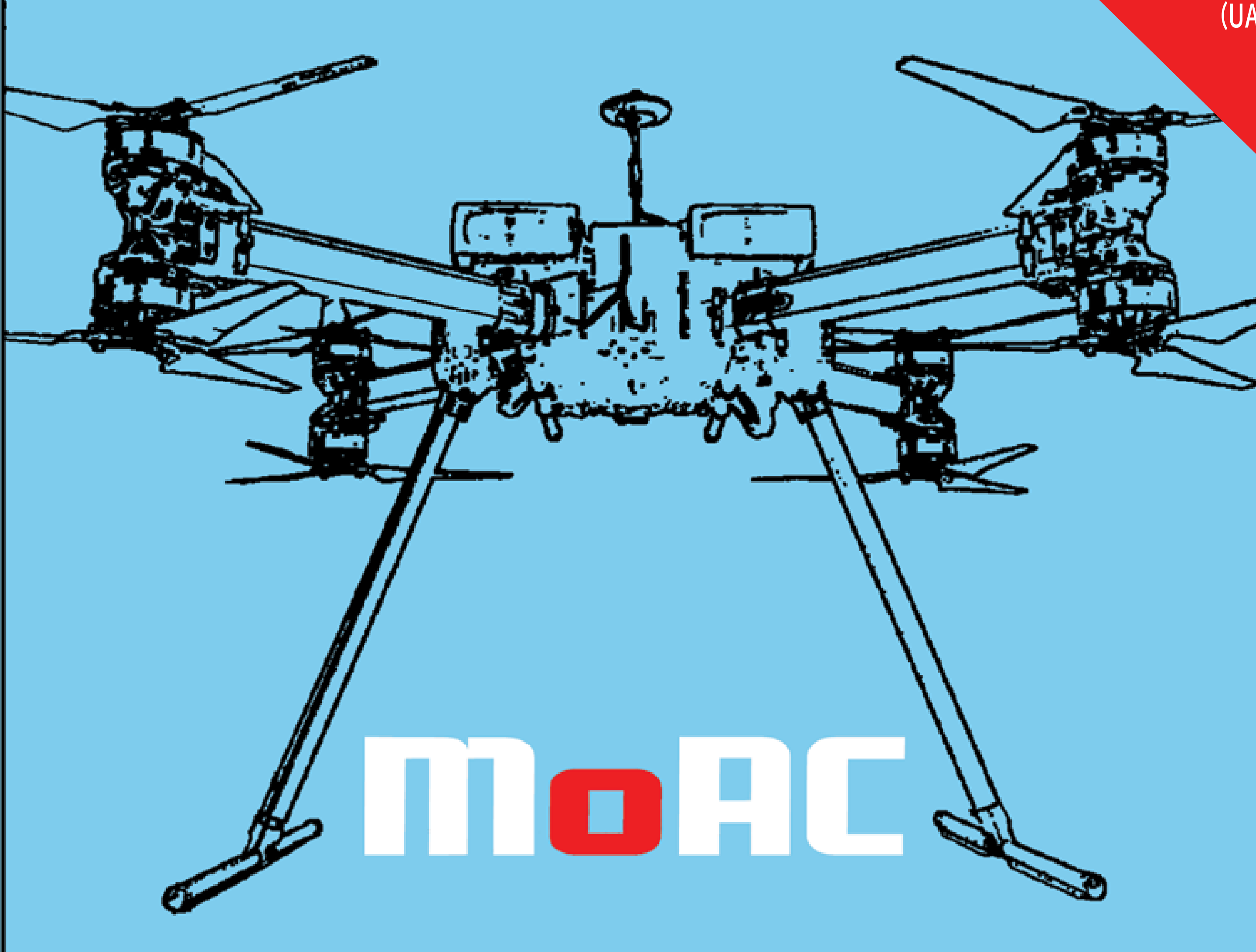
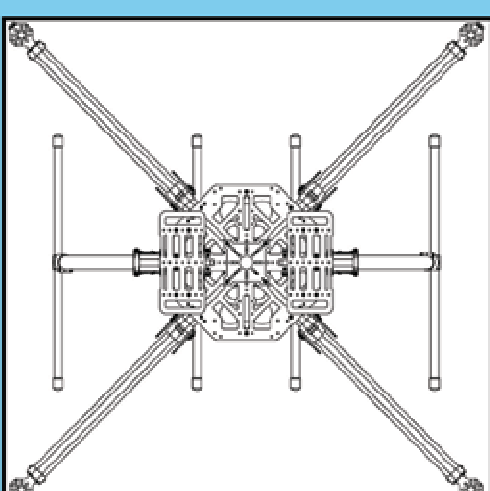
PE&RS

