Special Issue on Remote Sensing - Monitoring for Urban Environment

PE&RS

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Photogrammetric Engineering & Remote Sensing

The official journal for imaging and geospatial information science and technology

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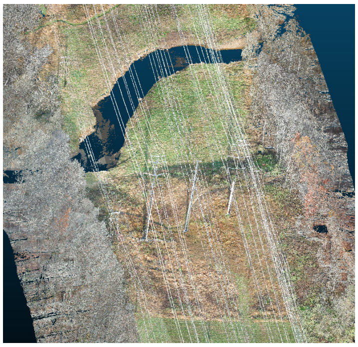
ANNOUNCEMENTS



Exelon Clearsight, industry-leading robotics inspection company, recently acquired **GeoCue Group Inc.'s** True View 615 3D Imaging System, adding to their fleet of cutting-edge drone mapping technologies. The True View 615 3D Imaging System collects high accuracy lidar and imagery concurrently in a single drone flight, increasing project productivity and efficiency. This mapping sensor is bundled with True View EVO, an extensive post-processing software and data management tool, forming a complete drone mapping solution. With this equipment, provides greater vegetation management insights with true colorized points clouds fused with 3D data. These outputs make it easier to visualize, inspect, and create derivative products such as vegetation encroachment data.

Exelon Clearsight is focused on leveraging innovation and technology to conduct sustainable and safe inspection for critical utility infrastructure to drive progress to a more sustainable future. They value the safety of their customers and strive to offer services that will improve efficiency and reliability, while reducing ownership costs. GeoCue's True View sensor aids Exelon Clearsight in that mission by providing a unique set of lidar/imagery fusion data to deliver high-accuracy measurements and analytics. Examples of derived products from the True View 3DIS include colorized 3D point clouds, breakline enforced 3D models, profiles, cross sections, topographic contours, volumetric analysis, classified ground models and more. These products increase the value Exelon Clearsight provides their customers, and allows for even more detailed services, plans, and insights.

Alex Harvey, Solutions Delivery Architect at Exelon Clearsight comments, "I am very impressed with the True View ecosystem, from simplifying data collection operations in the field to post processing. I look forward to exploring new opportunities for Exelon Clearsight to provide value to our customers with the GeoCue's True View platform."

"We are extremely pleased to add Exelon Clearsight to our growing list of professional users of our True View ecosystem," said Lewis Graham, President/CTO of GeoCue. "We are looking forward to refining our collection and processing tools to meet a new array of utility-based drone mapping applications that will be pioneered by Exelon."

To learn more, visit www.geocue.com or www.exelonclearsight.com.

METAGEO announces the launch of its GIS platform to enable organizations of all sizes to host, analyze, find and share 3D map datasets between any internet-capable device. The platform processes any location-based map or sensor data from the real world, combines it into a single 3D virtual environment and streams it to any device or Metaverse platform.

METAGEO offers an affordable and easy-to-use platform that can load data from multiple sources. These sources include satellites, drones, mobile devices, public and crowdsourced repositories, IoT sensor data, 3D models, and topographic maps. The data is then processed by the METAGEO platform into a 3D world and streamed to any internet-connected device, enabling live collaboration between the office and field via mobile or AR device.

Key innovations in the METAGEO 3D map platform include:

- Fast and intuitive multi-user interface for easy data sharing and collaboration
- Aggregation of map and location-based data from a multitude of sources on a global scale
- Seamlessly import and sync data from multiple different systems into a single platform
- Easily host and stream large datasets between internet-connected devices
- Provide ability to find open source and private data
- Plugin SDK will allow for 3rd party tools to scale and fit any user needs

METAGEO has been designed for a wide range of applications in academia, architecture, engineering, construction, energy, natural resource management, environmental monitoring, utilities, and public safety, among others. The platform uses include planning and managing construction sites, organizing the layouts of events, maps for disaster management, public safety, visualizing inspection imagery from drones and mobile devices, and much more.

"After working with 3D map data for several years, it became apparent that there was no easy way to share big datasets with those who need the information most, those with the boots on the ground," said Paul Spaur, Founder of METAGEO. "Now with the rapid advancement of mobile hardware, and using advanced processing techniques, we can now leverage this data in real life, and in the metaverse."

METAGEO will be offered in several affordable subscription tiers, including Free Single User, Free Educational, Standard, Commercial and Enterprise. Each tier provides added features and benefits, enabling organizations to scale. METAGEO is available to a limited number of beta subscribers. Interested parties can get started today at www.metageo.io.

