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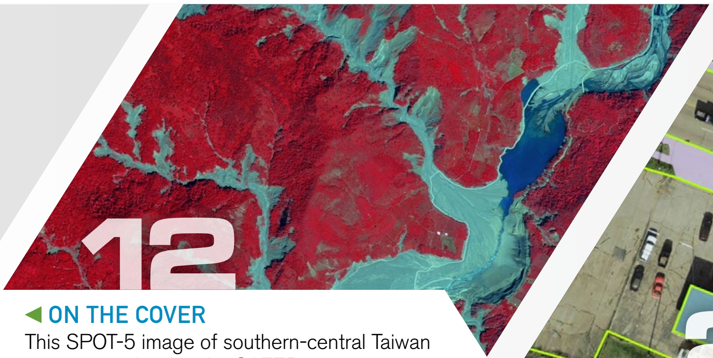

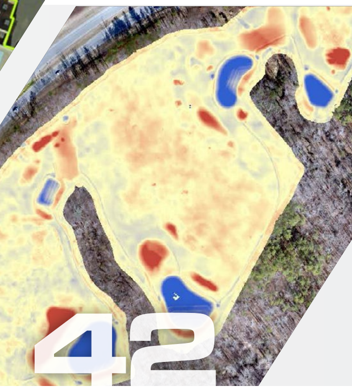

◀ **ON THE COVER**
This SPOT-5 image of southern-central Taiwan was acquired within the SAFER project.
Image Credit: CNES (National Centre for Space Studies).

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FROM THE EDITOR

A. STEWART WALKER

Taming the tumultuous times

I have joined *LIDAR Magazine* as our geospatial world whirls amongst spectacular advances. Recent visits to the 56th Photogrammetric Week in Stuttgart and the enormous Intergeo event in Berlin underlined the vibrancy of both the stakeholders and the technology. It is a weighty responsibility and considerable privilege to try to help you discern the directions we are taking. My position as managing editor has some airborne emphasis—because that is the focus of my own experience—and we have ideas to deploy further editors with skills in terrestrial and mobile LIDAR.

The Stuttgart event was epochal, in the sense that it was the first presided over by Professor Uwe Sörgel, chair of the Institute for Photogrammetry at the University of Stuttgart. Appointed in 2015, he took over from Professor Dieter Fritsch, a world name in modern photogrammetry. These professors stay in their posts for decades, so this change was significant! We are interviewing Uwe to find out what's going on. Uwe's field is synthetic aperture radar (SAR) and this topic unsurprisingly featured in the tutorial preceding the main event. Our industry has moved beyond the myth of competitive technologies and we seldom hear from Luddites who think you don't need photogrammetry because you have LIDAR—or *vice versa*—so we will try to present to you updates on the *complementary* technologies that may be used in conjunction with LIDAR. Amongst many memorable presentations was a masterly comparison of "traditional" and emerging LIDAR technologies (Geiger-mode, single-photon) from a scientific point of view by Dr. Boris Jutzi, Karlsruhe Institute of Technology, providing succinct, invaluable background for understanding the recent arrivals.

For readers who have not attended Intergeo, the sheer scale is hard to assimilate. The focus is the trade show—hundreds of booths, some bigger than the biggest I've seen at the San Diego Auto Show, spanning six halls of the Berlin Messe. The throngs on some of the booths were reminiscent, too, of auto enthusiasts anxious to get up close with a new Corvette or Aston Martin! In three days it is impossible to visit all these booths, so one must travel with a list of must-visits. The vibrancy of our industry was reflected in the many new products on show, some of which had been previewed in Stuttgart two weeks earlier. There is no question that customers of the exhibitors continue to benefit from higher performance, more economically delivered, than ever before. First impressions can be misleading, but we remember the enormous number of unmanned airborne systems (UASs) of all shapes and sizes, and the range of successful integrations that have been accomplished. I am in the early stages of preparing a feature for you on the integration of LIDAR on UASs, which is rather more demanding than integrating a camera on its own.

I've been around in the photogrammetry world for decades, first in academic life in London, then in private industry, working for system suppliers in UK, Switzerland and US. I became conscious of LIDAR in the

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1990s, but I remember a turning point when I was working for LH Systems, a joint venture between GDE Systems and Leica for the development, marketing, sale and support of photogrammetric systems. My boss, CEO Bruce Wald, another geospatial veteran, called me in one day and said something like, "I'm not very sure what this LIDAR thing is, but I want you to keep an eye on it for us." Perhaps three years later, we acquired Azimuth Corporation, a manufacturer of airborne LIDAR sensors in Westford, Massachusetts. The Azimuth AeroScan became the Leica ALS40 and the rest is history, but I want to catch up soon with Ron Roth, co-founder of Azimuth Systems and popular globetrotting LIDAR guru, as he works on the integration of Sigma Space into the Hexagon empire.

Many of us have noticed with approval the increasing number of jurisdictions that have made their LIDAR data available free of charge. LIDAR compressor Martin Isenburg recently reminded us on LinkedIn that Scotland has joined the throng. As a Glaswegian, I spent a nostalgic few minutes on the portal looking for coverage of the haunts of my youth. We're planning an article to report on the progress of similar availability across the globe. A rather parallel, perhaps less riveting yet equally critical, trend is the publication of guidelines for LIDAR acquisition, for example those for Canada published in September —we have a duty to keep you up to date on this too.

Since I am "mature", an "industry veteran", or whatever euphemism you prefer to use for a boomer, perhaps you will indulge a soupçon of nostalgia. Having retired from full-time work in the summer, I have been trying to reduce the volume of my belongings by scanning my thousands of technical papers. This week I came across a paper by G. Babbage, reprinted from *The Canadian Surveyor*, volume 19, no. 2, pp 133-146, June 1965, "The subtense bar—its use and its errors". The paper describes measuring, with a theodolite, the ends of a horizontal bar set up over a point to be positioned, giving a standard error in distance of 0.8 inches at 300 feet. Measurement required great care, so perhaps some tens of points could be measured per day. Contrast this with a terrestrial laser scanner, such as the one demonstrated to me at Intergeo, measuring more points by a factor of at least 10^6, with higher accuracy and no manual computation! The second nugget is Bergstrand's 1949 description, "A new distance measuring equipment". This was the dawning of electromagnetic distance measurement, of which LIDAR is one of today's most fantastic manifestations. What is the relevance of this? Firstly, marvel at how our technology has advanced in only two or three generations. Secondly, reflect that even with the incredible tools at our fingertips, projects continue to be challenging, requiring imaginative, rigorous use of appropriate hardware and software to meet the goals. More key to success than ever is human ingenuity, albeit no longer for laborious, repetitive field observations or office computations. Accompanying this dramatic progress and unlimited potential is a delicate framework of certification, licensure, ethics, standards, guidelines and procurement regulations, which we have created and maintain to ensure that the client receives what is expected. More of this in issues to come!

Enjoy the magazine

Stewart Walker

A. Stewart Walker // Managing Editor


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Laser-Equipped Drone Helps Improve Safety and Efficiency on Highway 4 Improvement Project

Emerging Drone Technology Moves Construction and Engineering into the Future

In September 2017, the Contra Costa Transportation Authority (CCTA) and Alta Vista Solutions showcased two emerging technologies on a construction project aimed to improve commutes on Highway 4. Engineers are piloting drones equipped with light detection and ranging (LiDAR) lasers--a surveying tool that uses a laser to create high-resolution geographical data. The combination of the two emerging technologies has never been done in construction before and opens untold possibilities for unmanned aerial vehicle (UAV) technology and related jobs in the future. CCTA featured the system in action by providing a live feed of a drone flight.

With assistance from engineering firm Alta Vista Solutions (Alta Vista), who proposed the new method, CCTA is flying the LiDAR scanners to measure the volumes of earth that need to be moved during this $74-million project to rework the Balfour Road interchange. The drones ensure that the cut-and-fill earthwork goes efficiently. With LiDAR's pinpoint accuracy, CCTA can now make needed calculations and monitor site conditions faster, eliminating the unavoidable guesswork involved in manual surveys. Putting LiDAR on drones gathers 15 gigabytes of precise, high-quality data per month, cutting down drastically on time spent surveying. The drones also improve safety by taking workers out of live traffic.

Drone capabilities enable CCTA to track construction progress firsthand as work on Highway 4 continues. "We are always looking for new ways to increase safety and efficiency on construction projects," says CCTA director Randy Iwasaki. "Drones give us aerial views of the site that were hard to come by before, making it safer for surveyors to do their job and helping us manage the large volumes of dirt that are being used to improve this intersection. This technology also allows us to monitor environmentally sensitive areas without disturbing the habitat."

"This will change engineering and surveying" says Ed Greutert, principal engineer at Alta Vista Solutions. "Innovations like combining LiDAR and UAVs are opening doors in infrastructure and making us efficient, effective, and safe in ways we couldn't achieve before." Mr. Greutert also addresses fears of job loss as automation increases. "Using technology to do the surveying work can lead people to ask if this is the next step to the robot apocalypse—are drones going to take our jobs?" he speculates. "Not quite. It's going to change jobs. It's going to create new jobs in technology—and in the Balfour Road case, help people get to work faster."

CCTA has faced challenges in being the first to test these technologies together. “This has never been done. LiDAR on a UAV hasn’t worked until now—there are huge possibilities if we can be creative enough to really tap into them,” Mr. Greutert notes. Handling the unprecedented quantity of data generated has also posed a challenge. However, in recent months, the team has succeeded in processing the hundreds of gigabytes collected. “There are always challenges to pioneering new technology,” Mr. Iwasaki says. “But with the benefits this technology can provide in terms of keeping workers safe and managing a complicated construction project, I believe we’ll start to see more widespread use of drones on construction sites within a few years – especially as we discover new applications that can help save time and money. Right now, CCTA is excited to be leading efforts in this new frontier.”

The Contra Costa Transportation Authority (CCTA) is a public agency formed by Contra Costa voters in 1988 to manage the county’s transportation sales tax program and oversee countywide transportation planning efforts. CCTA is responsible for planning, funding and delivering critical transportation infrastructure projects and programs that connect our communities, foster a strong economy, increase sustainability, and safely and efficiently get people where they need to go. CCTA also serves as the county’s designated Congestion Management Agency, responsible for putting programs in place to keep traffic levels manageable. More information about CCTA is available at ccta.net.

Alta Vista is a California-based engineering firm that has been recognized as the 20th fastest-growing engineering firm in America by Inc. 5000 and was named by Zweig Group as one of America’s Hot Firms. Alta Vista has quickly differentiated itself by performing customized quality management strategies for some of the most complex infrastructure projects in the world. Over the past decade, Alta Vista has worked with public and private organizations to complete large-scale engineering projects that better serve their regions. Known for engineering services that include engineering, inspection, testing, unmanned aerial systems, quality management, and structural health monitoring, Alta Vista has grown and diversified and has been acknowledged in 2017 by ENR Magazine and other media outlets for using innovative solutions and technologies to deliver infrastructure projects faster, better and more cost effectively. For more information about Alta Vista, visit altavistasolutions.com.

Cepton Introduces Lightweight 3D LIDAR Sensing Solution for UAV Mapping

SORA 200 3D LIDAR brings UAV mapping to new heights for partner LIDAR USA

Cepton Technologies, Inc., a provider of 3D LIDAR sensing solutions for automotive, industrial and mapping applications, has announced the launch of SORA 200, its lightweight 3D LIDAR sensor, at the annual Commercial UAV Expo. SORA 200 delivers long-range, high-resolution and low-cost mapping capabilities to unmanned aerial vehicles (UAVs). The launch of SORA 200 follows Cepton's recent unveiling of its HR80 series of high-performance 3D LIDAR products for ground applications.

Cepton is partnering with LIDAR USA, a total LIDAR geospatial solutions company, to bring SORA 200 to market. LIDAR USA is Cepton's first reseller and system integrator in the UAV mapping industry.

"To meet the increasing demands of UAVs, LIDAR sensors must be long-range, lightweight and high-resolution," said Dr. Mark McCord, co-founder and VP of engineering at Cepton. "SORA 200 allows for highly efficient 3D map data production at increased altitudes and velocities in various environments. With 200-meter range and a weight of just 550 grams, SORA 200 is the lightest high-performance UAV LIDAR on the market today. We are thrilled to partner with LIDAR USA on this product to bring a new solution to the UAV mapping industry."

Cepton's micro-motion LIDAR technology removes expensive, ungainly spinning parts common in traditional LIDAR units, resulting in smaller and more reliable sensors that do not compromise on resolution or range. Use of off-the-shelf materials reduces delivery wait time and overall cost.

"For years, the UAV mapping industry has been waiting for a long-range, lightweight and low-cost 3D LIDAR solution," said Jeff Fagerman, CEO of LIDAR USA. "No one has been able to produce anything like SORA 200. We are very excited that Cepton is fulfilling this market need."

Product highlights include:

- Lightweight: At 550 grams, the SORA 200 can be deployed in situations where payload weight matters. Its light weight means that UAVs enabled with SORA 200 can fly for longer trips.
- Long-range: With its scanning range extending up to 200 meters, the SORA 200 allows UAVs to fly at higher altitudes and cover more ground.
- High-frame rate: With a 200-hertz frame rate, UAVs equipped with the SORA 200 can operate faster while maintaining high-density map data acquisition.

Cepton is a 3D sensing solutions provider that is shipping next generation LIDAR products for the automotive, industrial and mapping markets. Cepton's LIDAR technology delivers unrivaled performance and resolution at low cost, to enable perception for the smart machines of tomorrow. For more information, visit www.cepton.com.

LIDAR USA, a Fagerman Technologies, Inc. geospatial solutions company, is committed to bringing fast, accurate, high-resolution LIDAR solutions to the UAV market. See www.LIDARusa.com for more details.


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SHIFTING APPROACHES TO LANDSLIDES

The glacier retreat in the Öræfajökull region leads to more unstable slopes, often causing large rockfalls.
Photo Credit: Daniel Hölbling.

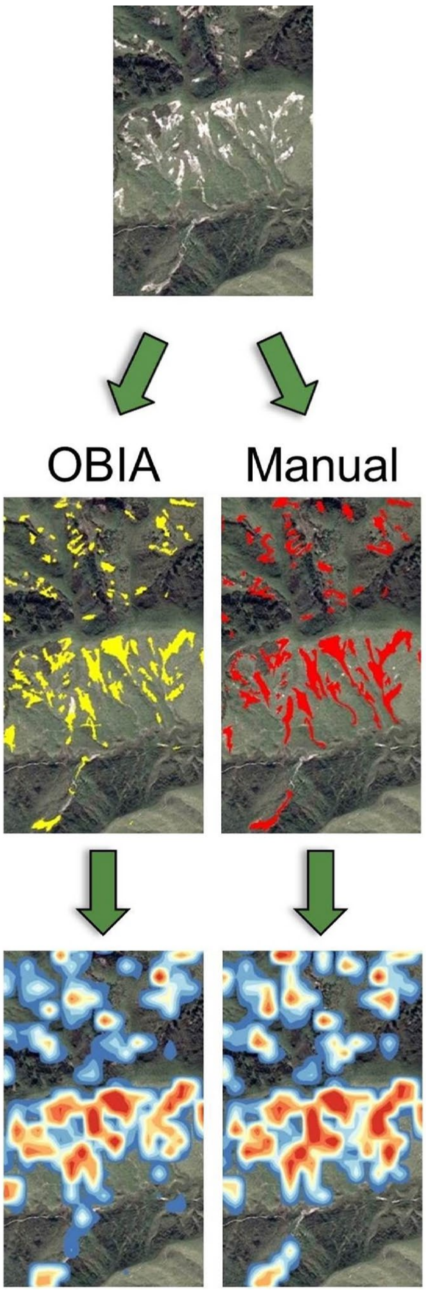
It happens in a blink of an eye. One second, the ground is there; the next second it's gone. That is the speed of a landslide: sudden, swift—and perhaps most unsettling, it strikes without warning. The UN Office for Disaster Risk Reduction ranks these natural hazards as the fifth most frequent and the seventh most damaging.