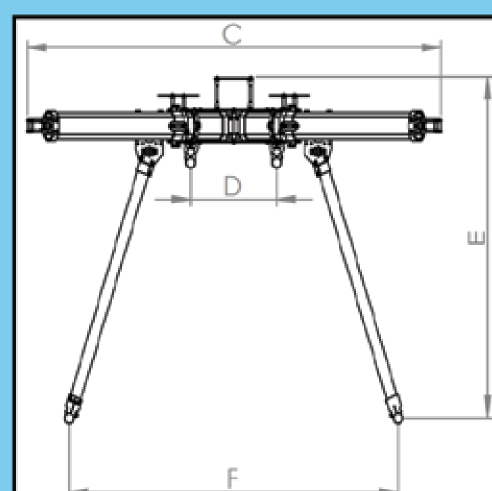
April 2015 Volume 81, Number 4

Monograph

Overview and Current Status of Remote Sensing Applications Based on Unmanned Aerial Vehicles (UAVs)







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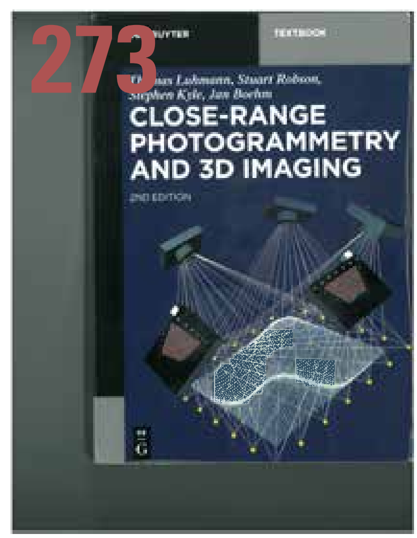