EVENTS

The 22nd William T. Pecora Memorial Remote Sensing Symposium (Pecora 22) will convene in Denver, Colorado, USA from October 23 – 28, 2022, and will focus on all aspects of Earth observation, spanning scientific discoveries to operational applications, and from sensors to decisions. Continuous monitoring of the Earth involves the integration and analysis of both historical and contemporary remotely sensed imagery. It occurs across spatial and temporal scales, measurement objectives, and embraces a broad range of remote sensing and analytical methodologies.

The Pecora 22 conference will also celebrate the 50th anniversary of the launch of the first Landsat satellite and the accomplishments that followed. The conference theme, Opening the Aperture to Innovation: Expanding Our Collective Understanding of a Changing Earth, embraces both the innovations and discoveries that resulted from 50 years of Landsat Earth observations, and also current and future innovations in science and technology that are contributing to our ability to improve our understanding and better manage the Earth's environment.

We are currently accepting proposals for conference sessions and abstracts. The deadline for both is February 15, 2022.

For more information see the conference website at http://pecora22.org

Questions? Contact the Pecora 22 Technical Program Committee at pecora@usgs.gov.

URISA is pleased to announce its 60th anniversary conference, GIS-Pro 2022, taking place October 3-6, 2022 in Boise, Idaho. The international conference, which connects GIS professionals at all stages of their careers - *from students to members of URISA's GIS Hall of Fame* - will be co-hosted by the Northwest GIS User Group and the Northern Rockies Chapter of URISA.

The planning committee is comprised of volunteers from all three organizations who are developing a conference packed with opportunities to learn, discover solutions, and build valuable professional relationships. GIS-Pro 2022 will feature pre-conference training and workshops (some two-day courses will begin on October 2), featured keynote speakers, and an abundance of sessions on the GIS topics of utmost importance to the community, from Climate Change and Community Resilience to GIS for Equity and Social Justice and Technology Innovations.

Members of URISA and the Northwest GIS User Group will be able to take advantage of significant registration discounts. All participants must be fully vaccinated against COVID-19 in order to attend the conference. Please bookmark https://www.urisa.org/gis-pro and follow #GISPro2022 for updates.

CALENDAR

- 3-6 October, **GIS-PRO 2022**, Boise, Idaho. For more information, visit https://www.urisa.org/gis-pro.
- 23-27 October, **Pecora 22**, Denver, Colorado. For more information, visit https://pecora22.org/.

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PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

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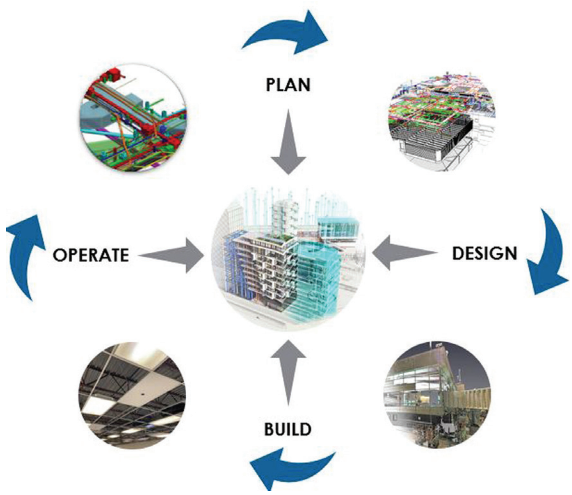

77 **Top Geospatial Trends to Watch in 2022**
By Qassim Abdullah, Ph.D., PLS, CP, Woolpert Vice President and Chief Scientist

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93 Spatiotemporal Temperature Fusion Based on a Deep Convolutional Network
Xuehan Wang, Zhenfeng Shao, Xiao Huang, and *Deren Li*

High-spatiotemporal-resolution land surface temperature (LST) images are essential in various fields of study. However, due to technical constraints, sensing systems have difficulty in providing LSTs with both high spatial and high temporal resolution. In this article, we propose a multi-scale spatiotemporal temperature-image fusion network (MSTTIFN) to generate high-spatial-resolution LST products.

