloting remote aircraft in volcanic terrain one must also consider the atmosphere below, just as importantly if not more significant is the reduction in altitude (Below Ground Level) BGL. A critical point of preflight planning as flying into an active crater is not already complicated enough but one must consider the Return to Home RTH flight will most likely require more battery energy than the flight path used to enter the volcanic crater because the drone needs to lift itself higher to get out of the crater. The same concept applies when launching from a volcanic summit and surveying the flanks or slopes of a volcano; the drone flight altitude will be lower than the altitude of the home point. In these high altitude volcanoes in Costa Rica random periodic rain showers pass by sometimes quite quickly perhaps 10 minutes from start to finish for example. Remote pilots will need to wait for their next window of opportunity and then weight the flight risk/reward ratio. These frequent rain showers can last from 10 minutes to over a full day.

Degassing fumaroles, steep slopes, and unconventional hidden factors all play a role in the environment a volcanic remote pilot must operate in. There can be visibility complication due to water vapor and volcanic degassing. Visibility issues can impact the drone itself and the display on the RC, and they can directly impact the remote pilot at the home point. For example, if a cloud passes and visibility is reduced by 70% at the home point than observing the drone via line of sight will be severely impacted. Tropical sunlight reflecting off the RC screen can all be challenging in volcanic environments so hat and sunglasses are quite essential. Usually there are people visiting or others studying these volcanoes and therefore it's highly recommended never to fly directly over any people, vehicle's or valuable infrastructure such as National Park housing or equipment and especially telecommunications towers. Telecommunications towers are frequently located at volcanic peaks due to their strategically high location being ideal for broadcasting networks. These broadcast towers also contribute to interference between the drone and the RC. Flying with an insurance policy is always important for risk reduction.

Figure 2 – Main Active Crater of the Irazú Volcano National Park Costa Rica via UAS 2022

Figure 3 – Main Active Crater of the Irazú Volcano National Park Costa Rica vie UAS January 2020

In the above image LAQAT-UNA researchers were trying to find a waterfall that drains to the main crater. At the end, we found the path of the water, but there wasn't water. That is the place where the water could fall. We used the drone to see the terrain and if there were problems with the way to go down to the crater. The conditions were good on this day, not much wind and good visibility. The drone was flying from the SW side of the crater and flew down the main lookout site of the park. They wanted to know if there were more places where the water could drain to the crater and used a UAS to make these observations at the Irazú Volcano National Park. One of the most complex remote flight climate conditions on Earth. The altitude above 10,000 feet has a different atmospheric make up with less 0_2 the air is thinner and operation of a remote aircraft becomes more complicated. Certain UAS have altitude ceilings which have significant improved over the past several years. Due to a reduction in air density in high altitudes flying a drone above 3,000 meters is significantly more complicated. How the drone hovers and uses batters is different, flight inclination is different and therefore the remote pilot must operate the UAS differently as well. Temperature in these volcanic regions are significantly reduced relative to the tropical lowlands of Costa Rica, and therefore remote pilots must also consider the temperature of the air during the drone flight and how that will affect the equipment.

Results

Between the lower air density due to altitude and reduced temperatures actual flight time will be reduced and this must be taken into consideration. Research with UAS pilots has shown pilots can expect a 10% reduction in battery preference every 2,000 meters. Remote flight operations will become extremely complicated at 4,000 meters and above, most drones will require proper modifications and specialized parts for these altitudes. There is greater wind turbulence inside craters, next to cliff faces and in valley's. If there is a Thunderstorm it's an almost certainly to cancel the flight mission and postpone for a better day. If there are lightning strikes it's an outright stand down. Lighting will destroy the connection capabilities of the RC and drone and will cause a complete disconnect [2]. The most unpredictable and hazardous feature of a volcano is the lava dome. Degassing fumaroles, updrafts, ambient temperature change and potential eruption with explosive molten material and volcanic bombs all add to the complexity of the atmospheric environment in which the remote pilot must operate the UAS [3]. During the course of an eruption volcanoes change levels of degassing and the species of emissions fluctuate. There may be various amounts of lava extruding from the volcano and during the eruption period the level of activity varies. This fluctuation results in ever changing geo morphology which can be mapped and tracked by UAS photogrammetry flight missions. UAS can also take measurements of volcanic plumes and industrial pollutants. One of the best volcanic plume samples taken by drone was published by Earth, Planets and Space scientific journal which focused on the Mt. Ontake eruption in Japan 2014 [4].