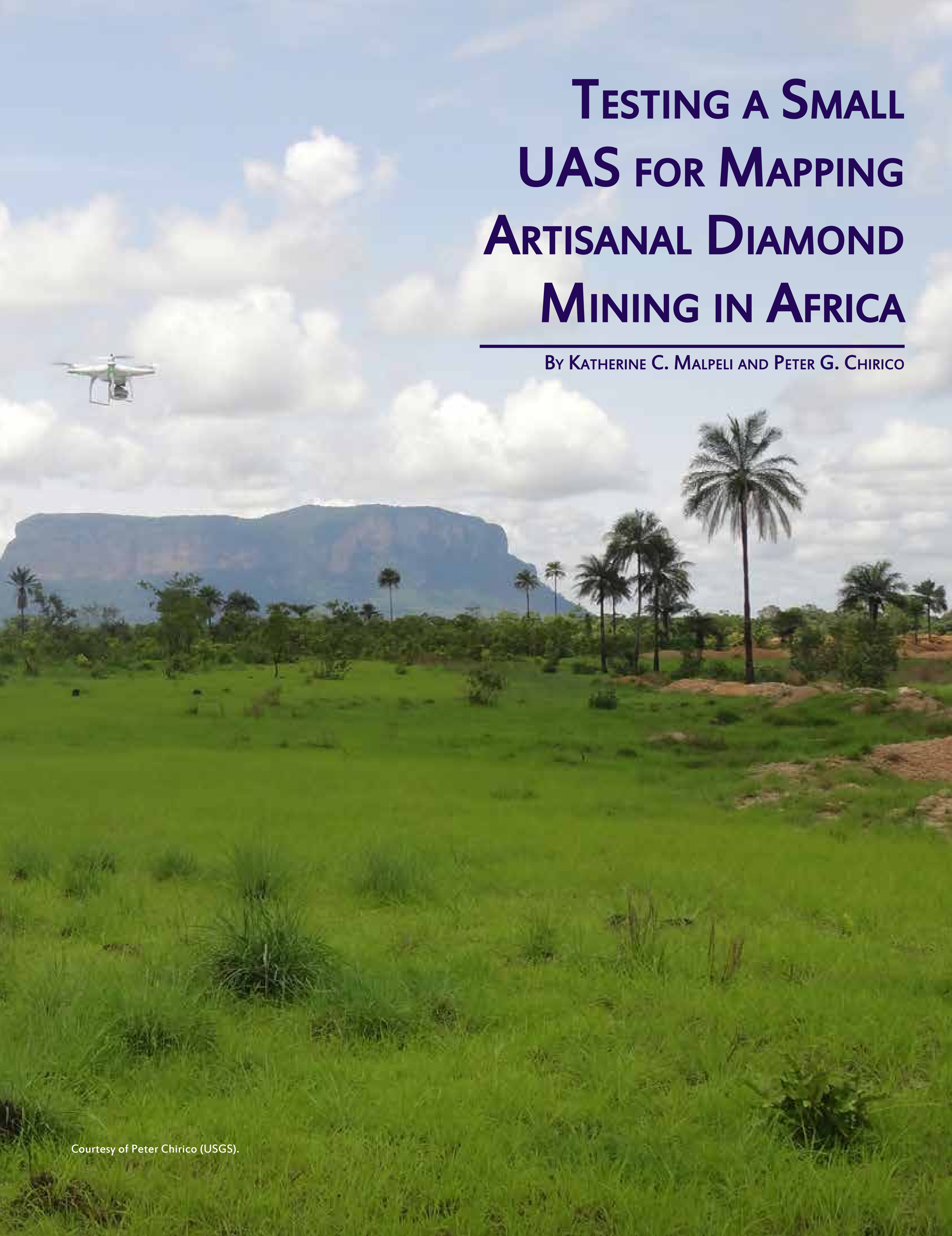
PEER-REVIEWED ARTICLES

SPECIAL MONOGRAPH

A monograph presenting an overview of the current status of UAVs and remote sensing applications based on unmanned aerial platforms equipped with a combination of specific sensors and instruments, including an expanded list of technical references.

Testing a Small UAS for Mapping Artisanal Diamond Mining in Africa

By Katherine C. Malpeli and Peter G. Chirico



Courtesy of Peter Chirico (USGS).


Courtesy of Souleymane Diallo (USAID PRADDII).

Introduction—Conflict Diamonds, Artisanal Mining, and Remote Sensing

Remote sensing technology is advancing at an unprecedented rate. At the forefront of the new technological developments are unmanned aircraft systems (UAS). The advent of small, lightweight, low-cost, and user-friendly UAS is greatly expanding the potential applications of remote sensing technology and improving the set of tools available to researchers seeking to map and monitor terrain from above. In this article, we explore the applications of a small UAS for mapping informal diamond mining sites in Africa. We found that this technology provides aerial imagery of unparalleled resolution in a data-sparse, difficult to access, and remote terrain.

This work stems from a long-term project carried out by the U.S. Geological Survey (USGS), the U.S. Department of State (DOS), and the U.S. Agency for International Development (USAID) in support of the Kimberley Process (KP), an international initiative aimed at preventing the flow of conflict diamonds. Concerns that natural resources were being used to fund conflicts first surfaced in the late 1990s and early 2000s during the brutal civil wars in Sierra Leone, Liberia, and Angola. During these conflicts, profits from diamond mining were exploited by rebel groups to purchase arms and finance the wars (Le Billon, 2008). The terms "blood diamonds" and "conflict diamonds" evolved as a result and were popularized to describe such scenarios. In an effort to halt the trade of conflict diamonds, the KP was initiated in 2003 to impose and enforce regulations on diamond producing, importing, and exporting countries. As of 2014, 81 countries were members of the KP.

Countries whose diamonds are produced through artisanal and small-scale mining (ASM), an activity in which individuals use only simple tools to mine, face unique challenges in adhering to the KP's regulations. ASM sites are often remote and spread over vast territories, and the diamonds found are frequently sold into informal networks, making it very difficult to track production – a key requirement of the KP. To support the KP and DOS in monitoring efforts, the USGS has been conducting country-scale diamond resource and production assessments in West and Central Africa since 2007.

In recent years, there has been an increased push by national governments and the international development community to formalize ASM. Formalization involves legalizing ASM, registering miners, delineating mining zones, and establishing a legal flow chain through which production is intended to move. The ability to map and monitor artisanal diamond mining sites is a necessary step towards achieving formalization. Doing so helps to identify where mining is taking place, the extent of activities, the amount of production, and how the activity and production change over time. The USGS is currently spearheading research on the applications of remote sensing technologies for mapping artisanal diamond mining sites. The USGS is using high-resolution panchromatic and multispectral satellite imagery, in combination with field observations, to successfully identify ASM activities and estimate the production in diamond mining zones throughout the region (Chirico and Malpeli, 2013; Kauffmann et al., 2013). While a useful tool, satellite imagery has its limitations, such as atmospheric constraints (cloud cover, haze, smoke, etc.), temporal resolutions that fail to capture the dynamic nature of ASM sites, and spatial resolutions that can be inadequate for identifying fine-scale features. With the advent of small, low-cost, and user-friendly UAS, the USGS and USAID recently began collaborating to explore the application of this technology for mapping and monitoring ASM. Specifically, the team is using UAS technology to support USAID's Property Rights and Artisanal Diamond Development (PRADD) project's efforts to formalize ASM in Guinea. In June 2014, a USGS and USAID team used a small UAS to map artisanal diamond mining sites in the Forecariah Prefecture of western Guinea (Figure 1). Building on a previously completed country-scale assessment of Guinea's diamond deposits in 2012 (Chirico et al., 2012), this current effort seeks to create detailed site maps and generate very-high resolution digital elevation models (DEMs) of the region to better inform diamond production evaluations.