103 Three-Dimensional Point Cloud Analysis for Building Seismic Damage Information
Fan Yang, Zhiwei Fan, Chao Wen, Xiaoshan Wang, Xiaoli Li, Zhiqiang Li, Xintao Wen, and *Zhanyu Wei*

This article presents a method of seismic damage information extraction using Terrestrial Laser Scanning data. This new method is based on principal component analysis calculating the local surface curvature of each point in the point cloud. Then use the nearest point angle algorithm, combined with the data features of the actual measured value to identify point cloud seismic information, and filter the points that tend to the plane by setting the threshold value.

113 Effectiveness of Deep Learning Trained on SynthCity Data for Urban Point-Cloud Classification
Steven Spiegel, Casey Shanks, and *Jorge Chen*

3D object recognition is one of the most popular areas of study in computer vision. Many of the more recent algorithms focus on indoor point clouds, classifying 3D geometric objects, and segmenting outdoor 3D scenes. One of the challenges of the classification pipeline is finding adequate and accurate training data. Hence, this article seeks to evaluate the accuracy of a synthetically generated data set called SynthCity, tested on two mobile laser-scan data sets.

121 Estimating the Aboveground Biomass of Urban Trees by Combining Optical and Lidar Data: A Case Study of Hengqin, Zhuhai, China
Linze Bai, Qimin Cheng, Yuxuan Shu, and *Sihang Zhang*

The aboveground biomass (AGB) of trees plays an important role in the urban ecological environment. Unlike forest biomass estimation, the estimation of AGB of urban trees is greatly influenced by human activities and has strong spatial heterogeneity. In this article, using Hengqin, China, as an example, we extract the tree area accurately and design a collaborative scheme of optical and lidar data.

129 Cloud Detection in ZY-3 Multi-Angle Remote Sensing Images
Haiyan Huang, Qimin Cheng, Yin Pan, Neema Nicodemus Lymo, Hao Peng, and *Gui Cheng*

Cloud pollution on remote sensing images seriously affects the actual use rate of remote sensing images. Aiming at the lack of short-wave infrared and thermal infrared bands in ZY-3 high-resolution satellite images resulting in the poor detection effect, considering the obvious difference in geographic height between cloud and ground surface objects, this paper proposes a thick and thin cloud detection method combining spectral information and digital height model (DHM) based on multi-scale features-convolutional neural network (MF-CNN) model.

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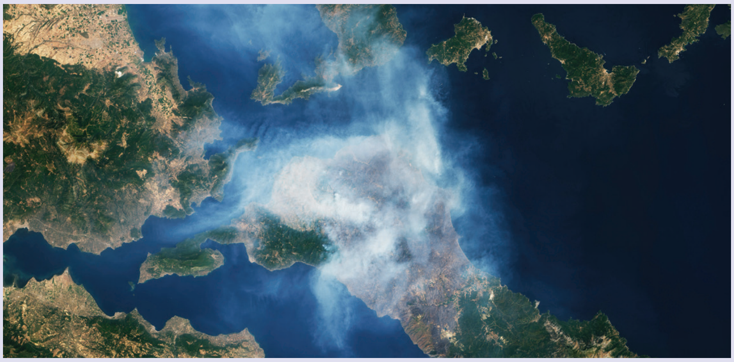
COVER DESCRIPTION



In the first two weeks of August 2021, Greece has endured a series of wildland fires that have charred a large swath of the island of Evia and several areas of the Peloponnese region. The fires followed closely after one of the worst heatwaves in the country since the 1980s, which dried up scarce moisture and left forests primed to burn. Greek Prime Minister Kyriakos Mitsotakis told several news agencies that the fire outbreak has been a "disaster of unprecedented proportions."

According to data from the European Forest Fire Information System (EFFIS), more than 110,000 hectares (424 square miles) have burned in Greece this year, more than five times the yearly average from 2008 to 2020 (21,000 hectares). EFFIS counted 58 fires (30 hectares or larger) in the country in 2021, already above the yearly average total of 46.

The Operational Land Imager (OLI) on Landsat 8 acquired natural- and false-color views (above) of the north end of Evia on August 10, 2021. The false-color image combines shortwave infrared, near infrared, and red light (OLI bands 6-5-4). In this view, burned vegetation appears dark brown, and greens and yellows indicate a combination of unburned trees and scrub.

On August 8, the Visible Infrared Imaging Radiometer Suite (VIIRS) on Suomi NPP acquired a wider view (left) of the fires and smoke in Greece. NASA Worldview imagery from August 3–11 shows the evolution of the smoke plumes with changing winds.