"Similar to earthquakes, landslides are next to impossible to predict," says Daniel Hölbling, a research scientist at the University of Salzburg's department of geoinformatics. "And they cause significant damage. They can wipe out entire villages in a few seconds. After the event, it can be difficult to rapidly assess and map the extent of the landslide as well as find adequate tools to identify high-risk areas and create planning strategies. There are still a number of issues to resolve with landslides. They're a puzzle—and this makes them intriguing to study."

To be sure, the puzzle of landslides—how to adequately define them, categorize them, detect them, map them and plan for them—has been an intriguing focus of much research since the late 1990s. But with the advancement of geospatial tools, such as very high-resolution satellite imagery and synthetic aperture radar interferometry (InSAR), coupled with powerful object-based image analysis (OBIA) technology, the interest in developing more effective solutions for landslide detection, mapping, inventorying, monitoring, and possibly, forecasting, has grown considerably in the last five years.

BY MARY JO **WAGNER**

Semi-automatically mapped landslides in the Pahiatua study area using the OBIA approach (in yellow) and manually mapped landslides (in red) for the aerial photograph from 2005. Although difficult to conclude whether the automated mapping was more accurate, researchers say the eCognition approach is considerably faster, more consistent, and more objective.



Landslides scar the hillside in New Zealand's Pahiatua region. Hölbling and colleagues chose this area as a test site because of its vulnerability to rain-triggered landslides.

Photo Credit: Harley Betts

Hölbling, for one, has had an almost laser-like focus on landslide-application research since 2009. Using a host of sources like optical imagery and SAR data in combination with Trimble's eCognition software, he has been both developing and testing automated approaches to landslide detection, mapping, inventorying and monitoring—tasks that are dominated by manual, traditional methods—to determine the feasibility of using these methods operationally.

And there is considerable promise. Based on his and other colleagues' research, Hölbling feels a groundswell of possibilities is afoot to help organizations better assess, map, prepare and plan for the unpredictable nature of landslides.

Complex by nature

The complexities in efficiently and accurately identifying, mapping and inventorying landslides are many. This is predominantly because the unpredictability of landslides means they don't have uniform behaviors or patterns; they don't always look and act the same. And identifying and mapping these disasters is a very individual approach—what is or is not a landslide is decided by the expert mapping the event.

"The quality of landslide mapping is based on the mapping expert—their skills, their geographical knowledge of the area, the size of the area and the data they use," says Hölbling. "Given the different types of landslides, their variability in shape and size, and the difficultly in distinguishing manmade features such as small quarries or harvested forests from clearings made from a landslide, the analysis and mapping can be quite labor intensive, subjective and highly inconsistent."

However, the rise of more extreme and damaging landslide events in the last decade has also given rise to more interest in funding research that's focused on trying to bring better efficacy, accuracy, and possibly, predictability to mapping and monitoring landslides.

Despite having no prior experience with studying landslide phenomena, Hölbling has focused on little else since beginning his research eight years ago. To date, he has conducted research in Taiwan, Italy, Austria, New Zealand and Iceland to develop new, semi-automated methods for a host of applications including classifying, inventorying and mapping landslides, detecting landslide hotspots and mapping landslide change detection. At the core of all his research has been Trimble eCognition OBIA technology.

"OBIA, with remote sensing data, is the most powerful tool for detecting and analyzing landslides," says Hölbling. "You can integrate spectral, spatial, morphological, textual, and contextual properties in one interlinked framework. All that diverse data enables the software to mimic how the human brain identifies and categorizes objects, making it far superior to traditional pixel-based approaches which can't do that."

But of all the research Hölbling has conducted, there are two areas he says hold particular promise: landslide hotspot mapping and combining optical and InSAR data to better map, track and possibly predict future landslides.

Hotspot Mapping

With its combination of steep slopes, erodible hill country, frequent earthquakes, intense rainstorms, deforestation and farming-induced clear cutting, New Zealand has not only been susceptible to extensive landslide erosion, it has seen landslide activity increase by about seven times its natural rate.

The country's local governments have diligently worked to build detailed landslide inventories and maps showing the location, extent and severity of each landslide event in order to develop effective mitigation measures. However, they have been conducting this work by traditional, manual means—visually interpreting each aerial or satellite image and manually delineating and mapping each landslide identified—which has been tedious, slow and subjective.

In 2016, Hölbling partnered with New Zealand's Landcare Research, a Crown Research Institute headquartered in Lincoln, to test an OBIA, semi-automated approach for identifying and mapping landslide-prone "hotspots" based on historical and recent aerial photography.

The team selected an approximately 1,000-hectare (2,470-acre) study area located about five kilometers southeast of the small town of Pahiatua, in New Zealand's North Island, a pastoral hilly region where rain-triggered landslides are common.

They acquired three black and white orthophotos, one from 1944, one from 1979 and one from 1997 as well as two natural color orthophotos from 2005 and 2011, which had nominal accuracies of 15 m and a spatial resolution of up to 0.4 m. Additionally, they obtained a 15-m-resolution DEM to provide ancillary data, such as slope information.

In order to adequately compare the OBIA approach to the manual approach, Landcare researchers spent two weeks manually digitizing visible landslides on each orthophoto in ArcGIS.

Southern Öræfajökull, an area routinely on alert for possible landslides. In particular, "creeping landslides," or deep-seated, slow-moving slides are a continual threat.

Photo Credit: Daniel Hölbling

It's time for Taiwan

If there is one country more invested in finding more efficient and accurate methods for identifying, inventorying and mapping landslides, it's Taiwan, a country that's battered by three to five typhoons nearly every year.

Landslide specialists at Taiwan's Disaster Prevention Research Center (DPRC), who use a combination of manual interpretation and pixel-based mapping systems, have been working with Hölbling since 2009 to develop a more automated approach to classifying and mapping landslides.

Hölbling has held several workshops illustrating OBIA technology and conducted nearly 10 studies to test the viability of an Trimble eCognition-based methodology. In one study, Hölbling produced map results in 2.5 hours for an area that took 12 hours to map manually. Hölbling says DPRC users have been impressed by the OBIA approach.

"The time aspect is a very important issue for them," he says. "They need to quickly acquire information about new landslides after landslide triggering events for their disaster management operations."

And research continues. Taiwan is part of a three-year study that began in August that aims to analyze a time-series of optical satellite imagery to determine spatio-temporal hotspots of landslide-induced river-course changes.

In parallel, Hölbling spent one day preparing Trimble's eCognition software for integrating the datasets and classifying the landslides. Since aerial photographs from five different points in time were used, Hölbling developed a single mapping routine that could be applied to all images, using the 2011 orthophoto as the master. The customized rule set used spectral, spatial, contextual and morphological properties to properly classify and map all detected landslides on the 2011 orthophoto. Confirming that the workflow was successful, he then applied that rule set—with a few modifications—to the other orthophotos. In a few hours, eCognition classified all visible landslides across all five time stamps.

With both the manual and automated mapping completed, the team compared the two approaches and found the eCognition mapping was on par with the manual results. Given the subjective nature of manual mapping, it was difficult to conclude whether the automated mapping was more accurate, but what was clear, is that the eCognition approach is considerably faster, more consistent, more objective, and it's easily repeatable.

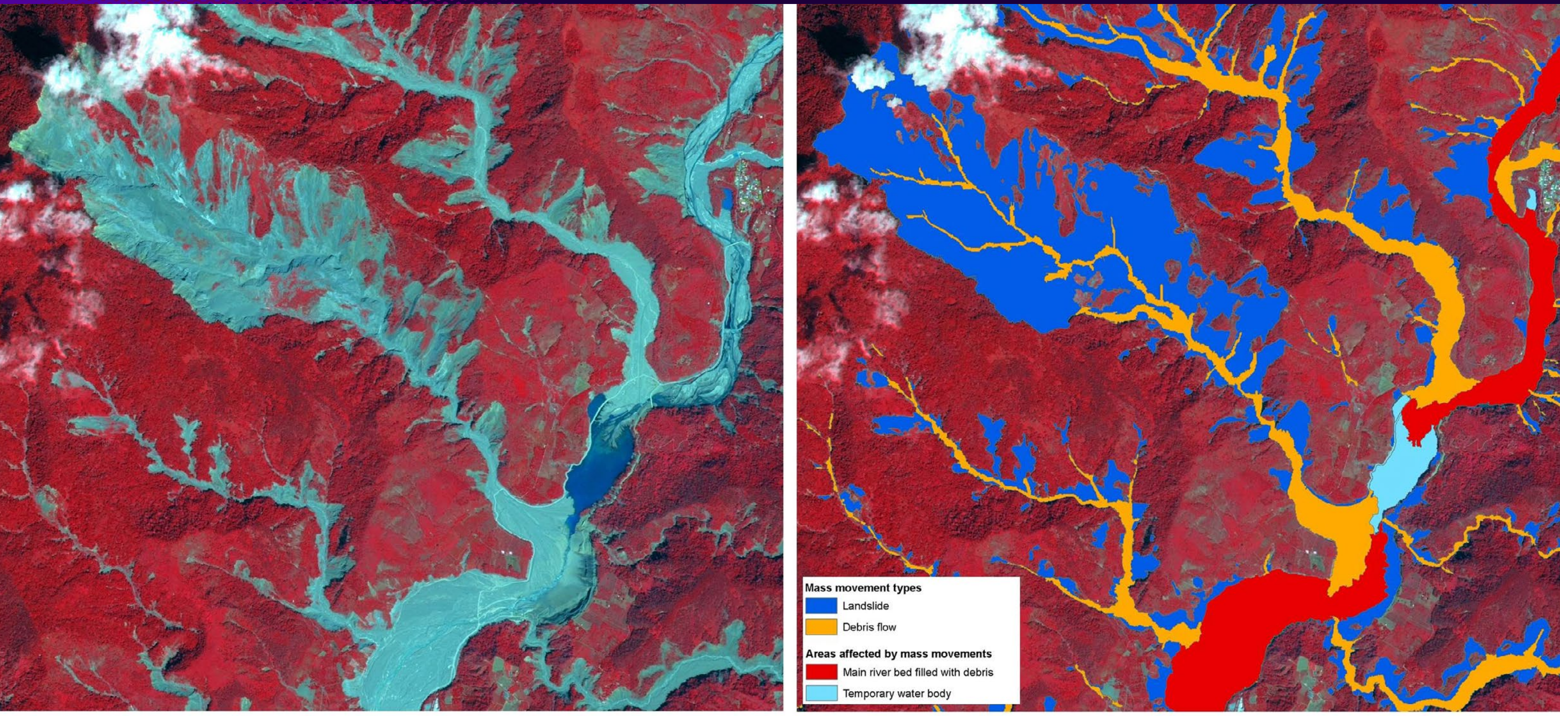
"The manual mapping was painfully slow," says Harley Betts, a researcher with the soils and landscapes team at Landcare Research's Palmerston North office. "The eCognition approach has the potential to cut out a big chunk of that manual stage. I was very impressed with that."

As a complement to manual methods, an automated system would both allow experts to quickly detect and inventory landslides over large areas and identify unstable areas. That could, over time, lead to predictive modelling.

"If you follow the idea that the past can be the best indicator for the future, then by studying the historical evolution of landslide hotspots and

Daniel Hölbling stands in front of a landslide in Taiwan. He has been to the country countless times to investigate landslides and hold workshops for Taiwanese landslide experts.
Photo Credit: Clemens Eisank.

Daniel Hölbling (right) prepares to conduct field work with Taiwanese colleagues.
Photo Credit: Barbara Friedl.



From one of many landslide studies in Taiwan: eCognition classified and mapped landslides and debris flows in three different areas in southern-central Taiwan after typhoon Morakot in 2009.

mapping the changes over time, you could use the hotspot mapping, to some degree, for prediction," says Hölbling. "The hotspot maps could help flag landslide-prone areas, giving valuable insight to land management experts to help them assess landscape dynamics, create location-specific, risk mitigation measures, and potentially, forecast where landslides might occur."

Morphing into automation

Similar to New Zealand, Iceland is no stranger to landslides. With its volcanic, tectonic and glacial activity, combined with extreme storm events, eastern and northern Iceland are routinely on alert for possible landslides. In particular, "creeping landslides," or deep-seated, slow-moving slides are a continual threat.

These characteristics made the country a particularly suitable study area for the MORPH (Mapping, Monitoring and Modelling the Spatio-Temporal Dynamics of Land Surface Morphology) project, one of Hölbling's most recent studies that aims to develop an efficient and transferable OBIA method for mapping slope instabilities, including landslides, and volcanic deposits. Although the overall objective is to combine multi-sensor imagery from optical and radar satellites into an eCognition mapping workflow, unique to this endeavor is the pairing of optical satellite imagery with InSAR datasets in eCognition to create a more powerful, integrated landslide tool.

"Typically, shallow, quick-moving landslides are visible on optical imagery so they are easier to map," says Hölbling. "But often, the land continues to slowly shift and move after an initial landslide and you can't readily see that on optical imagery. InSAR data derived from radar satellite imagery can detect ground-surface movements of centimeters and even millimeters, which can show us where deep-seated landslides are and how quickly they're moving. That combination could result in a more comprehensive and detailed landslide inventory."

To test the viability of this integrated mapping approach, the team chose a site in the Öræfajökull region, a southeastern area that is susceptible to unstable slopes, dynamic landscape movements, soil erosion and floods—a ripe recipe for landslides.

For this initial study, the team used a 5-m-resolution optical RapidEye image, a 2-m-resolution LiDAR-derived DEM and two 3-m-resolution TerraSAR-X StripMap scenes. In addition to calculating a vegetation index from the optical image and slope values from the DEM, they used the two SAR scenes to calculate the phase difference between the two images, which helps identify areas on the ground surface that have moved.

Hölbling and his team developed an eCognition rule set to integrate the imagery and InSAR data information to identify and map all landslides as well as designate areas potentially affected by landslides. The software not only distinguished landslides based on the RapidEye image but with the additional InSAR data, it identified more potentially affected landslide areas. That approach opens up "remarkable possibilities" for improved landslide mapping, says Hölbling.

Daniel Hölbling (in black jacket) conducts an eCognition training session for landslide specialists at Taiwan's Disaster Prevention Research Center. They have been working with Hölbling since 2009 to develop a more automated approach to classifying and mapping landslides.
Photo Credit: Barbara Friedl.