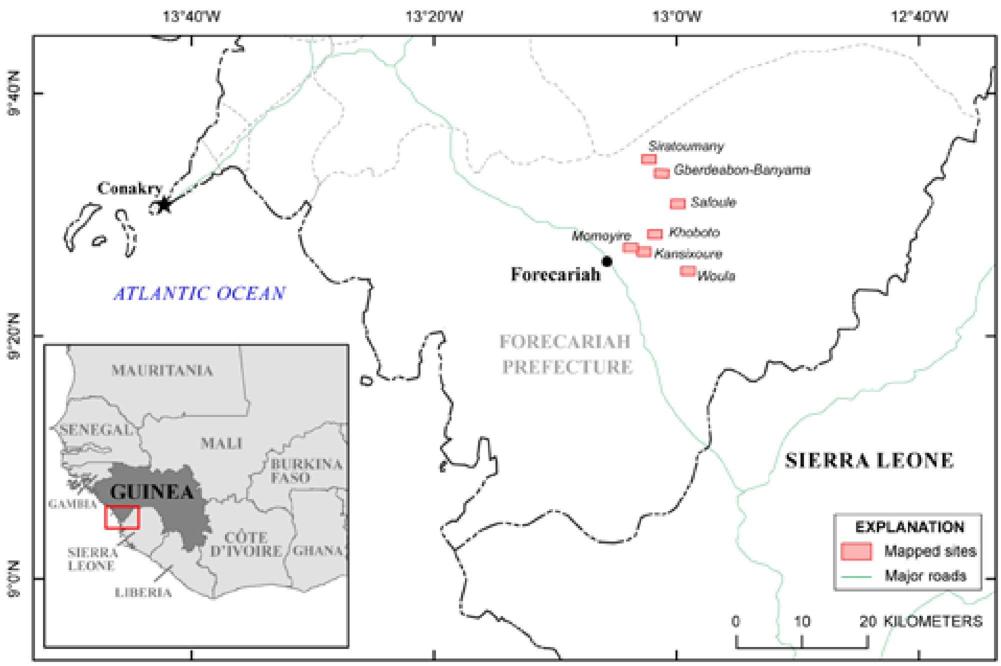


Figure 1. Map of the Forecariah Prefecture study area in western Guinea.

UAS for Environmental Research

While the development of UAS technology has been driven largely by military requirements, it is increasingly being employed for civilian applications (Hardin and Jensen, 2011). Researchers began investigating the development of remotely-piloted vehicles for environmental applications in the 1980s. Early research encountered numerous challenges such as navigation and aircraft control difficulties, limited payload capacities, and difficulties in ensuring complete target coverage (Tomlins, 1983). Many of these challenges have since been addressed, and within the past 7 to 8 years small UAS technology capable of environmental data collection has become widely available. Today, researchers are using UAS for a variety of environmental purposes including precision agriculture, soil assessments, and vegetation, habitat, and biodiversity monitoring (Hardin and Hardin, 2010).

While numerous types of UAS are now available, most environmental research employing this technology is carried out with small, lightweight aerial vehicles that have short flight ranges and limited flying altitudes (Paneque-Gálvez et al., 2014; Hardin and Jensen 2011). Such UAS can only carry light payloads, so small consumer-grade (non-metric) digital cameras are the most commonly used sensors. However, UAS technology is continually evolving, and infrared, multispectral, thermal, hyperspectral, LiDAR, and Synthetic Aperture Radar (SAR) systems are also being tested on UAS (Hardin and Jensen, 2011).

Using a UAS to Map Artisanal Mining Activities in Guinea

In June 2014, a joint USGS/USAID team employed a small (350 mm x 350 mm; 670 g) battery-powered rotary-wing quadcopter to collect data at seven artisanal diamond mining sites in the Forecariah Prefecture of western Guinea (Figures 1 and 2). Two lightweight (74 g) non-metric digital cameras were tested on the quadcopter. The first camera (Camera 1) had a 2.5 mm wide-angle lens (101.96° horizontal Angle of View (AOV), 84.6° vertical AOV) and was used to collect nadir, oblique, and reverse oblique videography at a rate of 30 frames per second. The second camera (Camera 2) had a 7.5 mm low distortion lens (44.72° horizontal AOV, 33.39° vertical AOV) and was used to collect nadir still frame photography at a rate of 2 frames per second. The quadcopter was powered with 2200 milliampere-hour (mAh) or 2600 mAh lithium-polymer (LiPo) batteries, which enabled a flight time of 8-12 minutes per battery.

