// *What's New in Geo?*

THE RISE OF UAVS SIGNALS A NEW ERA IN GEOTECHNICS

Big Data in Geotechnics Is Coming from Above

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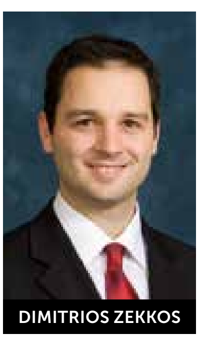
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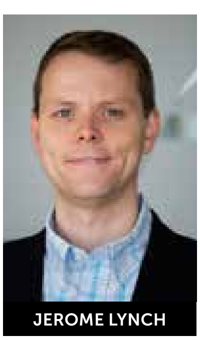
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A quadrotor UAV inspecting damaged area on the island of Lefkada in Greece, following the November 17, 2015, M_w 6.0 earthquake.

If you have been following the news, browsing the internet, or even gazing up in the sky, it is likely that you have seen an Unmanned Aerial Vehicle (UAV), also commonly known as Unmanned Aircraft System (UAS) or simply "drone." Although UAVs have existed for many years, a rapidly growing market of small UAV (defined by the Federal Aviation Administration (FAA) as weighing less than 25 kg) has recently emerged. UAVs comprise a global, multi-billion dollar industry, and although the defense sector currently makes up the majority of the market in dollars, an increasingly significant segment is being deployed for civilian purposes, including surveillance, mapping, resource monitoring, cinematography, and entertainment. Every day, more UAV technologies are becoming available in the market: UAVs with integrated cameras, racing UAVs, as well as large and small fixed-wing or multi-rotor UAVs. It is estimated that nearly one million UAVs were sold in last year's holiday season alone!

Prepare for Change

As the UAV market grows, the capabilities of these devices are improving dramatically. This is a rapidly evolving technology that is bringing change to many industries and scientific fields. It is thus not an exaggeration to predict that the era of UAVs will also cause a dramatic change in the field of geotechnical engineering. In fact, those of us who work with UAVs and have an understanding of what UAVs can do, and what they will likely be able to do in the near future, expect that UAVs will be an indispensable tool for conventional geotechnical engineering practice. There are many reasons for this, but there are three that are key.

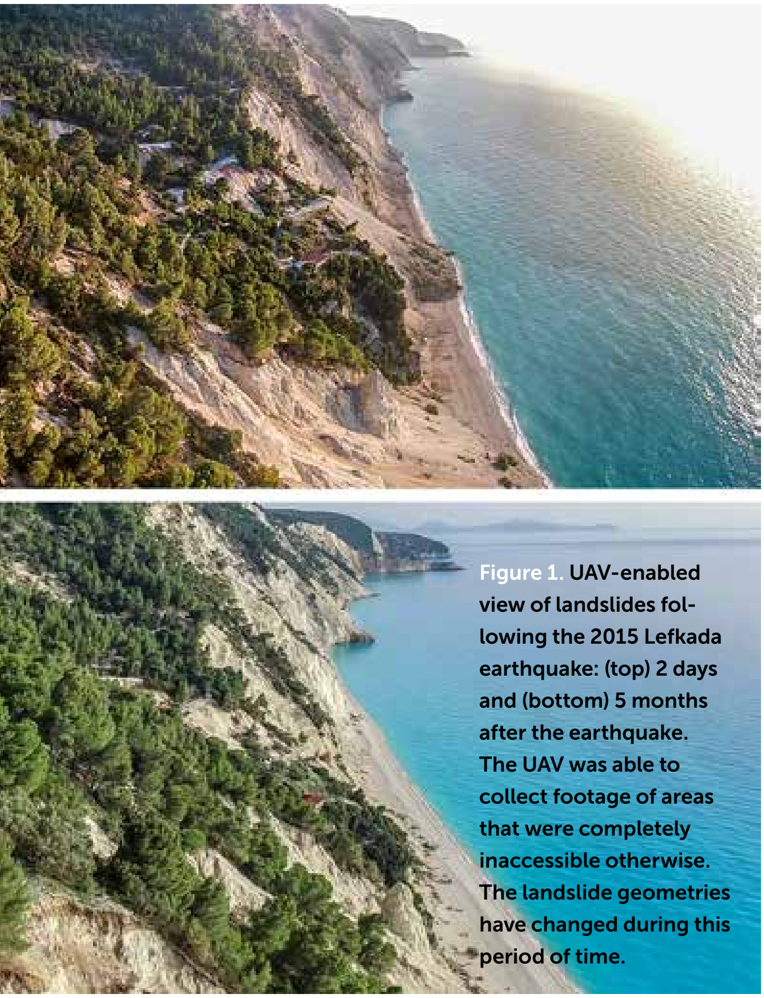

Figure 1. UAV-enabled view of landslides following the 2015 Lefkada earthquake: (top) 2 days and (bottom) 5 months after the earthquake. The UAV was able to collect footage of areas that were completely inaccessible otherwise. The landslide geometries have changed during this period of time.