Some of the worst fires in the country have burned on Evia, the second largest island in Greece and a major hub for tourism. Much of the island has been in a state of high fire alert for a week. The Associated Press reported that an estimated 50,000 hectares (123,000 acres) have burned on Evia, as well as hundreds of homes.

Significant fires also broke out near Athens, Olympia, and Arcadia, and 63 organized evacuations have been reported across Greece in the past nine days. Firefighters and equipment have been sent from at least 15 countries to help Greek authorities.

As of August 11, EFFIS reported that more than 338,000 hectares (1,300 square miles) have already burned across Europe in 2021, more than the 2008-2020 average for an entire year (295,000). More than 109,000 hectares have burned so far in Italy, 2.5 times the annual average. Large fires have also been burning in Algeria and Turkey.

The heatwaves and fires fit with patterns described in the latest assessment report from the Intergovernmental Panel on Climate Change (IPCC), to which NASA-funded scientists contribute. In its summary of climate conditions in Europe, the IPCC noted: "The frequency and intensity of hot extremes...have increased in recent decades and are projected to keep increasing regardless of the greenhouse gas emissions scenario. Despite strong internal variability, observed trends in European mean and extreme temperatures cannot be explained without accounting for anthropogenic factors."

For more information on these images, visit https://landsat.visibleearth.nasa.gov/view.php?id=148682.

NASA Earth Observatory image by Lauren Dauphin, using VIIRS data from NASA EOSDIS LANCE, GIBS/Worldview, and the Suomi National Polar-orbiting Partnership. Story by Michael Carlowicz.

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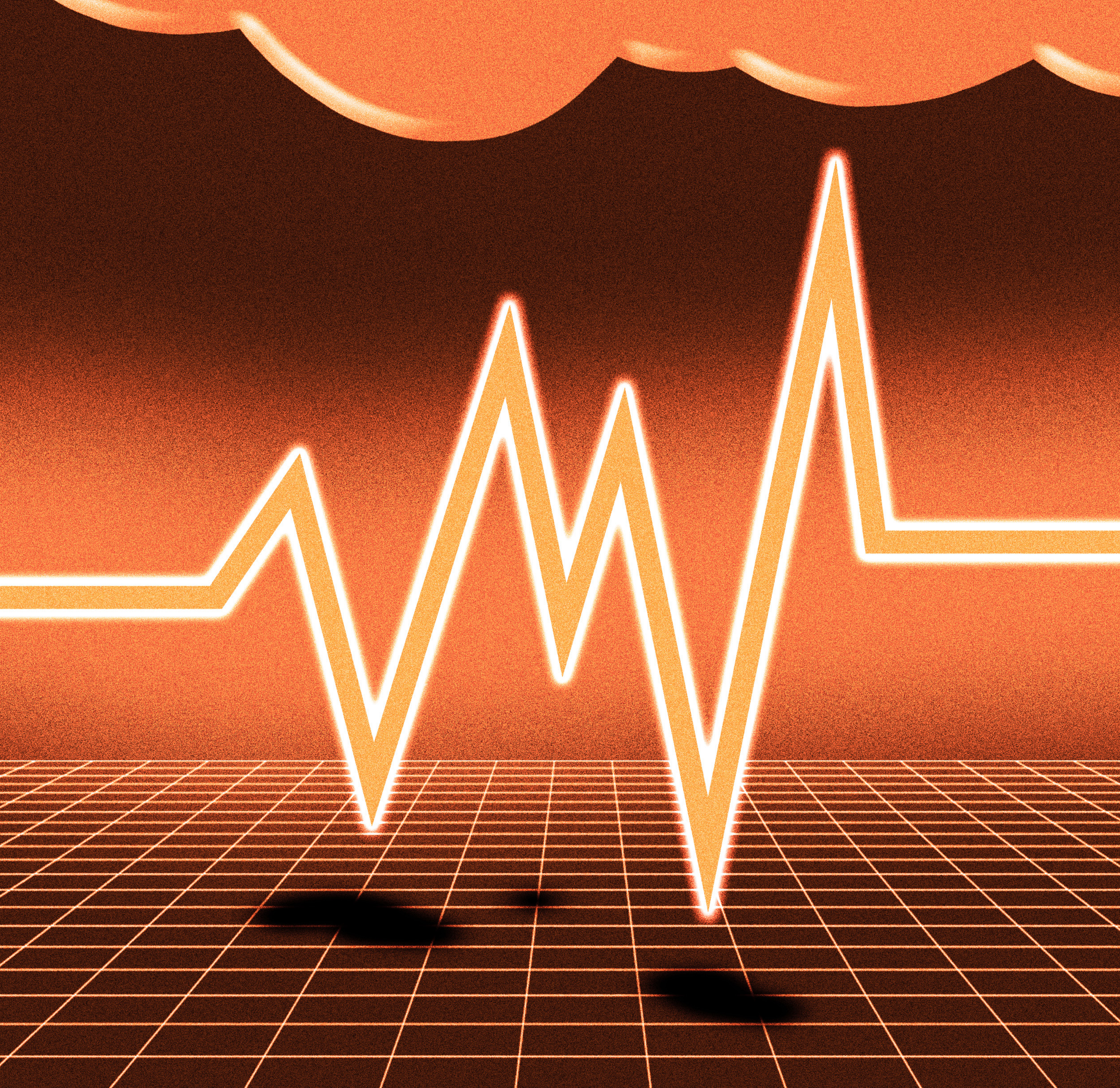
Top Geospatial Trends to Watch in 2022