Figure 2. A PRADD team member flying the UAS at an artisanal diamond mining site.

The quadcopter was flown multiple times over each site, at an altitude of 100 m. At this flying height, Camera 2 had a field of view (FOV) height of 64 m and width of 85 m, resulting in still photography with a horizontal image resolution of 2.13 cm at nadir. However, in our evaluations of the imagery, we calculated an image resolution range of 2-4 cm, due to slight variations in flying height and view angle. A photo collection rate of 2 frames per second resulted in about 800 photos per 0.1 km², with a forward overlap of greater than 80% and a sidelap of approximately 60%. Utilizing a wide-angle lens on Camera 1 to collect video resulted in a wider FOV height and width (102 m and 256 m, respectively) but a lower image resolution (Figure 3).

Courtesy of Peter Chirico (USGS).

Figure 3. A mosaic of several oblique images of the Siratoumany site in the Forecariah Prefecture study area in western Guinea captured from video collected using the wide-angle lens camera.

Benefits of Using a UAS

While UAS are currently being used for numerous environmental mapping applications, to our knowledge this project represents the first time a UAS has been used for mapping ASM. One of the principle benefits of using a UAS for this application is that very high-resolution data can be collected over a relatively large area in a short amount of time. In this study, the UAS collected data at an approximate rate of 1.5 km² (150 hectares) per hour. Small UAS have low operational flying altitudes (typically 50-300 m) and therefore the resolution of the data significantly enhances visual image analysis (Galvez et al., 2014) (Figure 4). The resolution of the data collected in Guinea allowed us to clearly distinguish active pits from inactive pits, locate and measure piles of extracted gravel and sedimentary layers, and detect changes in water color and sediment properties (Figures 5 and 6). The ability to map an entire site from one or two field locations is particularly beneficial for ASM research, as mine sites are often located in remote areas, can be several square kilometers in size, and sections of sites may be inaccessible or even dangerous for researchers to traverse due to a lack of roads, surficial disturbance due to mining, or other challenging terrain. Utilizing a UAS, the field team was able to acquire complete aerial coverage of a site in under an hour.

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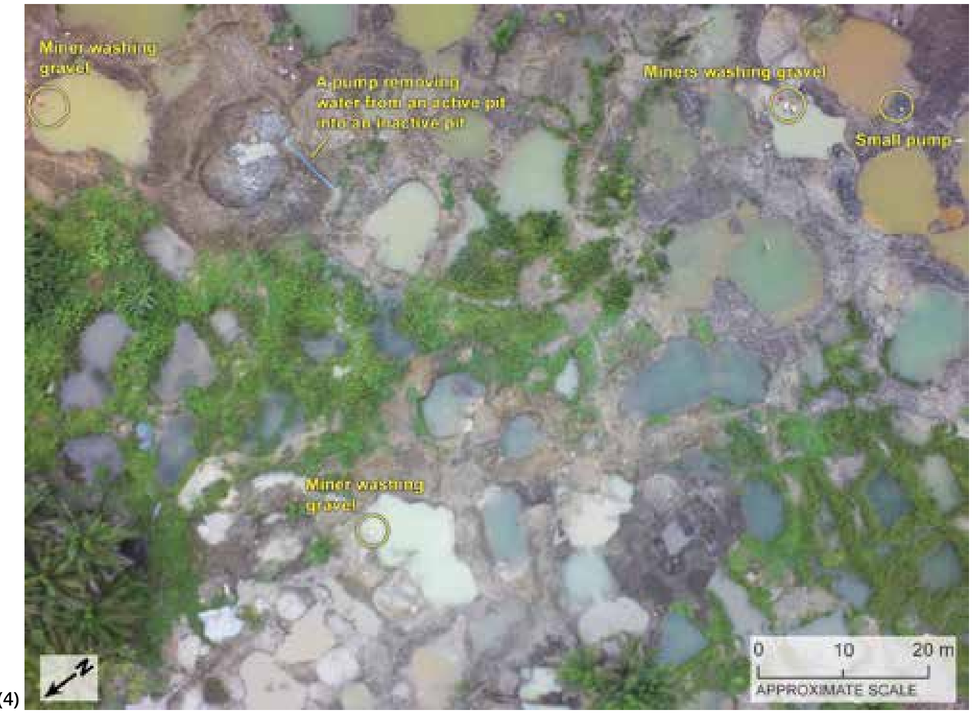