Mobility and Accessibility: Small UAVs are very mobile; some of them can even be carried in a backpack. They can bypass obstacles on the ground and aerially gain access to areas that may be completely inaccessible or unsafe for people or vehicles. Robots have already been used for condition assessment studies in the Fukushima nuclear plant in Japan, where they reached areas of high radioactivity following the earthquake and associated tsunami disaster. They have demonstrated usefulness at sites affected by natural disasters as well, such as for reconnaissance and mapping of affected areas, including collapsed buildings, damaged roads and bridges, and landslides. Figure 1 shows UAV footage of landslides that were caused by the November 17, 2015, M_w 6.5 Lefkada earthquake in Greece. These 200-m-high landslides were completely inaccessible to the public and scientists, but a UAV was able to collect footage just two days after the earthquake. Additional footage collected five months after the earthquake in still inaccessible areas shows how the slide mass is being actively eroded by ocean wave action. Thus, UAVs can help to safely collect valuable, perishable data soon after events occur.

Cost: The growth of the commercial small unmanned aerial vehicle (sUAV) market is great news for our profession. A large market for this technology brings costs down and makes the devices affordable to conventional geotechnical practice. The necessary basic hardware equipment can be purchased for less than $5,000; although depending on the application, more expensive UAVs that cost $50-100k or more may be needed. In any case, these are very reasonable costs for such a powerful tool!

Big, Better Data: UAVs occupy a truly unique place in the space-time domain of our field geo-characterization toolbox. Their role cannot be completely replaced by satellites, which are limited to remote sensing from a significant distance away from the target, or ground-based stationary measurements. UAVs with mounted sensors can collect unprecedented amounts of high-resolution data and can cover large