"The additional detail and movement information of InSAR could help us produce more refined landslide maps," he says. "You can map the visible landslides with the optical imagery and the 'invisible' slow-moving slides with the SAR data and put these two datasets together to create a complete landslide inventory. And by using the velocity detail from InSAR, we can analyze land movement over time and potentially forecast how the landslide might continue to move based on the historical movement. That's incredibly promising."

As the MORPH work won't conclude until 2019, the true assessment of this automated, integrated method will have to wait. But Hölbling is optimistic, both about these initial results and future ones to come.

"From the beginning, a goal has been to develop a more efficient and reliable mapping framework that we can port to other countries vulnerable to landslides," he says. "Each study gives us the opportunity to extend our knowledge, test the capabilities of OBIA technology and refine our tools, all of which could lead to significant, positive shifts in our approaches to detecting and mapping landslides."

That kind of movement would no doubt be welcome.

Mary Jo Wagner is a Vancouver-based freelance writer with 25 year's experience in covering geospatial technology.

Taiwan gets battered by three to five typhoons nearly every year, causing devastating landslides in their wake.


Develop Rulesets
Developer
Calibrate and execute Ruleware
Architect
Batch process data
Server

Left: Jamie Young, CP, CMS—Director LiDAR Services for PrecisionHawk

Right: M600 drone and Yellowscan Surveyor taking off for a mission

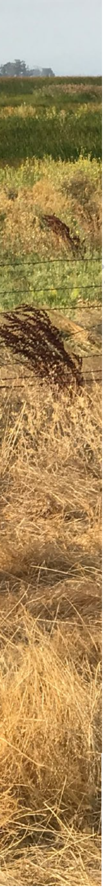
My Drone LiDAR is Better than Yours

The New Geospatial Shiny Object!

BY JAMIE YOUNG

The Drone LiDAR world is exploding right now and everyone wants one. Does anyone know what they are doing? Is Drone LIDAR any more accurate then manned LiDAR? What contributes to the accuracy and why isn't it better? What's all that noise in the Drone LiDAR? How much control is needed? When should Drone LiDAR be used? How does Drone LiDAR compare to Drone Image autocorrelation? Drones are clearly the latest shiny object in the geospatial profession and to make it shine brighter, we decided to add LiDAR to it. The problem is that it is imperative to understand LiDAR regardless of platform to be able to make the object shine correctly.

It is clear that LiDAR works on a drone but there are limitations to the technology. How do we properly operate LiDAR on a drone? The change in Drone LiDAR technology is advancing at light speed, this is in part a result of the manned LiDAR evolution. In the process of moving from the manned



Recent research project area with very thick cattails and vegetation in a swamp. Much like manned LIDAR, the likelihood of getting though this vegetation is extremely small and probably isn't going to happen.

LiDAR world to the drone LiDAR world some realizations have come to light that not all drone LiDAR operators know what they are doing but as always there are companies that operate drones with LiDAR on them and companies that operate LiDAR on Drones. It is imperative for a company to understand LiDAR and LiDAR sensors because there are a lot of people that can operate drones properly. A lot of the questions on operation of Drone LiDAR are being answered as we conduct successful and unsuccessful Drone LiDAR projects. The best company to have conduct your Drone LIDAR project is a company that operates LiDAR on Drones. Why you ask? The understanding of LiDAR and the limitation of the components integrated into the Drone LiDAR is paramount in successful data capture.

The positional (POS) component is a much less expensive version and uses lesser technology than that of the manned POS systems currently being used today. The POS system is the GPS and IMU part of the LiDAR. The POS data is only as accurate as the technology allows it to be and there is a clear correlation between cost and accuracy in most cases. This doesn't mean that the data will be bad, just less accurate. The lasers on most drone LiDAR systems are less experience and less accurate as well. This begs the question, well if the Drone flies much lower to the ground than how accurate do I need these components to be? The obvious answer is that given the flying height, the components can be less expensive and less accurate. Also, the functionality of the laser will play into the equation of accuracy and the resulting data. An example of this is the Velodyne Puke is a very popular laser currently being used on Drone LiDARs. The Velodyne Puke was designed for autonomous vehicle mapping and has 16 lasers on it, operating in a 360 degree field of view (FOV) with 2 returns. This is an excellent inexpensive laser but it has its

Horizontal and vertical control point for Drone LIDAR

limitation and this becomes apparent in the resulting LiDAR data. The most concerning element of the Puke is the resulting intensity information from this laser. The Puke really wasn't designed to output intensity information the way the mapping profession currently wants it to be. So be ready to be a little disappointed as it relates to what you traditionally see.

When drone and sensor technology first started to become available there really wasn't drone LiDAR yet but everyone was quick to develop the technology. A lot of the providers offered autocorrelated points form imagery as an alternative and the accuracy of this information ranged depending on process at which the missions where flown and how the data was processed. Most of the provides limited the expected accuracies to between 11 and 15 centimeters. In ideal situations, the data was more accurate than that but the limitation to autocorrelation is the same as it always has been and the ability to get accurate information is a function of the amount of vegetation in the area of interest (AOI). The more vegetation the less likely the success of the digital elevation model accurately representing ground. Basically, if there is vegetation in the AOI, then there is no likelihood that the ground will be represented correctly, if not at all. Additionally, The Drone LiDAR with a 2-return sensor will have a difficult time getting to the ground in heavy vegetated areas but it does get to the ground depending on the vegetation characteristics. This is similar to the manned LiDAR sensors. The advantages of the Drone LiDAR is that the number of points collected per meter is significantly more so the likelihood of getting to the ground is much higher based on point density. The Drone LiDAR typically get between 100 and 200 points per meter (PPM) but it can be higher depending on repetition rate, number of returns, and flying height. The new Reigl Mini-VUX has the ability to collect up to 5 returns which is a step in the right direction to increasing the likelihood of getting to the ground in vegetated areas. There are going to be situations where it is very unlikely that any LIDAR will get to the ground just like the manned LIDARs but your vegetation definition will look excellent.

> “Does anyone know what they are doing?”

The noise in Drone LiDAR appears to currently be much greater than that of manned LiDAR depending on the type of manned lidar being used. Noise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-Take measurements
-Scalable Solutions
-Works with any PointCloud (LiDAR or image derived)

in this case is defined as point return repeatability. If the LIDAR was capable of pulsing the same location all the time the measurement of that point return for that location will vary to a degree. Some manned LiDAR sensors have much more noise than others. This is the same for the Drone LiDAR sensors. Like manned LiDAR each Drone LiDAR regardless of make and model will have different characteristic just like the exact same lasers will have different intensity aesthetics. Typically, the noise associated can range from between 10 to 15cm on some systems down to 5cm on other systems. The key to dealing with the noise is how the data is processed to remove the noise. When flying Drone LIDAR and getting between 100 to 200 ppm or more is it really necessary to have that many points to define the feature in that square meter. In most cases the answer in no it is not necessary so the processing can take out the noise based on the best way to define those features and put them in a different class.

The fact that most current Drone LIDARs have more noise than we would like facilitates the importance of ground control. The algorithms used to define the noise and detect what is ground and noise need to be checked to make sure they are working right and that ground was actually what was found. Additionally, like most metric mapping projects, clients like to know their data is accurate to the specifications agreed on. Additionally, because of the limitations of the less expensive POS systems used it is nice to have horizontal information to assert the horizontal accuracy of the Drone LiDAR. There are no specifications on what is required for control currently and it really depends on the project characteristics and size but having control increases the level of confidence in the technology significantly.

> "The best types of company to conduct your Drone LiDAR project is a company that operates LIDAR on Drones."

Drone LIDAR is typically less expensive then manned LiDAR in most cases based on the relative sizes of Drone LiDAR project as they relate to manned LiDAR projects. Typically, Drone LIDAR provides consider a 3-square mile project as a large project whereas the manned folks consider that to be an extremely small project. It is important to remember that Drone LIDAR like many other LIDAR technologies is another tool in the Geonerd tool box and typically doesn't replace any other tool. The Yellowscan Surveyor typically flies between 40 and 60 meters above ground and other similar Drone LIDARs fly at that less attitudes. The Reigl Mini-VUX can fly at this attitude but also can fly up to 150m AGL but you probably wouldn't fly it at that attitude. It seems that reasonable attitude for this sensor is between 90 and 100 meters. Given the following Flight attitudes it could expected at 40meters that a square mile would take about a day to fly at 3 m/sec. This seems to be the best flight configuration for the Yellowscan Surveyor. The same area would take about half that with a Reigl Mini-VUX. Typically, these systems could roughly fly up to 15 linear miles in one day. It should be noted that exact numbers would be best given by the LIDAR provider chosen.

Drone LIDAR technology is evolving extremely quick and provides a unique tool for small project. The cost should be less than the same project using manned LiDAR in most cases. The data generated for this technology is extremely detailed and the amount of detailed information that can be extracted from this type of LIDAR is impressive. The technology has its limitations as does other LIDAR technologies but the benefits are impressive. It is imperative to understand the limitations of the technology so that it properly solves the problems and provides the solutions for intended applications. The accuracies depending on the type of Drone LIDAR can range between 2 to 3 cm up to 9 to 10 cm. It is always important to ask the questions about the technology and feel conformable with the answers you are getting before trusting a provider and the technology.

James Wilder Young (Jamie) CP, CMS-L, GISP is currently Director – LiDAR Services for PrecisionHawk, headquartered in Raleigh, North Carolina, the leader in providing innovative information data using drones. He is currently supporting all components of LiDAR technology as it relates to drone technology. His experience includes all aspects of LiDAR including sensor development, applications development, data acquisition, data processing and project management. He graduated from The University of Colorado.


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• max. operating flight altitude 330 ft AGL
• range up to 250 m
• accuracy 15 mm, precision 10 mm
• well suited for measuring snow and ice terrains
RIEGL VUX-1UAV
3.5 kg
7.7 lbs
330° FOV
up to 330° Field of View
Compact & Lightweight
3.5 kg / 7.7 lbs
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RIEGL miniVUX-SYS | miniaturized laser scanning system comprising RIEGL miniVUX-1, IMU/GNSS unit and optional camera(s)
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An example of planimetric mapping created using remote sensing and utilizing aerial lidar and imagery.

Demystifying Smart Cities:

How Base Mapping Will Help Navigate Your Future

BY ANDRIA **SHAMAN** & BRIAN **STEVENS**

Technological advances seem to take place in leaps and bounds, as news breaks about innovations like the debut of autonomous vehicles or the availability of statewide base mapping or the concept/application of a smart city.

These innovative solutions are most often based upon the merging of incremental advances, many of which take place over years and through a variety of technological disciplines. The concept and application of a smart city is a great example of how multiple advances coming together to produce a unified, constructive leap forward in technology—both in generation and application.

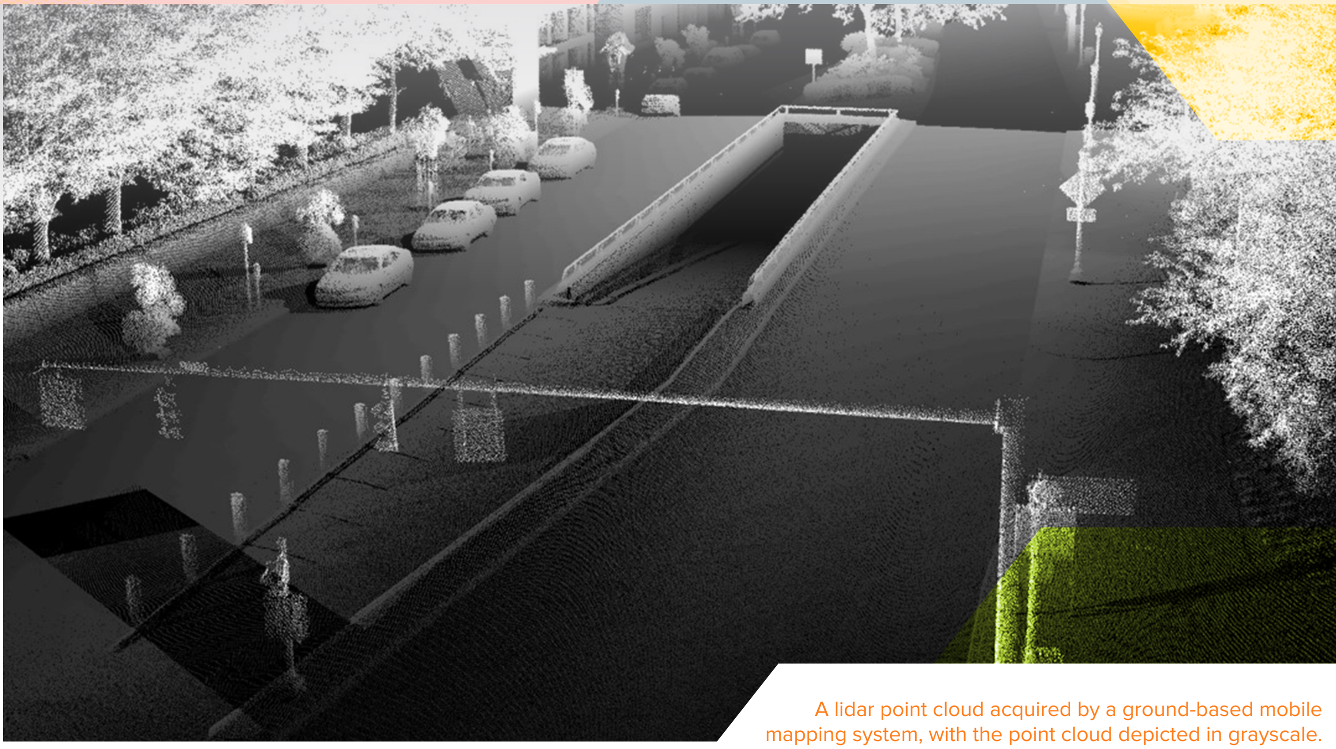
By pulling together components that support autonomous vehicle transportation, asset management, 3D technologies and more, a foundation can be created that will ultimately shape the experience and functionality for the sensory-enhanced metropolitan areas of the future.

Base mapping is essential for the accessibility and organization of these components, and the connectivity it provides forms the template needed for the smart city.

Connectivy Provides Baseline

The Smart Cities Council acknowledges that there isn't a strict definition of what makes a smart city, but notes on its website that one consistently agreed upon characteristic is that it has "digital technology embedded across all city functions."

This connected technology is what forms the requirement for base mapping and subsequent operation of a smart city. It can be likened to planting a garden: When you plan what you're



A lidar point cloud acquired by a ground-based mobile mapping system, with the point cloud depicted in grayscale.

going to plant, it's important to view the garden as a whole and make sure everything works together from the start. And it's the work done below the soil, at the root level, that makes the difference in how well the garden grows.

For a smart city to work, you have to standardize the technology used across all city departments and accurately connect each data field.