By Qassim Abdullah, Ph.D., PLS, CP
Woolpert Vice President and Chief Scientist



As we celebrate the end of a challenging year and look ahead to what 2022 holds, many of us are thankful for the good health we maintained while many of our friends and family members were not as fortunate. The pandemic has imposed many daily challenges and created a sense of urgency that we had never witnessed before. This was driven by the need to rebuild our economies and regain some sense of normalcy and has inspired the need to bridge the vast digital divide between advanced geospatial professionals and those who require these solutions but are less technologically savvy.

Regardless of where people fall on that continuum, the need to work and communicate virtually has permeated all sectors of global society. "Zoom" became a common household term for all ages and abilities, while that platform and others like Microsoft Teams has provided vital corporate lifelines around the world. Curbside grocery pickup and virtual doctor visits also became the norm, while fitness centers have been replaced with remote Zumba classes and home gyms.

These digital demands presented great opportunities for the advancement of cloud-based data sharing and processing, which directly and indirectly resulted in improved 3D processing and modeling. Despite the pandemic changing how we conduct business, geospatial sensor manufacturers and technologies continued their upward trend, although more modestly than expected. In the following sections, I will revisit my predictions in geospatial trends made at this time last year, while looking ahead to what's expected in the industry this year.

Virtual Collaboration Rooms and Mixed Reality

Although developments in virtual and augmented reality started long before 2021, the lowered costs of data processing, computing power, algorithms, data compression and the cloud processing platform have advanced these technologies from video games to engineering and environmental solutions with direct societal benefits.

The release of Microsoft Mesh, a software platform for virtual collaboration, has taken VR and AR to a new level. Within Mesh, team members who are continents apart can engage via eye contact, facial expressions and gestures as 3D avatars in a shared space, collectively discussing and implementing modifications to a 3D replica of their project or design. Team members can participate in a Mesh session using Microsoft HoloLens 2, VR headsets, mobile phones, tablets or PCs via a Mesh-enabled app. HoloLens 2 is a self-contained holographic computer that enables hands-free and heads-up interaction with digital models via eye goggles.

These accessible platforms generate the need for 3D data while providing a new means of data modeling and interpretation. The geospatial industry reaps the technological fruits of these platforms when these applications involve 3D data modeling for engineering and environmental projects. Bentley, for example, has released its mixed reality platform, SYNCHRO XR. SYNCHRO XR is an app designed for visualizing 4D (3D data plus time) construction digital twins that also uses HoloLens 2.

A similar approach was introduced this year by NVIDIA with its NVIDIA Omniverse platform, which is described as "a scalable, multi-GPU, real-time reference development platform for 3D simulation and design collaboration, based on Pixar's Universal Scene Description and NVIDIA RTX technology." Omniverse enables a variety of client applications, renderers and microservices to share and modify representations of virtual worlds.

Deep into Miniaturized Sensors

Apple achieved a great milestone in 2020 with the introduction of a lidar sensor on its iPhone 12 Pro, and it continued that capability on the iPhone 13 Pro. As a result, we have witnessed more surveyors and field technicians using smartphone-based lidar. A technician who is repairing a faulty circuit in an underground manhole can use this easy lidar tool to document and create an above ground or underground 3D model. There were many articles published last year that summarized applications and data accuracy verification of lidar point cloud from iPhone 12 and iPhone 13, providing an expanding and accessible way for people to benefit from geospatial technologies.