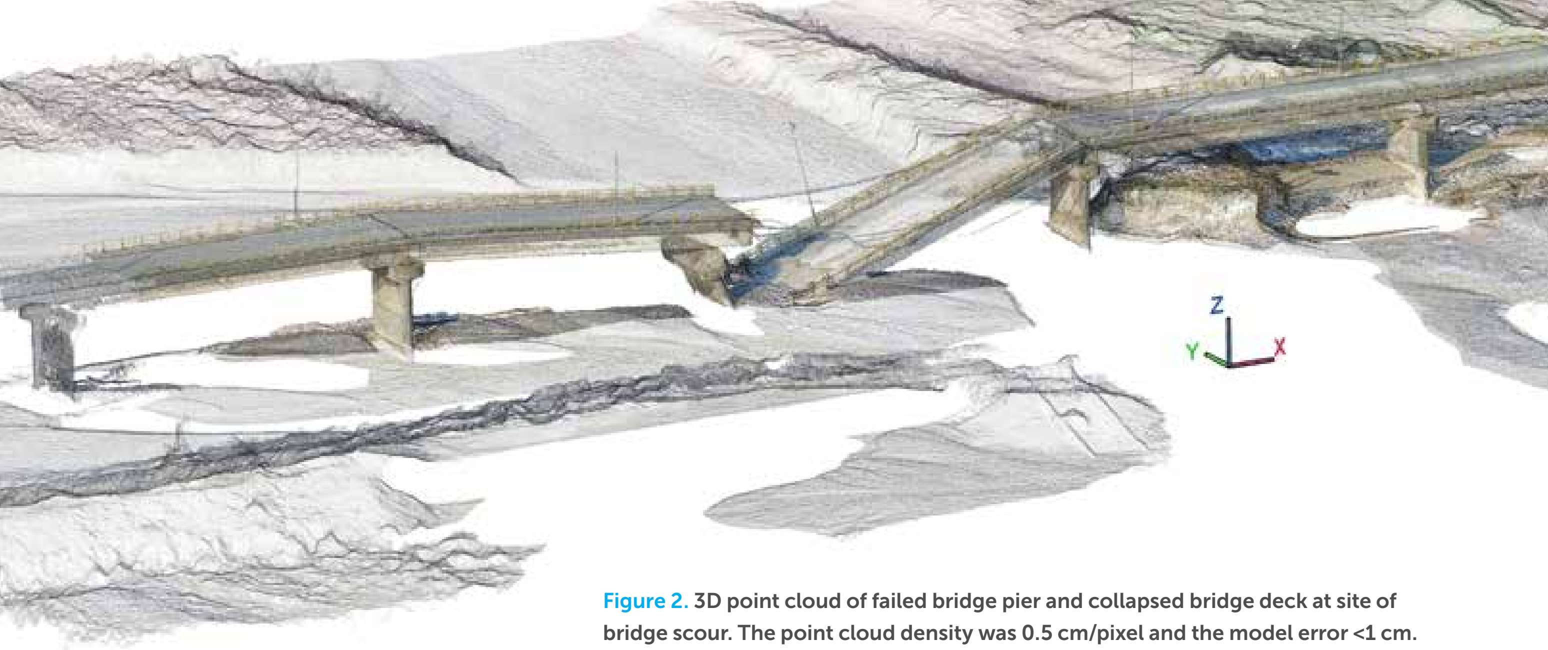

Figure 2. 3D point cloud of failed bridge pier and collapsed bridge deck at site of bridge scour. The point cloud density was 0.5 cm/pixel and the model error <1 cm.

areas. Because of their mobility, they can be deployed quickly and collect data at short time intervals if monitoring an evolving process. The spatially distributed, high-quality data generated by UAVs, such as picture/video, is fundamentally ushering in the "Big Data Era" of geotechnical engineering.

The Mobile Sensing Revolution

With the rise of UAVs, comes a rise in portable sensing technology that can generate data we could barely fathom more than a decade ago. Numerous sensors, including light detection and ranging (LIDAR), high-definition optical cameras, as well as thermal, near-infrared, infrared, and hyperspectral cameras, have already been mounted on UAVs and are being used for a variety of applications. In addition, sensors that are used in geophysical applications are being mounted on, or deployed by, UAVs, including magnetic sensors, micro-gravity sensors, and even seismic sensors. While geotechnical instrumentation has transitioned from wired to wireless monitoring technology over the past decade, current sensing paradigms are based on stationary sensor deployments. In contrast, UAVs enable mobility in sensing. UAVs can carry or deploy portable sensors that can collect field performance data, in many cases remotely, and allow us to collect spatially-distributed, time-sensitive data from a distance.

UAV-enabled Vision Sensing and Geotechnical Engineering

Of the variety of sensors that are being mounted on UAVs, optical cameras are by far the most common. UAV-based cameras are already being employed in many fields of science, as well as in cinematography and by hobbyists. From a geotechnical engineering perspective, the rise of UAVs as data acquisition platforms, paired with recent advances in digital image processing, is destined to profoundly alter our methods and practices in geotechnical engineering.

In its simplest application, still photos or high-definition video are used to perform a visual, largely qualitative inspection or condition assessment of a target feature by taking advantage of the UAV's ability to fly over obstacles and inspect a target from different perspectives. Although satellites typically collect data in plan view only, the UAV can capture footage also in side or oblique views, thereby providing a better assessment of the target. When necessary, the UAV can also zoom-in and inspect certain features of the target that may be difficult to discern from a larger standoff distance.

UAVs can also be used to generate orthorectified imagery and, more importantly, three-dimensional (3D) point clouds of a target. This is achieved using Structure-from-Motion (SfM), which is a range imaging technique, and essentially a digital implementation of photogrammetry principles. In SfM, a series of overlapping images are used to create a 3D model of the target feature that can be subsequently used in analyses. Figure 2 shows a 3D point cloud of a bridge that collapsed due to scour of one of its piers. Because the bridge was unsafe and inaccessible, UAV imagery was vital to the creation of an accurate 3D model that was then analyzed to measure the horizontal displacement, settlement, rotation, and tilt of the bridge pier from a distance. This 3D model has a resolution of about 0.5 cm/pixel and a relative model error that is less than 1 cm.