To do this, a city must coordinate and think ahead. A city's information technology (IT) department is at the heart of this crucial planning stage because it has the holistic view of the city. Unlike utilities, which initially were a focus of the smart city movement, IT departments cross the lines of every city department. They work with utilities, transportation, city planners, etc., to not only see the potential of what you can do with this information, but also understand the chaos that will ensue if you don't coordinate.

The connectivity concept needed for smart cities has been recognized by multiple geospatial companies that leverage location-based services to generate geographic insights. These companies work with connected workplaces to automate, monitor and control products and services, while engaging and linking customers and the marketplace.

In other words, they analyze collected data to form citywide base mapping.

CREATING BASE MAPPING

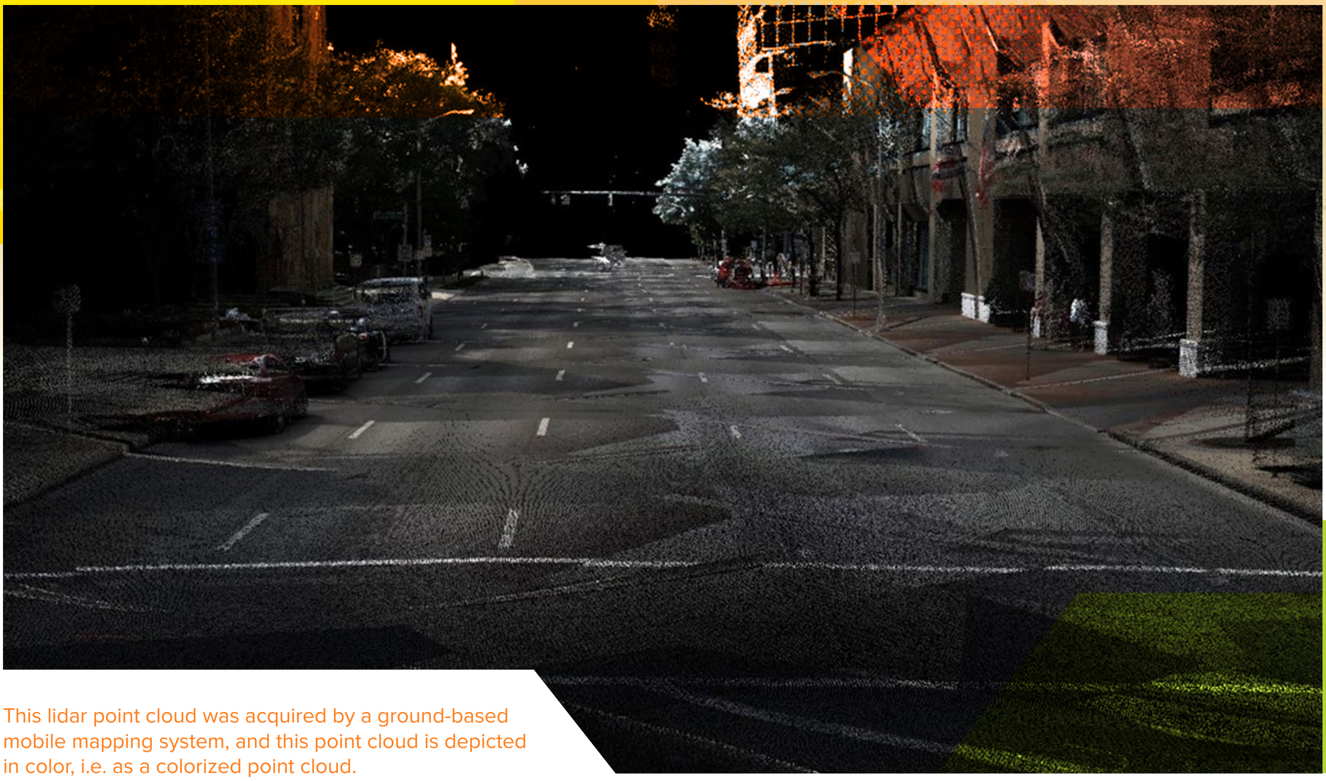
Geography has become the new alphabet for the organization of data; it gives people a literal place to start and a relevance to and investment in that information.

Cities have to decipher what level of accuracy is sufficient enough to fulfill these connectivity needs. They will want to address the varying data needs across a municipality, while maintaining the ability to standardize that data across the municipality's departments. This requires the kind of accuracy provided by 3D technology.

Generated from underground, indoor, street level, aerial and satellite imagery, 3D data creates a foundation for an asset registry. Through this registry, assets can be managed as part of an integrated GIS data framework within whatever scope is relevant—from a nationwide perspective down to a specific property.

The plan for managing assets within the framework of the smart city initiative is to create an architecture of network, policies and procedures with no default settings to create an auditing structure to know what exists and what needs to work together.

Asset management, traditionally maintained in a paper and/or CAD-based system, is progressing toward the use of high-accuracy base mapping in a GIS environment, which is a recent way of thinking that applies to every municipality. By identifying and accurately locating the assets (light poles, roadway paint, signage, etc.) across the municipality, cities can better manage



This lidar point cloud was acquired by a ground-based mobile mapping system, and this point cloud is depicted in color, i.e. as a colorized point cloud.

and budget maintenance accordingly across all departments.

By focusing on the life cycle pervasively throughout an organization, information systems are integrated and employed. Some of those include GIS, Computerized Maintenance Management Systems (CMMS), enterprise asset management (EAM) systems, computer-aided facility management (CAFM) systems and risk-informed critical infrastructure protection (CIP) strategies.

At the heart of this framework is GIS base mapping and topology, which is a product of infrastructure inventory from planning to design, from inventory to assessment, and from implementation to maintaining.

Examples Of What Connectivity Can Produce

There have been precedents set for the kind of collaborative connectivity that will be needed to lay the groundwork for smart cities.

Houston is the fourth largest U.S. city, with a population of more than 2 million. Like thousands of other cities, content was at one time managed by people standing in lines at a city building filling out thousands of forms. Woolpert is helping Houston implement a modern permitting portal to streamline the permitting process and more efficient connect the city with its citizens. The new Houston Permitting Portal will allow customers to quickly navigate the process online.

The introduction of high-performance computing, online forms, assistance and payment makes the city function better and centralizes information for record-keeping and accountability.

Houston is one example of this kind of data implementation, which benefits both the city and its citizens. Many municipalities are compiling available data to make information consistent, accessible and applicable to multiple city functions, which also lays the groundwork for future connected functions.

Statewide base mapping programs are examples of how public collaboration between federal, state and local governments can benefit from the smart city initiative by providing base mapping, an integral dataset needed to support the foundation of any geospatially referenced initiative. Statewide base mapping programs typically include the collection/processing of high-resolution imagery and lidar, which provides consistent geographic data that is made available to a wide range of users, including public agencies, private industries, private citizens and educational institutions.

The smart city concept has the same framework as state base mapping programs; by collecting data, performing data analytics and making it accessible across the board, it connects all those who stand to benefit from it.

When there is consistent, applicable information made accessible at multiple levels, better decisions can be made.

Columbus Selected To Lead The Way

In 2016, Columbus, Ohio, beat 77 other midsize cities nationwide to win the U.S. Department of Transportation's (USDOT) Smart City Challenge.

Columbus, dubbed the fastest growing city in the Midwest, was awarded

An example of an asset inventory created using remote sensing and utilizing mobile lidar and imagery.

$40 million from the USDOT and $10 million from Vulcan Inc. to develop ideas "for an integrated, first-of-its-kind smart transportation system that would use data, applications and technology to help people and goods move more quickly, economically and efficiently."

In an editorial published by the local newspaper, former USDOT secretary Anthony Foxx wrote about how Columbus was chosen because the city took the challenge a step further by connecting its deployment of technology and its larger challenges.

"We were impressed not only by Columbus' grasp of the technological possibilities, but also by how it knitted together those possibilities within its present-day challenges and longer-term aspirations," Foxx wrote. "Make no mistake: Columbus will do some cool things with technology. It will install street-side mobility kiosks, a new bus-rapid transit system and smart lighting to increase safety for pedestrians. It also will install traffic signals that communicate with vehicles so that the signals can adjust in real-time to the flow, rhythm and demands of traffic."

Since that designation, Smart Columbus was an organization formed to provide the vision for this reinvention of mobility.

Conclusion

We all work and live in a three-dimensional world, which makes us all geospatially dependent when traversing through life. Base mapping, which is a foundation and lies at the heart of any geospatially referenced initiative (i.e. autonomous vehicles), provides a means to travel intelligently and establishes a "base" from which a smart city can grow.

When people are trying to work together, it is suggested often that they "get on the same page." Connected technology operates on the same premise. For smart cities to succeed, it will be necessary for the multiple technological elements involved to be able to communicate and work together effectively.

At the heart of the communication is base mapping, which provides all entities involved an accurate starting point to tie and bring together all aspects of integrating a successful program.

Fortunately, the technology required to create base mapping for these cites of the future already exists and has an established track record. The "trick" is to understand how base mapping integrates and complements with other technologies. The next step is simply a matter of connecting them to achieve a city's fullest potential.

If and when the people and departments creating these smart cities "get on the same page," we'll be able to work intelligently and leverage our resources to create an efficient, effective and highly advanced system that is well positioned for the technology of the future.

Andria Shaman is a photogrammetric specialist and associate at Woolpert—a national architecture, engineering and geospatial firm—where she has worked for 18 years. The Wright State University graduate has a Bachelor of Science degree in physics/optics, and specializes in lidar, remote sensing, and the integration and implementation of commercial and custom aerial sensors.

Brian Stevens is a geospatial program director and senior associate at Woolpert, where he has worked for 21 years. The Ohio State University graduate has a Bachelor of Science degree in geography and geographic information systems (GIS). The certified GIS professional and photogrammetrist is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS).

Director of Flight Operations Rob Dannenberg, verifying mechanical set-up of the Pulse Vapor 55 for wide area aerial LiDAR mapping.

HURRICANE DRONES

Anatomy of UAVs in the Eye of Disaster

Only a handful of years ago, the sleek, hi-tech Unmanned Aerial Vehicles (UAVs), or drones as we know them, sounded more like aircraft science fiction. But as this technology has developed, it has finally migrated into the mainstream as a valuable tool that enables professional operators to fly a peeping eye into critical airspace. UAVs are sent into the heart of accident scenes and storm damaged areas alike, and can be fitted with a multitude of specialized sensors that collect highly accurate data. When equipped with LiDAR scanners, UAVs collect high-definition survey data economically from large and complex spaces. Other types of data can be captured using sensors such as thermal, gamma or multi-spectral that for instance, detect harmful, invisible gaseous leaks ahead of an inspection team. In disaster situations, they become a high-flying aid, giving emergency personnel a bird's eye view of dangerous situations so they can plan their response. Equipped with cameras, UAVs take high-resolution photos and videos for inspection and surveillance while keeping the flight team safely at bay.

While the uses for UAVs keep on growing, nothing has catapulted them into the limelight of mainstream workflow the way hurricanes Harvey, Irma, Jose and Maria did. All occurring in less than a month between August 31 and September 23, 2017, these four severe storms marched on the heels of one another producing catastrophic damage as they repeatedly gnawed their way through the Caribbean Sea, Gulf of Mexico and Atlantic Ocean. Houses

BY MARALIESE **BEVERIDGE**

Maser Consulting's Vapor 55 with Riegl VUX 1 UAV LiDAR sensor prepared for flight operation.

were flattened, industries destroyed, infrastructure completely compromised, trees and heavy debris tossed into the streets like rag dolls and relentless flooding has caused sustained damage.

So, when it comes to natural disasters, where does UAV usage begin? Two of the top priorities during, and especially after any event of this type—are communication and power. Emergency responders need to be able to communicate in order to prioritize deployment of equipment and help to the areas in need of the most urgent assistance—especially in critical situations when response time can mean the difference between life and death.

In an effort to get communications back online, UAV teams have been sent into storm-ravaged areas to fly-high over cell towers and other power utilities to examine their condition and surroundings. Doing this ahead of repair team deployment, helps them in determining whether or not the towers are even safe to approach. UAVs can also be released into action quickly once storms subside and maneuvered to provide highly accurate visuals (photo and video) of damage. This information is invaluable in aiding repair teams plan what actions to take before debris is cleared and without having to physically scale the tower which can put them in danger. If flood waters exist—this structural pre-assessment facilitates repair teams in using their time more efficiently in developing their plan for scheduling equipment and crews while waiting for the waters to subside.

"Through advanced data acquisition, we've been able to assess the condition of cell tower sites with up-to-date information for streamlining repair activities", explained Maser Consulting's Chief Pilot and Director of UAV Services, Rob Dannenberg. "Once repairs have been made, the UAS crews can return to the site and access the quality of the repairs to give telecommunication clients confidence that their equipment is operating at an optimum level." Maser Consulting P.A., a multidiscipline engineering firm with a large geospatial survey presence nationally, has developed an Unmanned Aerial System (UAS) program for numerous clients requiring aerial inspection as part of ongoing workflows. Having this data as a baseline prior to the storms helped with damage assessment. Aside from utility inspection, the UAS division is also equipped with a variety of UAVs capable of supporting emergency management and recovery efforts, disaster response,

Maser Consulting's Vapor 55 with Riegl VUX 1 UAV LiDAR sensor prepared for flight operation.

tactical support for law enforcement and forensic LiDAR mapping.

But before anyone can launch an eye in the sky, professional UAV operators need to be authorized for flight by the Federal Aviation Administration (FAA), who oversees all aerial operations with strict guidelines, particularly where safety and security are concerned. As a note, this article is being written just as Hurricane Jose exited the US seaboard and Maria left Puerto Rico in its wake for the second time in less than three weeks, so we don't know the full outcome. However, some of the damage information being reported is harrowing. A segment from Inside Towers (Friday September 22, 2017 Volume 5, Issue 186), insidetowers.com/cell-tower-news-fcc-urged-reject-3-5-ghz-proposals/ (wireless tower industry magazine) stated: "More than 95 percent of the cell tower sites in Puerto Rico are out of service, according to the FCC's Disaster Information Reporting System. All counties have greater than 75 percent of their cell sites out of service and 48 out of the 78 counties on the island have 100 percent of their cell sites out of service." Public Works Magazine pwmag.com/administration/gis-asset-management/drones-to-the-rescue-after-monster-hurricanes-strike September 18, 2017 reported, "…the FAA approved 137 [UAV] flights related to Harvey and 132 Irma flights alone, some within minutes of receipt".

Typical aerial view of a cell tower detail using UAV technology

Maser Consulting's UAS emergency response team comprised of participants from multiple offices for telecommunication support in Florida after Hurricane Irma.

FAA guidelines are complicated because they are loaded with public safety and privacy challenges. Regulations also vary by region and jurisdiction. But during this mass state of emergency, state and local officials have been working hard with each other and the federal government to resolve these regulations enough to enable UAVs to do what they do best—enabling stakeholders to make critical decisions while keeping themselves out of harm's way.

The final results of implementing the full capabilities of UAV technology remains to be seen because the story is still unfolding. Foremost, all areas affected by these deadly storms need help in getting back online. But the bigger picture encompasses settling the regulatory issues for the successful integration of UAVs, the fastest growing field in aviation, into disaster response and workflow, particularly where critical infrastructure is concerned.