Miniature lidar has been used on automated vehicles for a few years, and similar technology has been adopted for advanced home cleaning robots like the Samsung Jet Bot AI+ Robot Vacuum Cleaner. The cleaning robot is equipped with a lidar system and SLAM navigation hardware to scan and map rooms in a building, guided by geofencing to address defined cleaning needs. The manufacturers of these vacuums are not using the laser for range finding and obstacle avoidance; the laser is part of a true mapping system.

In addition to Samsung, Dreametech, Narwal and iRobot have followed a similar design and added lidar to their products. These developments should be welcomed by our industry as they illustrate how miniaturized lidar systems can be used, with slight modification, onboard mapping drones. These expanding applications will propel more advances in lidar manufacturing and will help bring down the cost of lidar systems.

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BIM and GIS, the Foundation for Digital Twin and Metaverse

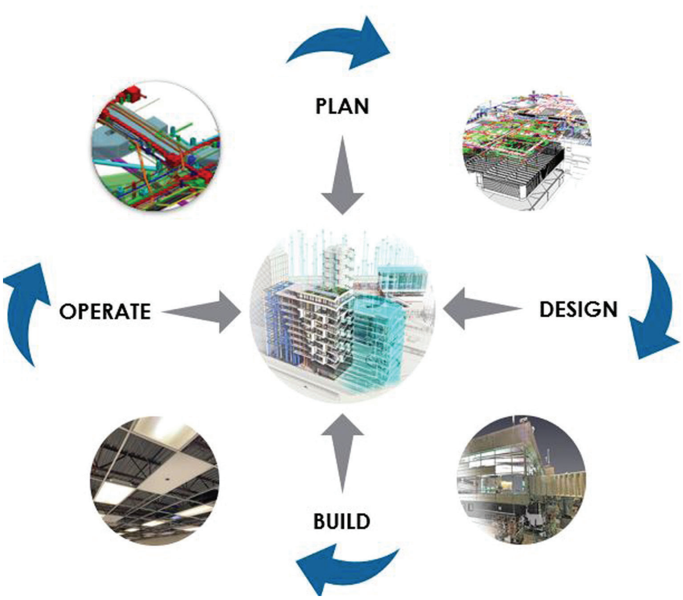
2021 brought a noticeable focus on the digital twin, with the industry learning more about its value to society. We also started hearing the term "metaverse," which is synonymous, or at least close, to digital twin. Often misunderstood and confused with a 3D model, a digital twin is much more complex. It encompasses multiple concepts—such as scan-to-BIM, 3D modeling and GIS—to produce the desired environment.

Over the course of the year, the industry has learned that a digital twin:

- Is a dynamic, up-to-date replica or representation of a physical object, an asset or system with a complete collection of data in one place
- Evolves with the flow of real-time input from sensors and other sources
- Is not a static 3D model or simulation; it continues to evolve with added data and information

This advancement is important because, without a full understanding of the digital twin and its value, the term would remain an abstract buzzword. The tri, digital twin, BIM and smart city concepts all share the overarching goal of managing data and information as a smart and interactive means of improving data accessibility for better decision-making and asset management.

The digital twin accelerates asset operational readiness as it transforms an asset's life cycle with the use of maintenance and performance data. The figure below illustrates the stages in an asset's life cycle when viewed through the digital twin lens. In that figure, design details do not end up as a static archive in someone's office but evolve into a living link to inform the asset owner or the operation manager to produce informed decisions.



When viewed through the lens of a digital twin, design details become living links to support more informed decision-making. Image courtesy of Woolpert.

Newly developed software platforms enabling virtual collaboration have taken virtual and augmented realities to new levels. Image courtesy of Getty Images