Another example is the case of a dam that failed due to underseepage, as shown in Figure 3. When a section of the dam failed, the impounded water began to empty out, abruptly generating a 5-m-high wave. This rapid water evacuation resulted in a secondary rapid drawdown slope failure that was also mapped and can be seen in the right side of the figure. Once a 3D point cloud is created, one can easily generate cross-sections to evaluate the before (if available) and after system geometries to quantitatively define failure. The SfM technique can also be used to create orthorectified imagery, commonly known as orthophotos, that can be used to measure distances. An example is shown in Figure 4, which illustrates a map of the dam site and the downstream area affected by the rapid release of the impoundment. Through high-resolution imagery obtained from an aerial drone, a scaled map of the 1-km-long area

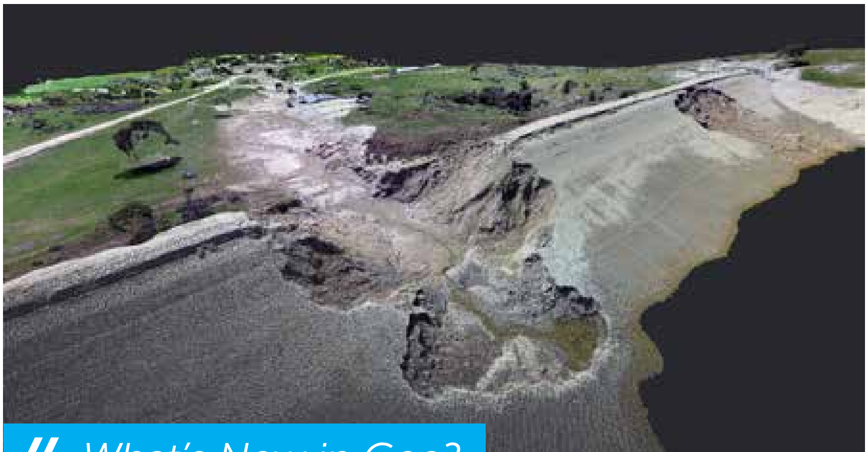

Figure 3. 3D point cloud of two failures at dam site. The left is a failure due to underseepage that resulted in a catastrophic evacuation of the impounded water. To the right, a subsequent rapid drawdown failure that occurred when the water level in the impoundment dropped.

was created to measure any needed dimensions.

Digital image processing can also be used to generate additional insights from the mapped area. For example, automatic feature recognition schemes can be used to identify target features (e.g., cracks) and measure their size. Through repeated surveys and change detection computation schemes, one can identify the evolution of progressively moving features, e.g., moving landslides. Digital imagery can also be used to characterize landslides or rock masses. An example is shown in Figure 5 for a rock slide that occurred during the 2015 earthquake in Gorkha, Nepal. The imagery collected allowed not only the characterization of the geometry of the rock slide, but also the geomechanical characteristics of the rock structure. Although the examples shown highlight some of the interesting applications of UAV-based digital imagery in geotechnics, with advances in digital image analysis, we can only expect to be able to do more in the future with UAV-generated data.

Current Barriers for UAV Technology in Geotechnics

Regulations

By far the most serious barrier of this technology today is the regulatory framework. Should an sUAV drop from the sky, it could hit and severely injure or even kill a person. In addition, the mobility of the UAVs, when misused, can have an impact on people's privacy. Thus, flying a UAV should not be taken lightly due to liability exposures for the UAV operator and owner. Current regulations in the U.S. present challenges to widespread use of UAVs in geotechnical practice. This is not the case in countries such as Europe, South America, and elsewhere, where executing flights with UAVs is much easier. The FAA recognizes that UAVs are a powerful tool that have major positive implications in science, emergency response, safety, and mobility, and is continuously revising its procedures to facilitate safe and lawful use of the technology within the national airspace. Legally, a UAV cannot fly for commercial purposes without explicit authorization by the FAA, a situation that greatly affects our ability to effectively use this technology. A certificate of authorization, air worthiness certificate, registration of UAV, and a fully-licensed pilot are among the current federal requirements; and there are additional geographic and application restrictions. The Section 333 Exemption that was introduced by the FAA in the last few years allows commercial operation of sUAVs with fewer requirements within certain parameters, but the process is still difficult. The new set of regulations, Part 107 of the Federal Aviation Regulations that became effective in August 2016, are expected to give a considerable boost to commercial applications of the technology, as they essentially simplify the process of flying with a UAS. A remote pilot certificate with a small UAS rating will be required to be allowed to pilot a UAS.

Battery Life and Weather Conditions

Beyond regulations, battery capacity is

Figure 4. Orthophoto of original water impoundment area, failed dam, and flooded area downstream of the failure location. The water travelled about 1 km downstream before reaching a natural gulley and stream.