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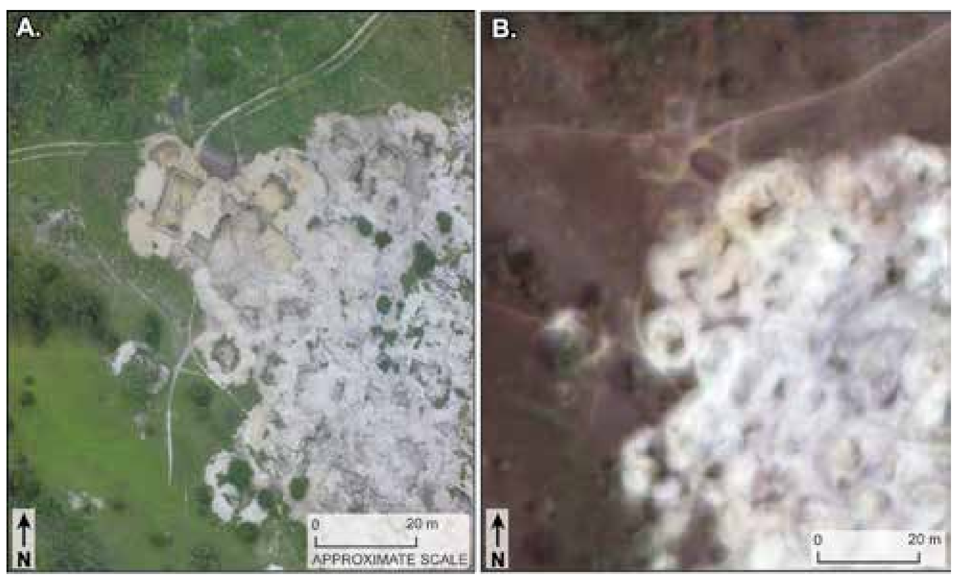

(6)


Figure 4. An example of UAS imagery collected at 100 m altitude over the Khoboto site in the Forecariah Prefecture study area in western Guinea.

Figure 5. Comparison of the spatial resolution of the UAS imagery (A) collected at the Banyama site in the Forecariah Prefecture in western Guinea with a pan-sharpened high-resolution (0.5 m) multispectral satellite image (B) of the same site.

Figure 6. A low altitude photo of miners working at a pit in the Forecariah Prefecture study area in western Guinea collected using the UAS.

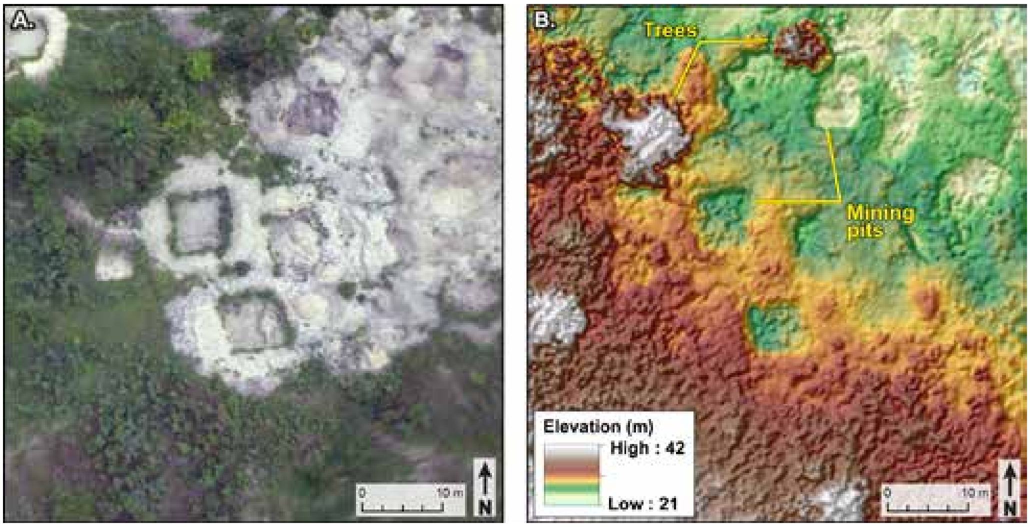

Figure 7. A subset of a UAS image mosaic collected at the Gberdeabon site (A) and a 10 cm resolution digital surface model (DSM) of the same site in the Forecariah Prefecture of western Guinea, derived from the UAS imagery using SfM techniques (B). The DSM incorporates both vegetation and tree cover features as well as ground elevation showing mining pits.