Another report in Civil + Structural Magazine (September 15, 2017), csengineermag.com/faa-works-florida-drone-operators-speed-hurricane-recovery/ sited FAA Administrator Michael Huerta, faa.gov/news/speeches/news_story.cfm?newsId=22134 who recently addressed the InterDrone Conference in relation to UAV operations specifically regarding recovery from hurricanes Harvey and Irma, "Essentially, every drone that flew meant that a traditional aircraft was not putting an additional strain on an already fragile system. I don't think it's an exaggeration to say that the hurricane response will be looked back upon as a landmark in the evolution of drone usage in this country."

Maraliese Beveridge is the Senior Technical Writer and Public Relations Specialist for Maser Consulting P.A., a multidiscipline engineering firm with a network of offices nationwide. With more than 25 years of experience in journalism, she is a nationally published writer within the engineering industry. Her expertise is focused on transforming complex technical ideas into comprehensible articles on trending subjects.

High Resolution Aerial LiDAR for Design Level Applications

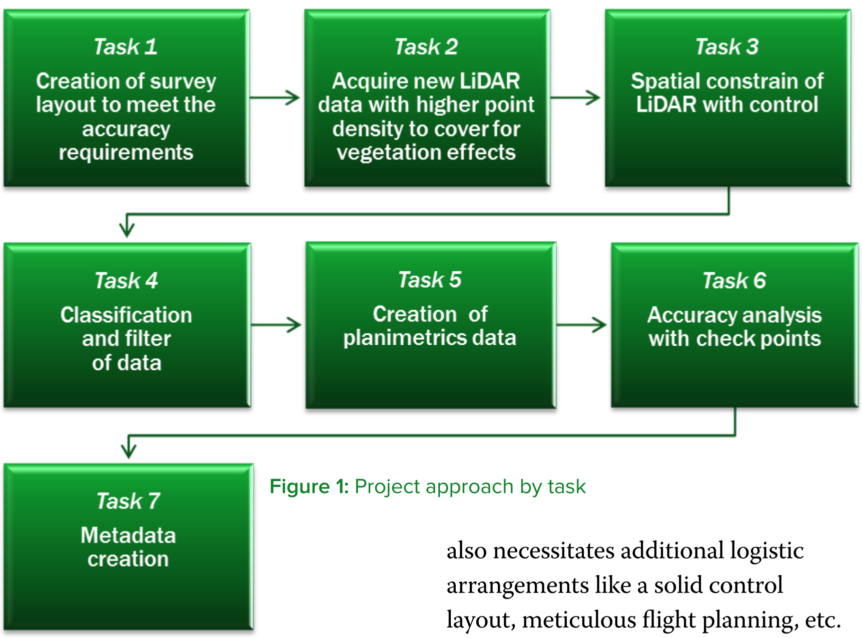


Figure 1: Project approach by task

A challenge faced by transportation agencies is the requirement of engineering quality topography during planning. The new design projects demand topographic information with a high vertical accuracy of 1.5 cm to 3 cm or even better and its generation is not only technically challenging but also necessitates additional logistic arrangements like a solid control layout, meticulous flight planning, etc. MA Engineering Consultants with its long history of investing in the best people and technology understands that surveying and mapping are critical elements to all road networks. Very recently, MA Engineering has performed multiple projects using helicopter-based aerial LiDAR supplemented with digital leveling and was able to achieve the vertical accuracy needed for such design level studies in a consistent manner.

Methodology

Understanding that the vertical accuracy requirements of the topographic data for the design level studies requires a new approach, MA Engineering has developed a comprehensive method for meeting the requirements. This multi-faceted approach was designed into seven (7) primary tasks to promote a logical progression of activities and ensure overall completeness. The flowchart shown in **Figure 1** provides an overview of identified project tasks described in further detail in subsequent sections.

Control Point Layout

As with any other LiDAR project, the success of any highly accurate topographic project depends on selection, placement, distribution and measurement of accurate ground control points. For all three projects, the control points were painted in pairs to control the entire mapping polygon with the majority of the control set on hard surfaces in order

BY SRINI **DHARMAPURI PHD, CP** & MATT **ELIOUS, CP**

to cover the mapping area. There a few exceptions at locations where hard surfaces did not exist. A permanent marker such as PK nail (painted) or a rebar (non-hard surface) was placed at the surveyed location of the panel points. All control were observed using Digital Levels Method and tied to the State Plane Grid Coordinate System using NAD83 (current adjustment) for horizontal datum and NAVD88 for vertical datum.

As part of the control process, Primary Survey Control (PSC) points were also established at the beginning and end of each project section as well as at intervals along the corridor sufficient for final construction. For each project area, a shape file was created showing all of the control points and check points in the study area which had been used during the accuracy investigations stage.

Data Collection

The low-altitude LiDAR surveys from helicopters provides a way of acquiring engineering grade elevation data. Based on the desired accuracy of the final product, the height, spacing, speed, and point density of the data acquisition were determined and a flight map was prepared. Understanding that the accuracy of the elevation is directly related to the elevation of the system during acquisition, an altitude of 600 ft. above ground level (AGL) was chosen as the flying altitude.

To maintain the required accuracy, the data collection was performed to stay within five miles of the base station at all times. Base stations were established in pairs so that if anything happens to a unit during the mission, the other station can be utilized and the mission does not have to be reflown. The satellite ephemeris are also consulted to determine the position dilution of precision (PDOP) and geometric dilution of precision (GDOP) of the satellite configuration at the project area. Aerial data acquisition was performed when PDOP no higher than 3.0. Two-hour missions were performed during periods of good PDOP.

After the data acquisition was complete, the trajectories were processed to a satisfactory level and the inertial measurement unit (IMU) data was then applied to the trajectory so that the attitude of the helicopter is known at each transmission of light from the LiDAR unit. Adjacent flight lines are flown in opposite directions to provide a quality control check of the point cloud. If there is a time or elevation bias, it can be seen by the comparison of opposing flight lines. Also, cross flight lines were used to provide quality control across all flight lines. For all three projects, the aerial LiDAR data collection flight plan was made with the intention of meeting the final vertical accuracy requirement of 1.5 to 3 cm. The data in all projects was collected with a Riegl Q560 laser scanner at an altitude of 600 ft. AGL by helicopter.

The flight parameters for all projects are given in **Table 1**.

Parameters	Project 1	Project 2	Project 3
Flight Height (AGL Feet)	600	600	600
Target Groundspeed (knots)	55-60	55-60	55-60
Number of Flight Lines	32	8	53
Swath Width (feet)	600	600	600
Scan Angle (Degrees)	60	60	60
Scan Frequency (kHz)	240	240	240
Points Per Square Meter	20	20	20
Vertical Accuracy (estimated) (ft.)	RMSE = 0.1	RMSE = 0.1	RMSE = 0.1
Horizontal Accuracy (estimated) (ft.)	0.35	0.35	0.35

Table 1

Calibration and Spatial Constrain of LiDAR Data

After the data was collected, a two-stage data calibration process was performed:

1. Assigning of scanner and trajectory parameters to each scan record
2. "Tie plane" least squares adjustment of the dataset in order to fit all lines to each other.

In the first step, laser data is imported into the Riegl processing software package RiProcess. RiProcess reads the timestamp recorded for every laser pulse and matches it to a precise location along the flight trajectory. The end product is a set of scan lines in the correct location and orientation, but due to small misalignments between the IMU and the laser scanner, as well as other sources of minor interference, further calibration is needed to "tighten up" the dataset before export.

The second step performed with RiProcess is a tie plane adjustment. In this step, an automated process finds planes of at least 10 to 15 points within each scan line and these matching planes are then adjusted by the least squares method to fit each other via roll, pitch, yaw, northing, easting, and height adjustments.

The collected LiDAR data was constrained to highly accurate control points collected using ground-based surveying. The LiDAR data was geometrically corrected in order to account for the potential errors that are inherent in the LiDAR geocoded data either due to calibration, GPS/IMU anomalies, or any other associated issues. Before performing the filtering/classification of LiDAR data, geometric correction of LiDAR data was completed by comparing the LiDAR data with known "control points". During this process, the ground control was intersected with the triangular irregular networks (TIN) model of the calibrated point cloud. The Z values were checked against one another, and the difference was calculated. These results were then used to adjust the LiDAR data. A calibrated and constrained LiDAR is shown in **Figure 2**.

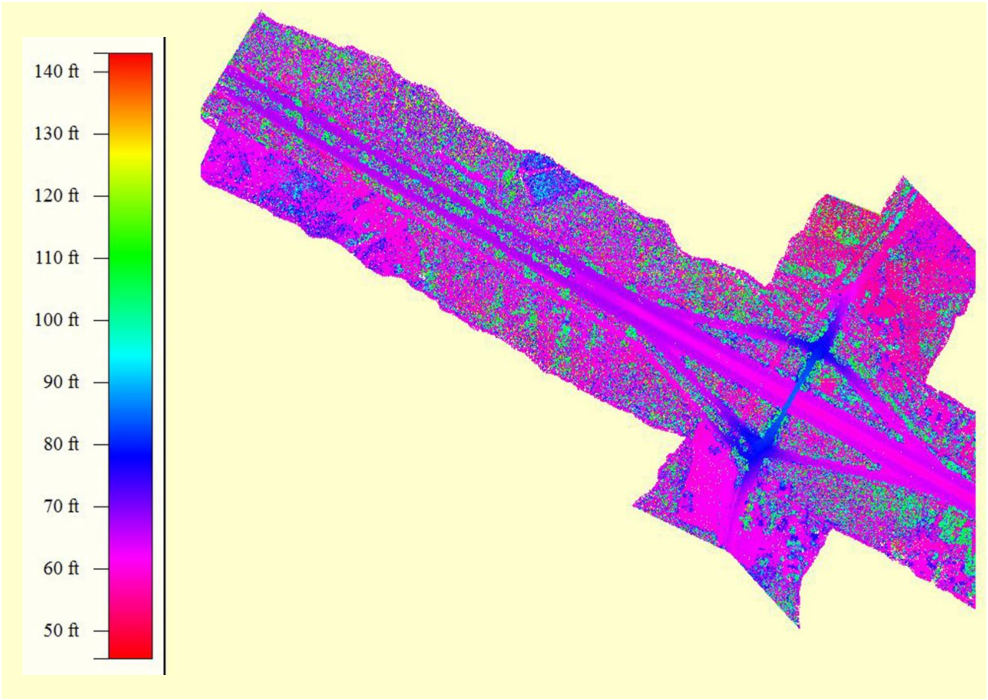


Figure 2: Calibrated and constrained LiDAR

Classification of LiDAR Data

LiDAR data processing using a three stage process:

1. Generation of bare earth involving the filtering of ground points using an algorithm that considers the geometry of adjacent points as well as parameters set by the user.
2. Interactive editing of the resulting ground surface involving surface visualization tools to reclassify points that were incorrectly classified during automatic processing.
3. Creation of intensity image and extraction of planimetric features using intensity images.

The ground classification process involves building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle, and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that they are ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint which determines the maximum terrain angle allowed within the classification model. Once the automated classification has finished, the second step is to rely on manual editing of the data to "clean up" artifacts still remaining in the data set which were left by the automated process. A grid generated from ground points is shown in **Figure 3**.

Accuracy Analysis

After the data processing is completed, the Non Vegetated Vertical Accuracy was computed using check points collected separately for each project site.

The vertical accuracy assessment of LiDAR data involves comparison of measured survey checkpoint elevations with those of the corresponding LiDAR

	Project Area 1	Project Area 2	Project Area 3
RMSE(z) Objective (ft.)	0.05-0.1	0.05-0.1	0.05-0.1
Number of Control Points in Report	13	29	22
Number of Control Points with LiDAR Coverage	13	29	21
Average Control Error Reported	0.0243	-0.006	0.0121
Maximum (highest) Control Error Reported (ft.)	0.116	0.11	0.065
Median Control Error Reported (ft.)	0.019	-0.013	0.017
Minimum (lowest) Control Error Reported (ft.)	-0.020	-0.095	-0.044
Standard Deviation (sigma) of Error for Sample	0.033	0.048	0.027
RMSE (RMSE(z)) (ft.)	0.042	0.048	0.030

Table 2

point. The determination of LiDAR x, y, z, was performed using TIN based approach. In the TIN based approach, the X/Y locations of the survey checkpoints are overlaid on the TIN and the interpolated Z values of the LiDAR are recorded. These interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements.

After calculating the LiDAR Z values corresponding to check point Z values, the Root Mean Square Error (RMSE) was calculated and the vertical accuracy scores are interpolated from the RMSE value. The RMSE equals the square root of the average of the set of squared differences between the dataset coordinate values and the coordinate values from the survey checkpoints.

A summary of the results has been provided in **Table 2**.

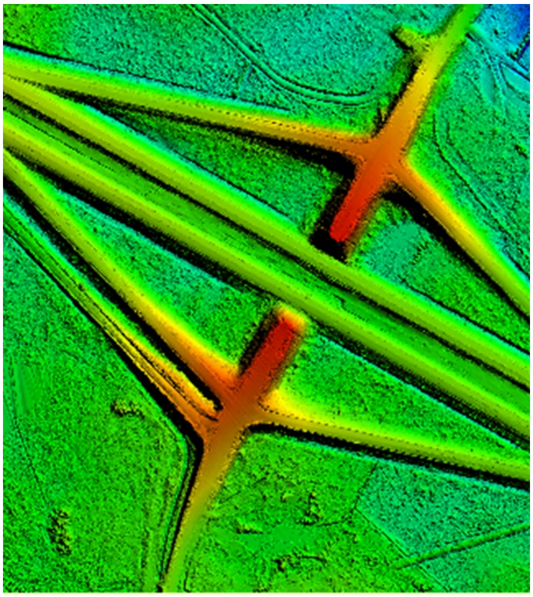


Figure 3: Grid generated from ground points

Conclusion

The accuracy results conclusively prove that high resolution aerial LiDAR can be used effectively to develop survey grade terrain mapping for use in engineering and planning work. This project was proof that aerial LiDAR can be more economical and easier to collect detailed data than standard ground-based surveys. Additionally, LiDAR data can be processed quickly and accurately into engineering quality mapping products. Vegetation canopy was not a major factor in this project, but brush vegetation was penetrated well due to the high resolution nature of this collection leading to more accurate topographic mapping. Finally, LiDAR serves multiple uses: providing not only topographic data, but intensity imagery that is very useful for delineating ground features, water bodies, and vegetation.

Dr. Srini Dharmapuri, CP, PMP, GISP is with MA Engineering Consultants (MAEC) in Dulles, VA as Director—Geospatial. Dr. Dharmapuri has Master of Science (Physics), Master of Technology (Remote Sensing), and Doctorate (Satellite Photogrammetry). Dr. Dharmapuri has over 30 years of extensive, wide-ranging experience within the Geospatial industry; most notably with LiDAR, Photogrammetry, and GIS. He has worked in both the private and public sectors, as well as internationally. In addition to his educational achievements, Dr. Dharmapuri is also an ASPRS Certified Photogrammetrist, Certified Mapping Scientist—LiDAR and licensed Photogrammetric Surveyor in South Carolina and Virginia, as well as a Certified GIS Professional and Project Management Professional. Dr. Dharmapuri is actively involved with ASPRS and ASPRS-EGLR.