Engineers with many research institutions, universities and private companies are designing strategies for UAS to assist with future challenges [5]. The Indian Institute of Technology in Roorkee conducted the UASG2021 conference specifically outlining how drones can be used to assist the United Nations with they're Sustainable Development Goals [6]. UAS have gained particular attention in the fields of geochemistry, atmospheric chemistry and interplanetary exploration. In 2018-2019 Chilean researchers used UAS to monitor carbon degassing at the Volcán Villarrica in Chile. Volcanic degassing is an essential aspect to monitor because it offers insight into the magmatic and hydrothermal systems below the degassing crater or fumarole. The article outlined plume transport & dispersion which was successfully documented by UAS in a very intense and extreme atmospheric environment. The authors published their work in Advancing Earth and Space Science 2019 [7]. The American Association for the Advancements of Science has particular interest in advanced engineering of micro sensor technology to optimize GIS applications via UAS, but also for interplanetary scientific mapping missions of the surface of the Moon and Mars. This team emphasized the importance of using UAS to monitor volcanic degassing to better understand Earth's Carbon Cycle. By deploying UAS with multi-GAS sensing technology, thermal IR sensors and other specially configured hardware, we can collectively advance mankind's ability to measure Global Volatile Fluxes from transport emissions, industrial manufacturing associated with economical productivity and degassing volcanoes around the world [8].

Conclusion

Volcanic environments are one of the most extreme climates on Earth, especially inside of active degassing craters. Today drones have become an important tool in different types of scientific and engineering jobs. The reason of it, is because they can facilitate the work, besides they can prevent injuries form repetitive and heavy works and can help us understand, explore, and study different subjects such as atmospheric science, or planetary exploration. Despite the different applications that drones have, there will be great focus on biological, physical, and chemical sampling in different fields such as enviromental science and interplanetary exploration.

Researchers with LAQAT-UNA retrieved water samples from the hyperacidic extremely hot crater lake named Laguna Caliente of the Poás Volcano National Park. José Pablo Sibaja Brenes of Universidad Nacional Costa Rica has been using an advances fleet of UAS for volcanic sampling of both water from the hyperacidic crater lake and they have completed air quality measurements around the degassing fumaroles with drones using electrochemical gas sensors as UAS payloads specially configured for volcanic emissions. The most difficult flight was in Poás volcano, 2022. When José Pablo was trying to collect the water from the hyperacid lake, there was a lot of evaporation.Visability droped to zero and he couldn't see anything. He continued descending the drone about 3 meters of the water, because there was a problem with the rope, the bottle and the batteries. At the end, the he had to return the drone to the look out launch site of the volcano and check the rope and change the batteries. After a few adjustments he did the measurement with the new batteries and successfully droped the bottle on the rope 30 meters down for a sampling the hyperacidic water.

Figure 4 – Laguna Caliente Active Crater of the Poás Volcano National Park via UAS February 2022

Figure 5 & 6 – Laguna Caliente Active Crater of the Poás Volcano National Park via UAS February 2022

Other applications of drones can be visualized in geoscience, especially in surface mapping. Applications of Unmanned Aerial Vehcles in Geosceince suggest that UAVs are commonly used by geoscientist for making maps of Earth's surface by photogrammetric methods. Beside of it, he also suggests that drones help geoscientist in underground survey and underwater survey by using an UAV-borne ground penetrating radar and an UAV's equipped with the light detection and ranging sensor specifically. He also implies that miniaturization of geophysical instrument has opened new opportunities in this kind of analysis. This can be verified by the efforts of NASA scientist. The reason of it, is because in 2020 mission they land a rover and a miniaturized helicopter, Perseverance and Ingenuity specifically [9].

In the case of Ingenuity, NASA planned to demonstrate the first controlled flight in another world were the physical conditions are different from Earth, and after three successful flights, he proved its technology demonstration. After that Ingenuity completed 41 flights, with a flight time of ~67.7 minutes and a distance flown of 8.191 meters. For the case of Perseverance rover, NASA planned to explore and study past life sings in the Jezero crater by identifying and collecting compelling rock core and soil samples. For these, NASA engineers and scientist attach to the rover different types of instruments to the rover such as the Mastcam-Z for imaging, the mMars Environmental Dynamics Analyzer (MEDA) for temperature, wind speed & direction, pressure, relative humidity and dust sampling for analysis of size a shape of the particulate matter PM (10).

The rover was also carrying equipment for the Mars Oxygen ISRU Experiment (MOXIE) designed for producing oxygen from atmospheric carbon dioxide, Planetaru Instrument for X-ray Lithochemistry (PIXL) for elemental composition of Martian surface by an X-ray fluorescence spectrometer, Radar Imager for Mars' Subsrface Experiment (RIMFAX) for centimeter-scale resolution of geological structure, Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC). The rover had equipment specially engineered for experiments in Mars mineralogy and detection of organic compounds by UV Raman spectrometer. Therefore, it can be concluded that drones are an helpful tool in our daily basis and can help us reach fields that the human being can explore in this moment such as upper atmosphere or interplanetary research [9].

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