"To our knowledge this project represents the first time a UAS has been used for mapping ASM".

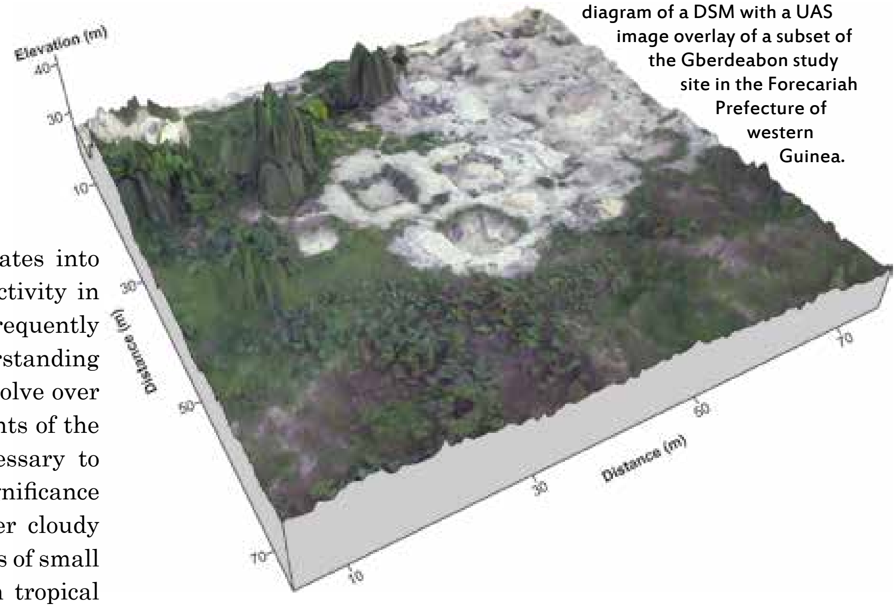

Figure 8. A three-dimensional diagram of a DSM with a UAS image overlay of a subset of the Gberdeabon study site in the Forecariah Prefecture of western Guinea.

This relative ease of data collection also translates into greater survey repeatability. ASM is a dynamic activity in which mine sites change rapidly. The ability to frequently collect imagery of sites will greatly improve our understanding of ASM and how sites, and therefore production, evolve over time. A goal of this project is to conduct repeat flights of the sites within six months to acquire the data necessary to perform a change detection analysis. Of further significance is the ability to collect high-quality imagery under cloudy conditions, due to the low operational flying altitudes of small UAS. This is of particular value when working in tropical climates. Other benefits include the small size of many UAS, which makes transportation into the field easier, as well as the vertical take-off and landing and hovering capabilities of rotary-wing UAS, which improves operability in terrains with dense vegetation and disturbed topography.

Data Analysis

Analysis of the UAS data collected in Guinea is currently underway. The nadir aerial images are being used to develop 10 cm resolution DEMs of each mine site. High-resolution ortho-image mosaics are being developed from the nadir image frames, the DEM data, and from field GPS control points. Together, the ortho-images and DEMs will help us to model the geomorphology of the terrain and enable us to better understand and identify areas of diamond deposition in the region. Products are being generated using both structure from motion (SfM) and traditional photogrammetric software algorithms, so that comparisons can be made to evaluate the costs and benefits of data processing in each environment (Figures 7 and 8). In addition, the PRADD project is utilizing the aerial videos and oblique still imagery captured using Camera 1 (wide angle lens) to conduct participatory mapping with local communities in Forecariah Prefecture to delineate mining and agricultural zones. This will assist with the formalization of property rights, thus reducing local-scale conflicts over land use.

Identified Challenges

While we identified numerous benefits to using UAS technology for collecting data at ASM sites, we also encountered several challenges. First, if a UAS has never been flown before in the country, as was the case in Guinea, there will likely be no set of established protocols to follow to acquire approval. Therefore, it was the team's responsibility to identify a process for contacting the appropriate authorities in Guinea to acquire permission to fly the UAS. This involved receiving signed letters from the Minister of Mines and Geology, the Minister of Transportation, and consent from the ministers of Defense and the Interior.

This step was achieved several months prior to fieldwork by U.S. Embassy and USAID staff based in Guinea. Equally as important as acquiring permission at the national government level was informing local communities near the field sites about the planned UAS mission. Because UAS in many parts of the world may be perceived as synonymous with military drones, it was critical that we educate the local population about the mission. To accomplish this, prior to fieldwork PRADD staff traveled to villages and mining sites to conduct a public relations campaign to notify local populations that the UAS would be flown in the area and to explain why it was being flown and what to expect. During the flight missions the team immediately downloaded and played video collected by the UAS for miners and villagers as a follow-up to the information campaign and to let them see their local landscapes from a birds-eye perspective. These steps added significant time to the field mission, but were essential to gaining the trust of local populations.