Mr. Matthew Elious, CP is with MA Engineering Consultants (MAEC) as Photogrammetry Director. Mr. Elious' professional career spans over 33 years and managed open-end photogrammetric and LiDAR projects for State DOT's as well as FAA's WAAS aeronautical and obstruction survey projects.

LiDAR/Camera Point & Pixel Aided Autonomous Navigation

Autonomous localization is the process of determining a platform's location without the use of any prior information external to the platform, using only what is available from the environment perceived through sensors. In this article, we describe a technique using a collaborative swarm of UAV's with the goal of assisted navigation in GPS-denied environments using vision-aided Point and Pixel data. We consider two teams of UAVs, operating at different times, and operating collaboratively. The first team, equipped with LiDAR, fly over the unknown area generating a digital terrain map (DTM) or digital surface map (DSM). The second team, equipped with low-end passive-vision sensors, fly over the same area at a later time, using the information generated by the first team, for landmark navigation. The second team operates without GPS using the terrain as a source of localization. To enable this scenario, we present an algorithm for terrain-aided navigation based on Point & Pixel matching to provide environment perception.

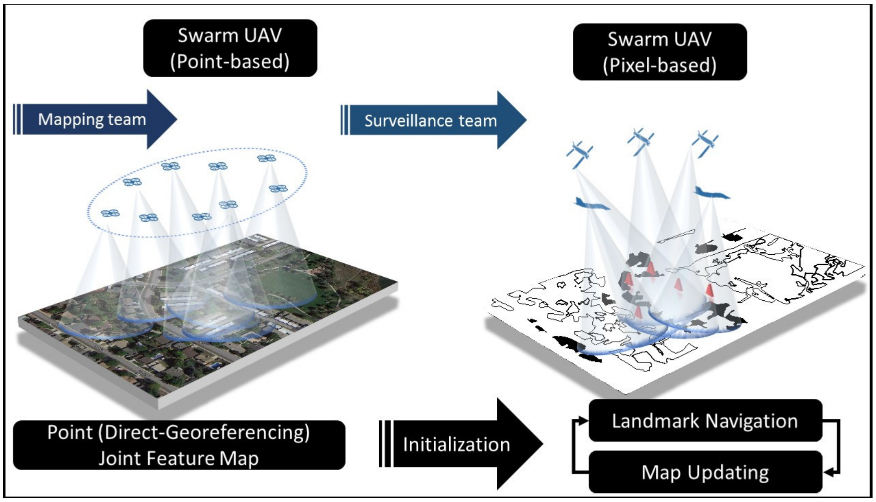


Figure 1: Collaborative navigation vision

Introduction

Autonomous localization is the process of determining a platform's location without the use of any information external to the platform using only what is available from the environment perceived through sensors. In this paper, we describe a technique based on the collaboration of UAV's with the goal of assisted navigation in GPS-denied environments. The capability can be extended to swarm UAV path/mission planning, navigation, and localization and as a mission planning and training tool. We consider two teams of UAV's working at different times in collaborative navigation. First, a small swarm of UAV's, equipped with a low-cost (camera) and high-end sensors (LiDAR), fly over a known/unknown area, when GPS is available. This swarm creates a landmark-map. Later, a larger team of UAVs, equipped only with low-end electro-optical (EO) sensors (cameras) fly over the same area using the map generated by the first team for landmark navigation. A sketch of our collaborative navigation system based on a swarm of UAVs is shown in **Figure 1**.

In this design, a Mapping team of UAVs flying in a hostile area is responsible for mapping and providing a reference terrain model from which a set of landmark can be identified. Later, a Surveillance team will go to the same area and use the reference terrain model for navigation in GPS-denied conditions. Collaboration is based on perception of the environment with

BY SHAHRAM **MOAFIPOOR**, LYDIA **BOCK**, JEFFREY A. **FAYMAN**

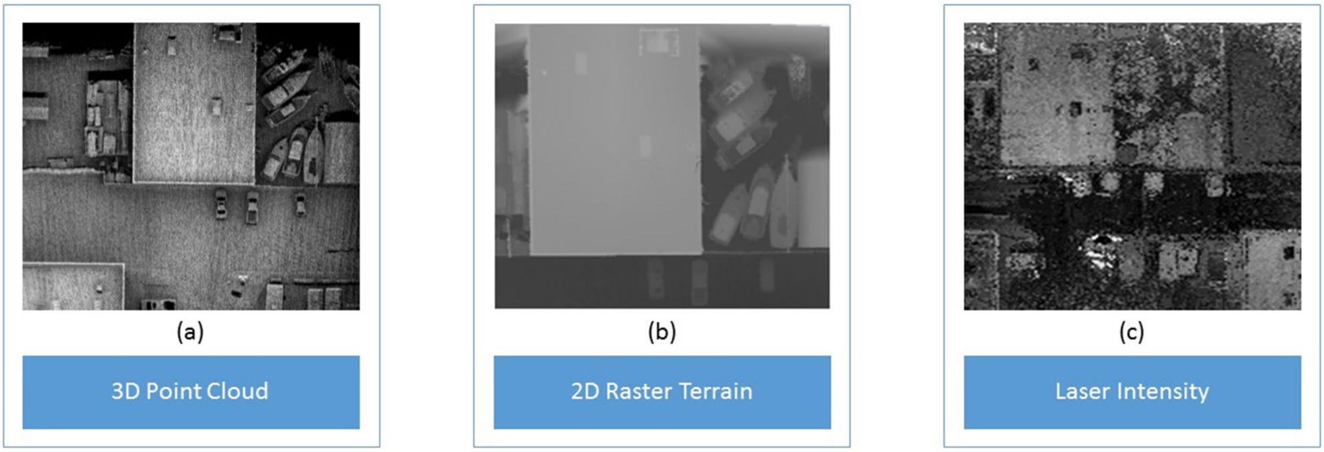


Figure 2: Point & Pixel feature presentation

vision sensory data captured by one swarm when GPS is available and used later by other platforms operating in the same area under GPS-denied conditions. The focus in this paper is on the use of LiDAR for perception by the first swarm of UAV's and EO cameras for perception by the second swarm of UAV's. We present an algorithm for vision-aided navigation based on Point (LiDAR) and Pixel (EO camera) matching to provide environment perception. We refer to this capability as Point & Pixel. In this Point & Pixel matching algorithm, we match camera images (pixels) to point cloud reference 2D range images provided by the LiDAR.

From perspective of data acquisition and sensor operations, there are major differences between the LiDAR and EO cameras. LiDAR is a high-power active sensor enabling direct-georeferencing and encoding 3D pointwise sampling (point clouds) and provides terrain models even in environments containing dense foliage. EO cameras, on the other hand, are low-energy passive sensors that can cover a full area in a snapshot within multispectral bands and high radiometric pixel information. However, the captured images require post-processing for calibration and encoding. The main advantage of LiDAR-based mobile-mapping is that there is no need for Ground Control Points (GCP) for real-time direct geo-referencing of the point clouds. This is particularly useful when the system operates in hostile environments. Another advantage is availability of multiple laser returns, at a high frequency, enabling penetration through canopy and forest. The sensor can separate off-ground objects from on-ground objects, providing DTM/DSM in areas of dense vegetation or tree canopy. The limitations of LiDAR are related to the classification and identification of objects from point clouds, point density variation with scan angle and the topography, and noise level caused by multi-return beams.

UAV Point & Pixel Mapping

Once the first group of UAV's finishes flying its mission, the map generated will be used as a reference terrain model to aid navigation of the second group of UAVs operating in GPS-denied conditions. In a navigation system based only on image aiding, the main challenges become real-time image-processing and integrating image features with the inertial system to provide filter updates during GPS-denied periods. In this article, the vision-aided inertial system is supported by the map features. The key in this algorithm is to extract landmark (key-points) from point-based map data and find corresponding features in image-based data. To illustrate the steps used in the Point & Pixel matching algorithm, sample Point & Pixel data, captured by Velodyne VLP-16 laser scanner is shown in **Figure 2**. In **Figure 2a**, a geo-referenced point-based image in which point cloud data are spaced with an irregular point density is shown. To use the geo-referenced point cloud as a terrain aiding map, we utilize several techniques, including (1) Interpolating/extrapolating the irregular point clouds to a regular grid and treating it as an 2D range image as shown in **Figure 2b** in which case each point carries a depth value and the laser intensity; (2) Delaunay

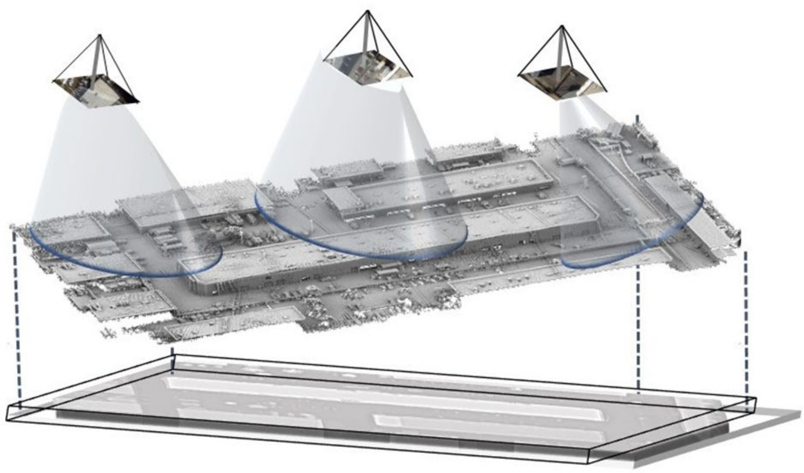


Figure 3: Image matching concept on a raster 2D DTM image

triangulation for terrain modeling (vector based); and (3) use the laser point density as a map **Figure 2c**.

As can be seen, the laser intensity signature is based on the reflectivity of the surface type and cannot be used to represent feature attributes that can be used for feature matching. One advantage of representing the point clouds in the raster form is that they can be treated as images and a variety of Photogrammetry/Computer Vision (CV) image-processing tools and techniques can be applied. Thus, we chose to represent the point-data in a raster 2D image.

Point & Pixel Matching Algorithm

In order to find a match between the camera image, and a raster DTM image, as illustrated in **Figure 3**, we first tried applying a standard feature matching algorithm to the Point & Pixel images. However, the feature-based algorithm failed due to the mixed-scale and radiometric resolution across the DTM raster image. The approach we used for matching was implemented in two stages; coarse and fine. In the coarse stage, we narrowed the search space in the image with respect to the raster 2D image and estimated the proper image scale and orientation of the pixel-image to the reference terrain image. Once the approximate location of the pixel-image was determined, in the fine stage, a feature matching algorithm was used to find the common features between two images. These features are used later in a space resection algorithm to estimate the Exterior Orientation Parameters (EOP) of the pixel-images in terms of position and attitude of the projection center. These EOPs are then used as auxiliary data to update the inertial navigation filters in the absence of GPS data.

The algorithm used in the coarse-stage is based on template matching. The template is provided by the pixel image, and the reference image is the DTM raster image. We found that standard template matching works only under ideal conditions. Firstly, the template image should be captured close to the nadir direction, as any over-tilt can cause a mismatch. Additionally, the two images should have a similar radiometric resolution. In our application, the pixel image radiometric resolution is higher than the DTM raster image as the radiometric quantization of a raster DTM image is a function of variations in altitude, while an RGB camera quantization level is usually more than 8-bits. In addition, the spatial resolution of the two images should be similar. The spatial resolution of the raster DTM image is a function of the point density, which directly related

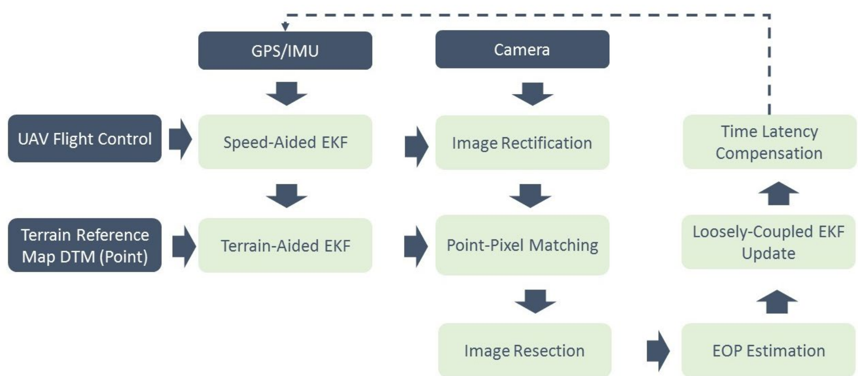


Figure 4: Architecture of the Point & Pixel matching algorithm

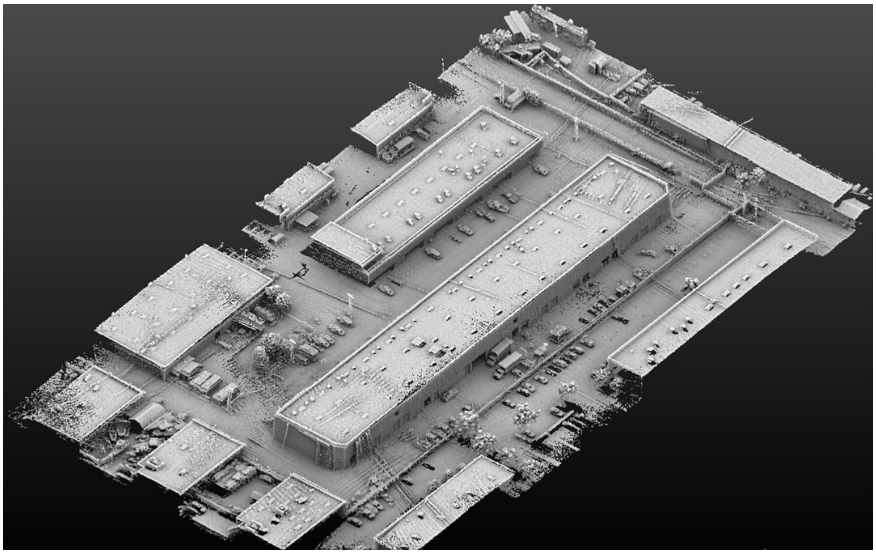


Figure 5: Direct-georeferencing terrain mapping

to the flight altitude (AGL), frequency setting, and platform speed.

Thus, additional quantization and rectification must be applied to the pixel images before they can be used for template matching. After these additional transformations, a Rotation-Scale-Translation (RST) invariant template matching algorithm can be used to estimate the coarse-location of the pixel image with respect to the DTM raster image. The Point & Pixel matching algorithm is illustrated in **Figure 4**. In this architecture, there are four sources of sensory data: (1) terrain reference map DTM generated by the first team of the UAVs, (2) UAV flight control of the second UAV team, (3) the GPS/IMU of the second UAV team with assumption of GPS denied, and (4) the camera mounted on the second team of UAVs.