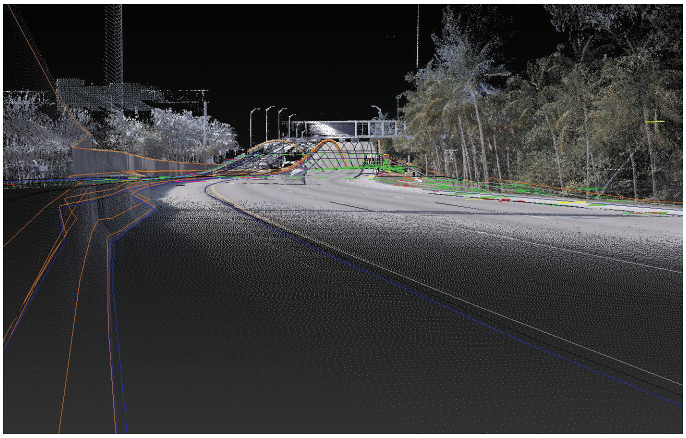
Experts believe that about 70% of the return on investment in an asset design ecosystem is realized through asset operation and management. Today's asset owner wants digital data at the outset, so project designs and models do not end up trapped in files (i.e., PDFs, spreadsheets, etc.); they live in dynamic objects that are easily accessed and managed. Without the digital twin approach, analog, unclassified and disconnected data present management challenges. This connection between the digital and physical worlds offers enhanced life cycles, informed decision-making and predictive capabilities.

Although our knowledge of these innovative concepts and their applications grew at a healthy pace in 2021, there still needs to be more outreach to educate clients and the industry about their collective benefits. Fortunately, a growing number of agencies and property owners understand the ROI and are willing to invest in building a digital twin for projects or assets. Architecture, engineering and geospatial (AEG) firms have a great opportunity to serve their clients by collecting, modeling, and managing data and building an integrated digital twin/BIM environment. This provides for better access to data and information to support efficient and effective asset management. The digital twin also opens huge opportunities for the geospatial community since it relies on services like scan-to-BIM, lidar scanning, GIS and other mapping services.

High-Definition Maps for Autonomous Driving

The concepts of smart cities and intelligent transportation systems continued to make progress in 2021. In particular, developments in autonomous driving made strides as an increasing number of car manufacturers worked toward putting their autonomous vehicles on the road in the next five to 10 years.

While connected and autonomous vehicles are equipped with a variety of sensors and artificial intelligence algorithms to help navigate the road, they also require high-quality maps to see beyond the vision of the onboard sensors and to assist during inclement weather. These maps are not like the navigation maps you see on a smartphone or a standard car navigation system; they are high-definition maps.



The geospatial industry has an immense opportunity to work with national and global transportation agencies to put forward a set of standards to govern the production of high-definition maps to support autonomous vehicles. Lidar and imagery data, as collected here in Florida in 2020, would support the accuracy of those maps. Image courtesy of the Florida Department of Transportation

High-definition maps provide the car control center, i.e. the brain, with extensive, precise information. This includes the lane number the car is in, freeway exit lanes, pedestrian crosswalks, bridges, overpasses, tunnels, locations of traffic control devices, smooth 3D trajectories for road edges and boundaries that are accurate to the centimeter level, meter-by-meter road grade and road superelevation, among other details.

Most self-driving vehicle manufacturers are planning to develop these maps for their vehicles. The exception is Tesla, which ascribes to autonomous navigation using sensors alone. Opponents of this sensors-only approach cite the following advantages to utilizing high-definition maps, saying they:

1. Have a longer range than sensors, with views for miles that wrap around corners and curves
2. Help the car drive smoothly around curves versus the jumpy updates of live sensors
3. Provide more accurate positions than sensors
4. Enable continual updates and improvements; sensors are static unless you get a new car
5. Can be used for car geofencing
6. Are not impacted by weather conditions like sensors
7. Can be used to check and verify the health of sensors, providing an extra layer of safety
8. Can correlate traffic lights to lane assignments

However, although these are proven benefits, high-definition maps for the global roads network do not yet exist for autonomous vehicles. Tremendous work and global cooperation are needed to remap the roads network to this level of detail. Some car manufacturers are attempting to build these maps themselves but are finding the job daunting. Additionally, these car manufacturers are producing maps according to their own specifications, which not only leads to a duplication of efforts but also creates an inherent and troubling lack of standardization.

The geospatial industry has an immense opportunity to work with national and global transportation agencies to put forward a set of standards to govern the production of high-definition maps to support autonomous vehicles. The industry can not only ensure the maps are created appropriately but can earn a substantial market share of the services and technologies needed to produce high-definition maps for a global roads network.

Drones, Drones Everywhere

While unmanned aircraft systems have been used for engineering and geospatial mapping applications for a few years, last year finally saw industry standardization. On the regulatory side, the Federal Aviation Administration issued positive modifications to Part 107 guidelines regarding flying restrictions over people and flying at night. This standardization has helped drones become integral to professional aerial data acquisition operations. Improved business practices and advancing technologies have helped drones prove that, when it comes to small projects, there are no other acquisition platforms that can compete with their capability and affordability.