Other challenges are unique to flying a UAS in a developing country or remote location. In Guinea, there was no consistent source of power available for the team to recharge the LiPo and camera batteries. Electricity was available for only a few hours each night via generator, so the field team needed to plan accordingly to procure enough fuel and generator time to charge the equipment. In addition, due to the remote nature of the field sites, the team needed to prepare in advance for foreseeable maintenance problems, and thus brought spare parts for the UAS, such as extra propellers, engines, and a basic toolset.

Weather conditions also posed challenges. While the UAS can collect data under cloud cover, moderate to strong winds and rain remain limiting factors and prohibit data collection. Conversely, flying in bright sun conditions made maintaining constant visual contact with the UAS, a necessary safety parameter, more difficult. Finally, an interesting challenge that was not foreseen by the team involved interactions with territorial birds. In particular, the pied crow (*Corvus albus*), found throughout sub-Saharan Africa, exhibited territorial harassing behavior on more than one occasion with the UAS. Given the small size of the UAS and the relatively large size of the crow and other predatory birds in West Africa, interactions of this nature are of a concern, though are perhaps unavoidable.

The Implications of UAS Technology for ASM Research

The very high-resolution imagery and videography collected by the UAS is facilitating the development of image maps and terrain models of the mining sites and surrounding areas in the Forecariah Prefecture at an unprecedented scale. An abundance of information is being gathered from these products, ranging from the scope of mining activities, the location of mining within the landscape, the amount of activity at each site, the impact of mining on the surrounding environment, and the type of mining activities being conducted at the time of image collection. The immediate application of this information will be to assist the PRADD project in working with the Guinean government to select appropriate zones to parcel for artisanal mining based on diamond potential, an important step towards formalization and resource governance. Interpretation of the data will also assist with the identification of abandoned mine sites that can be remediated into other income-generating activities, such as fish farming and vegetable gardens, thus helping to reduce the long-term environmental degradation caused by ASM.

We are only beginning to uncover the many potential applications of UAS technology for environmental remote sensing. For ASM research, it will greatly enhance our ability to map and monitor difficult-to-access and dynamic mining sites. The level of detail garnered from UAS flight data is unparalleled and will serve diverse purposes, from helping governments and local communities allocate land for mining, to enabling researchers to identify landforms with greater diamond potential. Small UAS technology is still a relatively new innovation and therefore still faces challenges; however, UAS provide many advantages over traditional satellite remote sensing, and its applications will only expand as the technology continues to grow.

References

Chirico, P.G., K.C. Malpeli, M.Van Bockstael, M. Diaby, K. Cissé, T.A. Diallo, and M. Sano, 2012. Alluvial diamond resource potential and production capacity assessment of Guinea, *U.S. Geological Survey Scientific Investigations Report 2012-5256*: 49 p.

Chirico, P.G., and K.C. Malpeli, 2013. Reconnaissance investigation of the rough diamond resource potential and production capacity of Côte d'Ivoire, *U.S. Geological Survey Scientific Investigations Report 2013-5185*: 46 p.

Kauffmann, M., D. Al Khudhairy, C. Louvrier, P.G. Chirico, and K.C. Malpeli, 2013. Joint EU-US methodology for monitoring alluvial diamond mining activities in Côte d'Ivoire, *A European Commission (JRC) and U.S. Geological Survey (USGS) report*: 30 p.

Hardin, P.J., and T.J. Hardin, 2010. Small-scale remotely piloted vehicles in environmental research, *Geography Compass*, 4(9): 1297-1311.

Hardin, P.J., and R.R. Jensen, 2011. Small-scale unmanned aerial vehicles in environmental remote sensing: Challenges and opportunities, *GIScience & Remote Sensing*, 48(1): 99-111.

Le Billon, P., 2008. Diamond resource wars? Conflict diamonds and geographies of resource wars, *Annals of the Association of American Geographers*, 98(2): 345-372.

Paneque-Gálvez, J., M.K. McCall, B.M. Napoletano, S.A. Wich, , and L.P. Koh, 2014. Small drones for community-based forest monitoring: An assessment of their feasibility and potential in tropical areas, *Forests*, 5(6): 1481-1507.

Tomlins, G.F., 1983. Some considerations in the design of low-cost remotely-piloted aircraft for civil remote sensing applications, *The Canadian Surveyor*, 37: 157-167.