Experimental Results

To simulate our collaborative navigation application, we collected data from two separate teams of UAVs using Geodetics' Geo-MMS™ Tactical system. The first was equipped with an auto-pilot providing inner loop attitude and velocity stabilization control, a Velodyne VLP-16 LiDAR sensor, a MEMS IMU, a radio modem and a dual-frequency RTK GPS sensor. The flight duration was approximately 20 minutes at an altitude of 40m AGL. The FOV of the laser scanner was 120˚ with the frequency of 20Hz (1200 RPM). The second group of UAV's were instrumented with an autopilot, a GoPro HERO4 camera, a MEMS IMU and a radio modem. This group of UAVs were flown at 20m AGL. The first team of UAVs, equipped with Geo-MMS LiDAR, were flown over the test area and a DTM was generated. At this stage, the laser point clouds were geo-referenced with the accuracy of ±5cm using RTK. **Figure 5** shows the generated map of the area.

Next, a UAV from the second team was flown over the same area at a higher altitude. The second team operates without GPS using the Point & Pixel algorithm described in this paper as a source of localization. As explained earlier, the first step was to make a raster 2D image of the DTM. **Figure 6** shows the raster image generated after a cubic interpolation/extrapolation from the irregular point cloud to a regular grid cell size of 0.1m. The reference image size was 2610 * 1480 pixels with 8-bit depth.

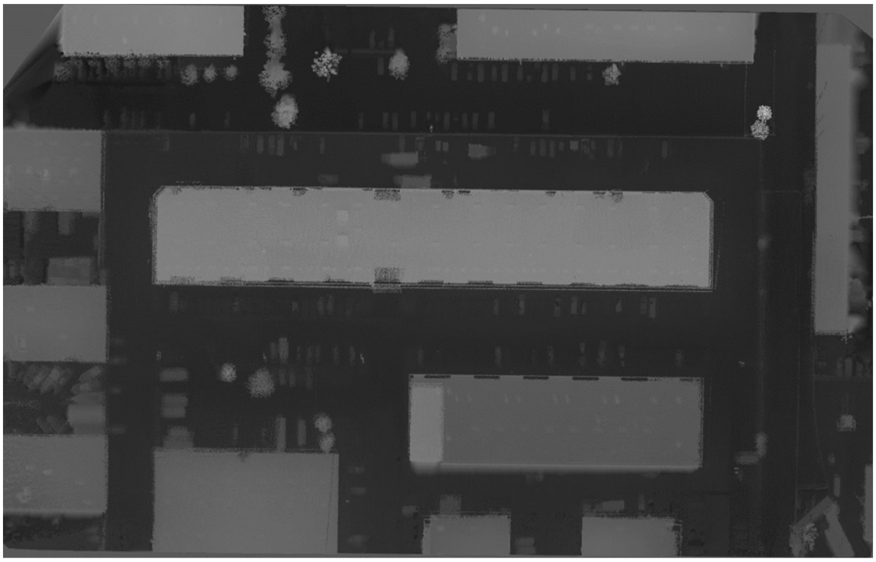


Figure 6: DTM raster image

Figure 7: Original image (a) and single image rectification and intensity normalization (b)

Next, the Point & Pixel matching algorithm was employed. For the purposes of vision-aided navigation, the camera was set to capture images at 1Hz, a sample rate allowing for filter updating in real-time. **Figure 7a** shows an example of the images fed to the Point & Pixel matching algorithm. The camera was installed with a tilt of approximately 30˚ with respect to the platform body frame. As previously mentioned, the template image should be captured close to the nadir direction, as any over-tilt can cause a mismatch, thus the 30˚ tilt must be compensated before it can be used for template matching. To accomplish this, an indirect rectification was performed using a central perspective transformation with a fixed focal length. This transformation was a projective transformation with the scale of focal length, as shown in **Figure 7b**. Additionally, intensity normalization was applied to the template image.

Once the image is rectified for tilt, it is used in an RST-invariant template matching algorithm. Due to the unknown scale difference between the template and DTM images, the first image was processed across the whole range of scale following which the scale factor was narrowed down for faster template matching. **Figure 8** shows the normalized cross correlation of the matching between the rectified image, **Figure 7b**, and the DTM raster image. Once the maximum cross correlation is identified, feature extraction and matching is applied to the restricted DTM raster image and the scaled down image. For camera images, there are a variety of standard methods for feature point extraction and matching, including SIFT and SURF. However, for rasterized DTM image, these methods could not provide a consistent solution. The main reason is related to the low quantitation and resolution of these images, which are restricted by the laser spacing in object space and quantization restricted by altitude range.

Despite significant research into image matching, matching points in a rasterized image remain a challenging problem. Thus, instead of point-based approach, we use feature-based matching based on region description. In the DTM raster image, a region is usually defined by point density, roughness, and elevation variations. In the pixel image, the same region is defined by shadow, texture, and scale. Thus, the region description was generated using a Maximum Stable External Regions (MSER) operator based on region density and region size attributes. Once this

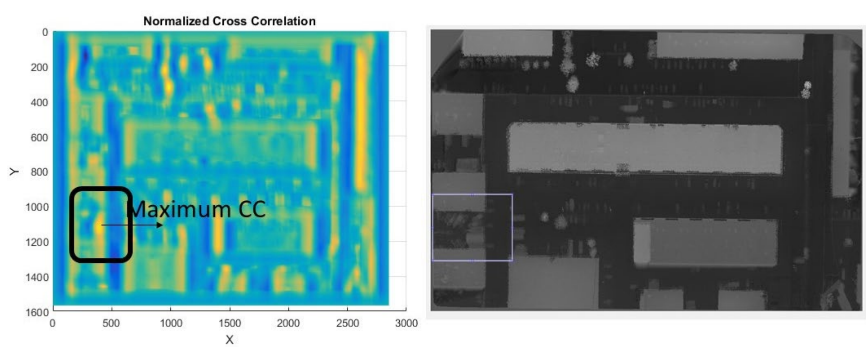


Figure 8: Normalized cross correlation template matching

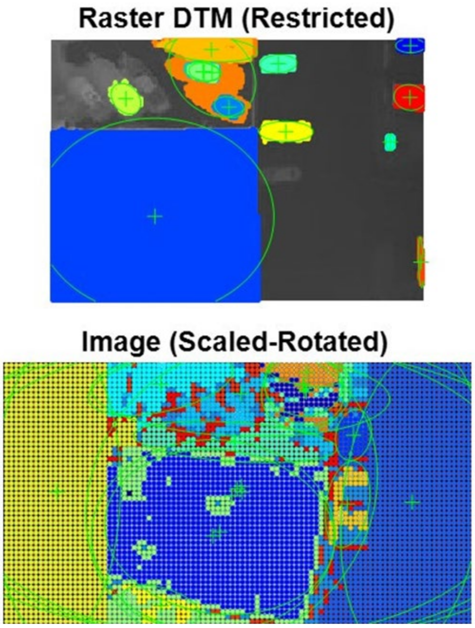


Figure 9: Feature extraction and matching sample case

operator was applied to the two images, a set of corresponding matching features was detected. **Figure 9** shows a sample of image feature matching based on the MSER matching region algorithm.

After removing outliers and detection of the strongest features, the matching features are used in the space resection algorithm, where the EOP of the captured images can be estimated using geo-referenced features in the raster DTM image. Applying this algorithm to a series of captured images along a flight strip can provide position updates that can be fed to the EKF in a loosely-coupled manner. The algorithm was tested on several sample images along the strip, and it was found that the algorithm is sensitive to the texture and the quantization level of the raster DTM image. RST advanced template matching found occurrences of the template regardless of their orientation and scale, but it could not match local brightness between two Point & Pixel images even after normalizing the intensity of both. One possible approach is to add the camera pixel data to the laser point clouds. In this approach, the DTM raster image will contain the quantization level of the camera image, which can enhance template and feature matching. **Figure 10** shows the results of applying the position updates to the navigation solution based on image EOPs estimation to the collected data.

The "true" solution is shown in blue, while the free-inertial (GPS-denied) solution is shown in red. Note that the red drifts very quickly. Navigation updates from the Pixel-Point Matching algorithm are shown in yellow. This preliminary performance evaluation shows improved performance of the navigation system in GPS-denied conditions based on a collaborative of two UAV teams. A more comprehensive performance analysis of the Point & Pixel Matching is currently under way for more complicated trajectories and environments, where the terrain signature texture is more homogenous.

Conclusion And Future Work

In this paper, we presented an algorithm for UAV navigation based on the collaboration of a swarm of UAVs that provide accurate terrain landmark mapping for use in terrain-aided navigation. We developed an algorithm to find matches between images captured by the camera and the point-based map data. The algorithm is called Point & Pixel Matching, which estimates the transformation from each captured image to the reference terrain. The algorithm was implemented in two steps and tested on several different images with different texture attributes show that performance is limited due to

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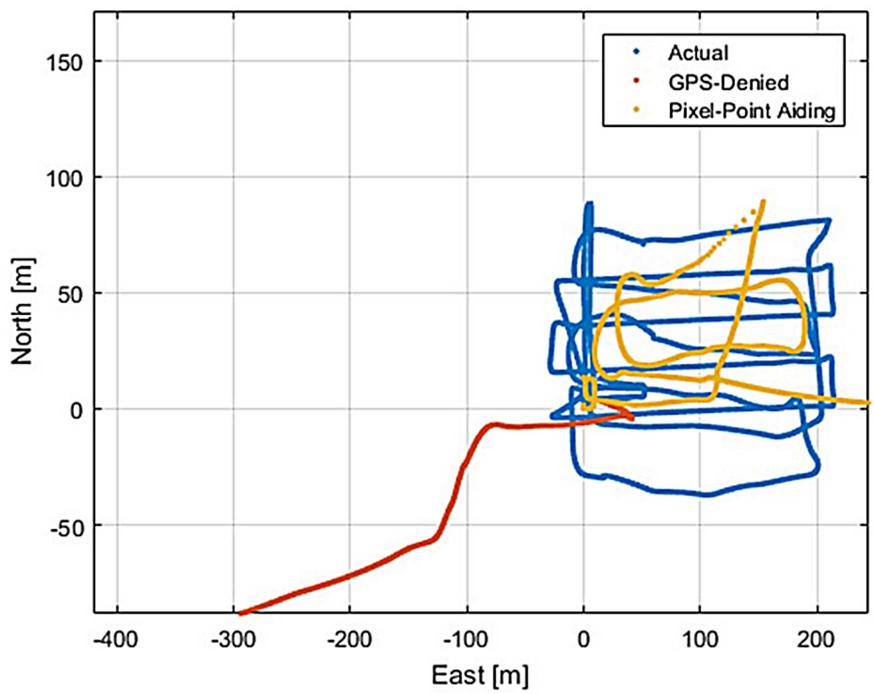


Figure 10: Navigation solution aided by Point & Pixel matching

Briar Chapel has nearly 1,500 homeowners, with approximately 10 new homes being occupied every week, according to Newland Senior Project Manager Lee Bowman.
Photo courtesy of Newland Communities

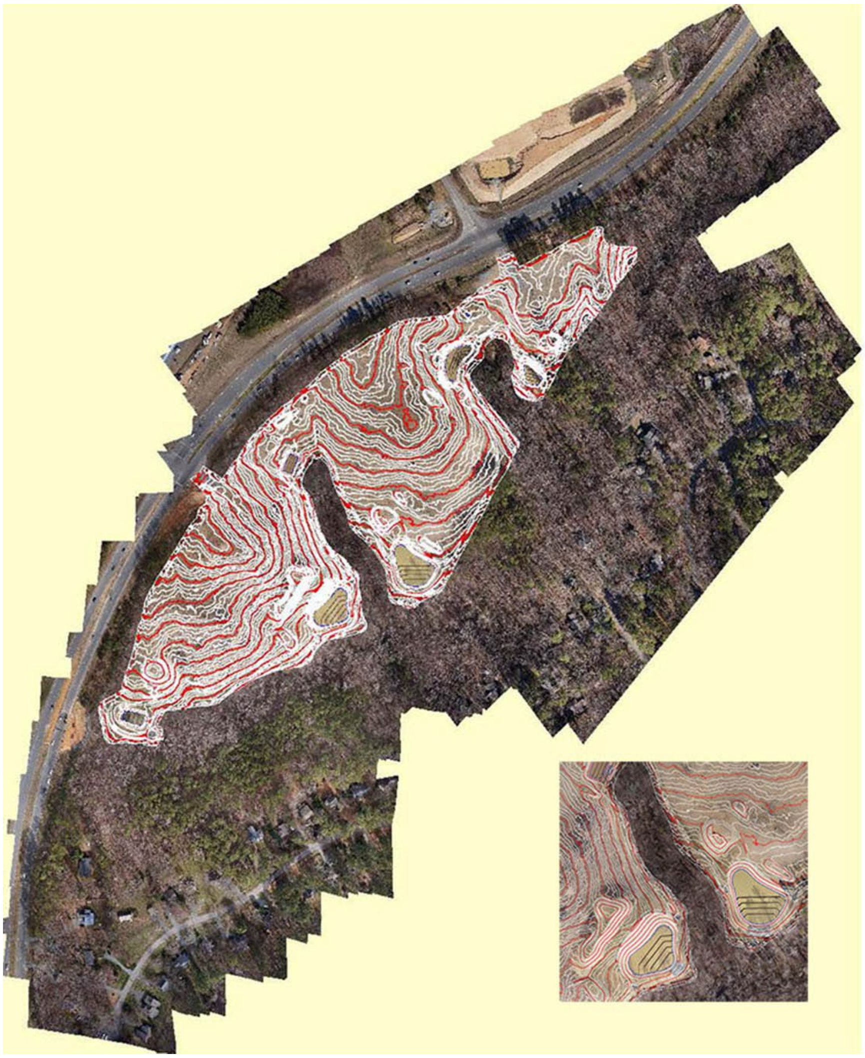
Rapid-Response UAS Keeps Construction on Schedule and Prevents Earthwork Overages

On a large development site, slight discrepancies in elevation can throw off earthwork volume estimates by tens of thousands of cubic yards. What looks small on paper becomes massive in the field.

McKim & Creed, Inc.—an ENR Top 500 engineering, surveying and planning firm— faced this situation when verifying elevations in Briar Chapel, a 1,600-acre master planned community in Chapel Hill, North Carolina. Developed by Newland Communities, Briar Chapel is one of the largest green residential communities in the Triangle (Raleigh/Durham/Chapel Hill) area. McKim & Creed is providing civil / site engineering and surveying services for the community.

Last spring, when the initial clearing was completed on a 25-acre commercial site within Briar Chapel, McKim & Creed surveyors were called in to verify elevations. An aerial photogrammetry survey of the entire community site had been conducted by another company several years earlier, and McKim & Creed needed to verify the

BY CHRISTIAN **STALLINGS**



This image was created so that Newland could visualize both the contours as well as the high-resolution ortho. (Inset) At 5 cm, the ortho showed exquisite detail. Capturing the data using conventional surveying methods would have taken approximately two days in the field with a two-person crew. UAS captured this same data in a few hours with the help of a one-person crew to provide ground control points.

accuracies. "As we prepare engineering design on each individual phase of the project, we have our survey crews do field checks of spot elevations to make sure the current grades still match the old survey," explained Chris Seamster, RLA, McKim & Creed's project manager for Briar Chapel.