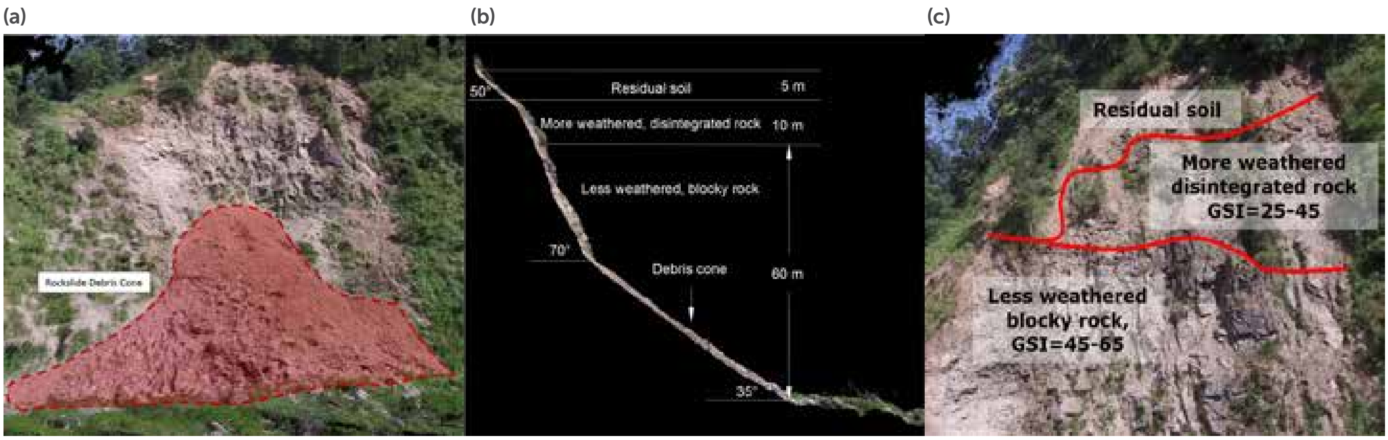

Figure 5. Characterization of a 75-m-high co-seismic rock slide in Nepal during the 2015 Gorkha earthquake. (a) 3D rock mass characterization; (b) cross-section through slide; (c) geomechanical characterization of rock mass.

another weakness. Currently, multi-rotor platforms can achieve a flight duration of up to 20-25 minutes, whereas fixed-wing UAVs can fly for nearly an hour. Depending on the sensors mounted and the total weight of the UAV platform, flight duration can be significantly reduced. Drones are also vulnerable to weather and environmental conditions. Safe flying may not be possible in high wind or rain, and many UAVs are sensitive to heat and moisture.

UAVs Beyond Data Acquisition Platforms

We are collectively still at the very beginning of leveraging the capabilities of UAVs. As our profession embraces increased use of this technology, UAVs will continue to evolve and mature. Present uses of UAVs are restricted to data acquisition; however, UAVs have extremely powerful on-board microprocessors that can potentially analyze data in-flight and make decisions on the basis of the acquired data.

The opportunities that arise with such advances are dramatic. During a natural disaster, for example, UAVs can be deployed to survey large affected areas, collect data, and apply semi-automatic or automatic feature recognition schemes to identify "hotspot" sites of interest (e.g., flood zones, landslides, or liquefaction sites). Using this information, UAVs can then make a decision to approach closer and collect better data or command other UAVs with the best-suited sensors to survey the target area. When fully autonomous, UAVs will be capable of making all decisions related to flight path and data collection frequency. Significant progress is currently being made in data analysis, computing, and advances in machine learning that will improve the automation capabilities of the UAVs in the not-too-distant future.

Preparing for the UAV Revolution

In the January/February 2016 issue of *GEOSTRATA*, Prof. Ellen Rathje provided recommendations to prepare for the "remote sensing revolution." She highlighted the need to understand the technology used for remote sensing as well as the training necessary to handle data processing, geomatics, and even the fundamentals of surveying. These comments and recommendations are valid when it comes to the use of UAVs as well.

When the civil engineering curriculum in the U.S. abandoned the instruction of surveying fundamentals, the ability of trained civil engineers to understand 3D geometries and spatial data diminished. Training in these fields is a necessity to handle UAV data. In addition, geotechnical engineers need to train in sensing fundamentals, data acquisition, and data analysis. Geotechnical site characterization courses commonly focus on the use of currently established technologies (e.g., SPT, CPT, drilling and sampling, various penetrometers, and geophysics) for site characterization. A strong educational background in modern sensing technologies can provide new avenues for site characterization. While many sensing technology options were previously difficult to implement in the field due to limitations with access and line-of-sight, the rise of UAVs and, more broadly, automated platforms and robotics, is creating new and truly exciting opportunities to implement them in our profession! GS

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