In their field checks, the surveyors discovered some variances, ranging from a few inches to over a foot, between their data and the existing aerial survey. "The discrepancies were not consistently low or high; they were just varied," Mr. Seamster commented. "The original aerial survey was done with full tree cover, which can sometimes skew survey data. In the other company's defense, it was probably within their contracted tolerance."

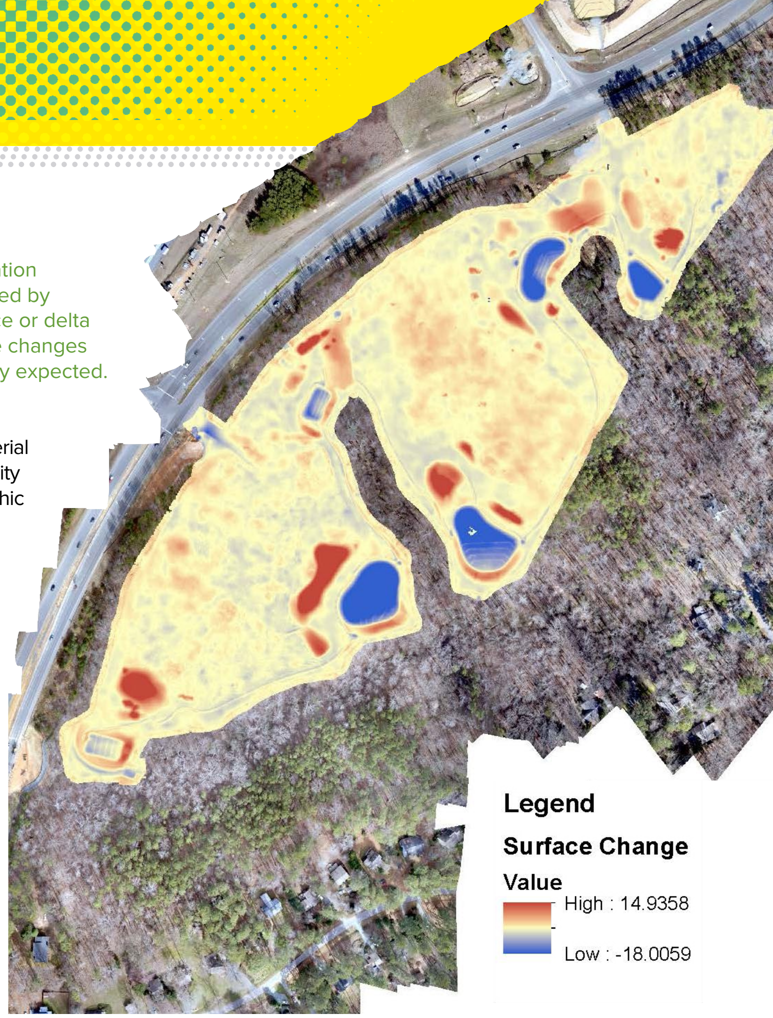
Even so, once construction began the slight differences on paper could quickly turn into mountains of wasted dirt. For Newland—a leader in sustainability, green building and open space—waste is not an option.

Because construction was imminent, the team needed a quick, reliable and cost-effective way to verify the elevations. Flying the site again would take too long and be too expensive. "The main things were time and the ability to provide quick results," said Mr. Seamster.

That's when the idea to use unmanned aerial systems (UAS), also known as drones, took off. UAS achieves the 5-cm data accuracy of aerial photogrammetry, but data can be collected much faster and more cost-effectively on sites that are less than one square mile. "We saw an opportunity to try out drone capabilities in our type of industry. In our partnership with McKim & Creed, we were trying to find another way to be more efficient, manage the whole design-build process, and be integrative. Hopefully it would be quicker," said Lee Bowman, senior project manager with Newland.

McKim & Creed's UAS team quickly deployed to the site, and a full survey of the site was performed within a few hours. The next day, Newland was presented with an updated survey CAD file of the topo, a high-resolution ortho photo, a classified point cloud of the bare earth, and a change detection analysis to compare the two surveys. The earthwork estimates were adjusted as needed and construction commenced on schedule, with no wasted time, money or fill.

"UAS is increasingly becoming a very attractive tool for land development. The conditions are ideal because there are no features to obstruct the surface, and we can easily conduct repeat visits to monitor progress," explained Mr. Seamster.



This image depicts the difference between the existing surface information and the surface information created from the drone. This is accomplished by subtracting one surface from the other and then reporting the difference or delta of the two surfaces. Newland was able to use this to determine that the changes from the previous surface to the new surface were in line with what they expected.

Concluded Mr. Bowman, "Getting the information that fast saved us money in the end."

Christian Stallings, CP, is responsible for overseeing LiDAR production operations at McKim & Creed, Inc. He holds a master's in geographic information technology and a graduate certificate in remote sensing from Northwestern, and extensive instruction in advanced LiDAR data processing and advanced production workflow from Penn State.

McKim & Creed is an employee-owned engineering, surveying and planning firm with more than 400 staff members in offices throughout the U.S., including North Carolina, Florida, Virginia, Georgia, Texas, and Pennsylvania. McKim & Creed specializes in airborne and mobile LiDAR/scanning; unmanned aerial systems; subsurface utility engineering; hydrographic and conventional surveying services; civil, environmental, mechanical, electrical, plumbing, and structural engineering; and industrial design-build services for the energy, transportation, federal, land development, water and building markets. For more information about McKim & Creed, visit www.mckimcreed.com.

THE BUSINESS OF **DRONE MAPPING**

TY **BRADY**

State Regulations

Should a surveyor's license be mandatory for creating topographic mapping? Everyone can agree that licensure of surveyors is necessary to protect the public for retracement of boundary lines. But should licensure extend into other realms of measurement? I think if it can be reasonably established that licensure is necessary to protect the public, and that if non-licensed practitioners could harm the public with an inferior service, then it should be a regulated field. As technology continues to increase and make our job easier, it also allows someone without a surveyor's license or background to create a topographic map that the customer believes to be accurate.

In August 2016 the FAA opened up an easier method to become a certified remote pilot. One only has to pay $150 and pass a fairly simple exam to become certified by the FAA to become a professional drone pilot. Now over a year later there are many tens of thousands of certified drone pilots hungry to cash in on the new drone economy. Many are discovering that the real money is in drone mapping. A simple search of the internet will result in many upstart drone companies offering mapping services. Anyone with a FAA part 107 certification could watch a few how-to videos on YouTube, take some pictures, then upload the pictures to one of several cloud based services that will process the imagery into mapping.

I believe that in order to protect the public, state agencies should regulate

"I believe that mapping created by someone who is self taught has more potential for critical mistakes than mapping created by a licensed surveyor."

drone mapping if that mapping is to be used for "the design, modification, or construction of improvements to real property or for flood plain determination", which is how the State of Virginia happens to define it. Drone pilots who are not licensed could still create mapping for general informational purposes. I believe that mapping created by someone who is self taught has more potential for critical mistakes than mapping created by a licensed surveyor. Licensed surveyors have many years of experience and know how to create checks and balances to ensure the mapping is reliable and accurate.

In February 2015, the Supreme court ruled on the case: North Carolina State Board Of Dental Examiners v. FTC. Here is the background: The State Board wrote cease and desist letters to unlicensed dentists operating teeth whitening services. The Federal Trade Commission thought that this was anti competitive and broke federal regulations. The Court ruled in favor of the Federal Trade Commission. I've seen this ruling misinterpreted by some who think that the FTC can therefore tell a state what is anti competitive. That is not quite true. In this case, the state of North Carolina admitted that they did not specifically regulate teeth whitening. In the majority opinion Justice Kennedy wrote, "state-action antitrust immunity cannot be invoked unless two requirements are met: 1) the challenged restraint of trade is clearly articulated and affirmatively expressed as state policy, and 2) The policy is actively supervised by the state." While I can only hope that the state boards are properly "actively supervised", the important thing to learn from this is that the state code, the state laws created by the legislature must be "clearly articulated and affirmatively expressed as state policy."

If you are concerned about unlicensed drone companies offering any kind of mapping services to the public, I would highly encourage you to investigate what your state code has to say about this subject and to work with your state board and legislative representative to ensure that your state code is "clearly articulated and affirmatively expressed" in regards to drone photogrammetry and mapping.

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to a high order function for relationship mapping or simply use a lookup table. An example of a high order function are the typical polynomial functions used to characterize radial lens distortion in cameras. A lookup table example would be corrections of stepper motors in LIDAR mirror controls such as **Figure 1**.

When compensating for errors between measured values and "truth", it is critically important to separate system errors from what we might call environmental or project-specific errors. For example, a global navigation satellite system (GNSS) receiver error contains elements of both. A simple example are the so-called lever arms which define the position of the phase center of the antenna with respect to the reference system of the platform. If the lever arms are carefully characterized, their contribution to systematic error can be totally eliminated. If they are not correct, their contribution will manifest as project (environmental) error. We were recently testing a new antenna on a drone and consistently seeing a 3 cm height error in our project results. Now a height bias can be caused by an incorrect vertical lever arm, incorrect measurement of drone attitude, a focal length error and a few other issues. After some research, it was discovered that we had used the wrong phase center for the antenna. In fact, our error was exactly 3 cm!

If you do not separate system errors from environmental errors, you will not be able to reliably model data collected from a project. In our example of stepper motor error, this will manifest in LIDAR data as a roll error. Various corrections can be applied to the LIDAR data based on measurements within the data but these corrections might be highly correlated with other error sources. If the stepper error were calibrated and a lookup table applied, this source of error would be eliminated, allowing one to focus solely on correcting environmental error.

A more insidious example is calibration of drone cameras. Unlike metric cameras used in manned aerial mapping, drone cameras tend to be "calibrated" in situ. That is, self-calibration is typically used on a project by project basis. This approach comes from computer vision where it is assumed that little is known about the actual characteristics of the camera. The big problem here is that focal length is highly correlated with other parameters such as flying height. With control on the same plane and some ambiguity in flying height, you will resolve to an inaccurate focal length. This causes both elevation bias and elevation scale errors. You can address this issue by always using a laboratory calibration of the camera.

The final word on calibration is its use as a diagnostic tool. Tracking various static calibration values such as lever arms, stepper position, focal length and so forth over time can be an indicator of a system problem. For example, if focal length has remained relatively constant over a number of calibration cycles and then suddenly changes, you may have a loose lens to camera coupling, a shift in the camera CMOS sensor or some other contributing cause. This would lead you to investigate and correct the problem before it manifests as an error in customer delivered data. A routine calibration process is just a good best practice!

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low resolution and quantization levels in the point-based image. One possible approach to resolving this issue is to add the camera pixel information to the laser point clouds by the first team. In this approach, the DTM raster image can be represented with a quantization level closer to the camera-based image; and thus, the matching algorithm can be implemented by point-to-pixel and vice versa. In addition, new features can be added into the map, while also improving the accuracy of the prior terrain information. In future flights, a camera will be added to the first set of the UAVs and the alignment between the laser and the camera will be developed. Another future effort is to merge the two steps of building the reference map and navigation in the GPS denied condition to a single step using a mono-SLAM technique for real-time mapping and using the map for navigation in GPS denied conditions.

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LEWIS GRAHAM

Calibrate This!

We have recently been doing a lot (and I mean a lot!) of flight testing with various cameras on small drones. This testing has been in conjunction with the release of ***Loki***, our new direct geopositioning system for DJI and other drones. We have been analyzing the aspects of "calibration" that can be performed as part of the actual project as opposed to what should rightly be done in the laboratory.

I put quotes around calibration because, first of all, we seldom actually calibrate anything these days and secondly, we very often conflate parameters that are a function of the sensor system with those that are project specific ("environmental" factors). This is particularly true of LIDAR and LIDAR "calibration" software.

Calibration is the process of characterizing a sensor system and then using these characterization parameters in data processing. For example, suppose in a LIDAR sensor we know that the mirror encoder is off by +3 steps such that when the mirror is commanded to direct the beam orthogonal to the sensor plane where we would expect an angle of zero, we are seeing this 3 step error. A calibration parameter would then be "Mirror Angle Correction" and its "calibration adjustment" would be -3 (to bring the +3 back to zero). Now just to be accurate (pun intended), when we add correction values to adjust for known, stable errors, we are performing sensor characterization. If we were to actually fix the mirror servo to remove the 3 step error, that would be true instrument calibration. An analogy would be a scale that reads 2 pounds when nothing is on the scale. If the scale has a calibration control (a "zero" control), the readout could be adjusted back to zero. This would be calibration. If not, you just mentally subtract 2 pounds each time you weigh something on the scale. This would be calibration characterization. Thus, as you can see, we very seldom do actual calibration since most systems do not have a "zero" control on each parameter. We nearly always simply characterize error and then apply corrections during data processing. It is also very important to characterize system parameters at their extremum. For example, if we routinely weight objects with weights up to 950 grams, we probably want to check our scale with a known 1 kg weight. Finally, many systems do not exhibit simple offset behavior with respect to calibration. For example, assume we zero set our scale such that it reads zero with nothing on board. We then add weight in 100 g increments, noting the scale reading. If we are lucky, it might be a nice, linear relationship such as reading 101 g, 202 g, 303 g and so forth for each 100 g addition we make to the scale. We can then devise a characterization formula (in this case, $W_T = W_M / 1.01$ where W_T is the true weight and W_M is the scale reading. Usually we are not so lucky and the relationship is much more complex. In these cases we either resort

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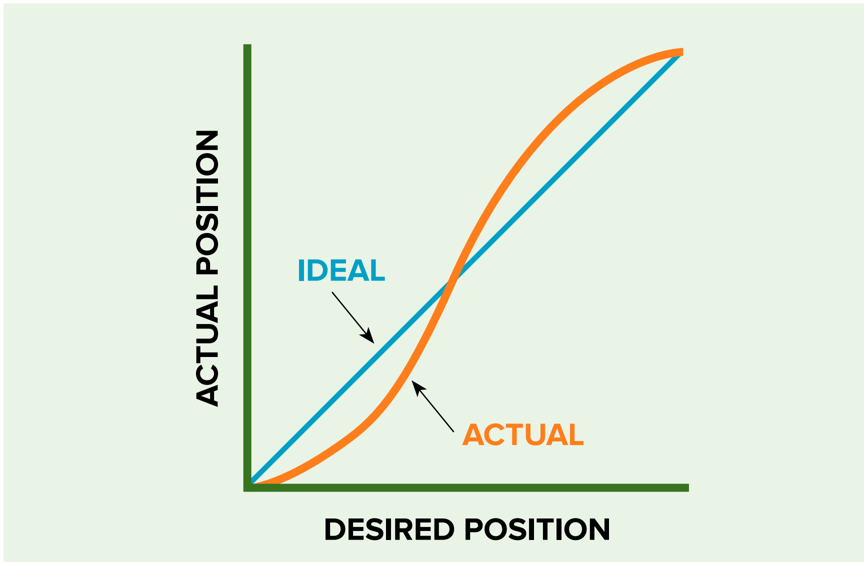

Figure 1: Nonlinear response curve