The other strong dynamic that 2021 brought to drone operations was the increase in UAS-based lidar. This healthy growth was helped by the release of DJI lidar system, Zenmuse L1. Zenmuse L1 integrates a Livox Lidar module, a high-accuracy inertial measurement unit, and a camera with a 1-inch CMOS on a 3-axis stabilized gimbal. Zenmuse L1 is offered with DJI newest drone, the Matrice 300 RTK, and DJI Terra. DJI Terra is DJI's suite of software for mission planning, data capture, and data processing and analysis. The differentiator for the DJI lidar solution is the lower cost as compared with other market offerings, which attracted the attention of small businesses and solo operator companies.

It is worth mentioning here that while the Zenmuse L1 provides a reasonable solution for many applications, it will not be suitable for applications that require the highest accuracy. Zenmuse L1 is marketed with 5-centimeter vertical accuracy and 10cm horizontal accuracy (as RMS). While 5cm vertical accuracy is suitable for many applications, it will not meet standards for road design as required by departments of transportation. I expect this growing trend in collecting lidar data via drones will continue through 2022 and in the years to come.

From Coastal and Deep into the Sea

As I predicted last year, bathymetric survey and data collection made industry news in 2021. That is partly due to the direction the global economy is taking to support and protect the blue economy. Multiple aspects of our life—from fisheries, aquaculture, maritime transport, coastal and marine and maritime tourism to the emerging utilization of marine spaces to harness coastal wind energy—contribute to the evolving blue economy and require updated approaches and technologies.

Here in the United States, deep ocean survey and advanced techniques for coastal and deep ocean mapping are in high demand, propelled by two high-profile initiatives of the National Oceanic and Atmospheric Administration (NOAA): National Strategy for Ocean Mapping, Exploring and Characterizing of the United States Exclusive Economic Zone (also known as the NOMEC Strategy) and Alaska Coastal Mapping.

On the coastal and inland water mapping front, mainstream lidar manufacturers continued to make innovations and enhancements for topographic and bathymetric systems. Recently we witnessed some creative developments in bathymetric lidar initiated by industry members outside traditional manufacturers. An example of this was the recent introduction of the first high-altitude topo-bathy lidar system, based on Geiger-mode technology. The Bathymetric Unmanned Littoral LiDar for Operational GEOINT (BULLDOG) system was developed by the Woolpert Maritime Research Lab for the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX).

Additionally, deep ocean hydrographic surveys witnessed good progress in the field of uncrewed deep water mapping technologies. Companies like SailDrones and other manufacturers are expected to continue to innovate to meet demand.

Whirl Around the Coastal Regions

Speaking of coastal wind energy, with the current U.S. administration backing renewable resources, that industry is expected to flourish in the coming years. Last year, the nation's first large-scale offshore wind farm was approved about 12 nautical miles off the coast of Martha's Vineyard, Mass. More projects are either already approved or in their final stages of approval. This development found a soft-landing spot within the geospatial industry since the planning, design and construction of wind farms requires geospatial and surveying services, including bathymetric lidar survey.

Data Democratization: Big Data Needs Big Tools

In my opinion, the field of data democratization grew sluggishly in 2021 as businesses struggled to survive a challenging year. We did not see clear signs from the mainstream geospatial industry on the growth of creative methods and tools needed to mine, extract and convert geospatial data into knowledge, and therefore we are still limited in our development of tools that can gather information from lidar point clouds and imagery using automated methods. Despite that, the industry continued its interest in data mining and machine learning as it relates to application development.

Outside the geospatial industry, crowdsourcing, big data and data science continued to grow. This was largely fueled by a hot market for tech companies selling location-based and social tracing data to the highest bidder, whether for business purposes, marketing or otherwise. The diverse sectors utilizing these location-based technologies—including planning, construction, utilities, transportation, government, and energy—will continue their growth and potential applications in 2022 and the years to come.

The planning, design and construction of wind farms requires geospatial and surveying services, including bathymetric lidar survey. With the current U.S. administration backing renewable resources, that industry is expected to flourish in the coming years. Image courtesy of Getty Images

AI and Deep Learning are Living in the Cloud

In my previous articles on annual geospatial trends, I acknowledged that progress was made by agencies moving computing powers to the cloud. More companies are offering business models for cloud data hosting and processing. However, Amazon, Google and Microsoft continue to lead that market and offer users and developers sophisticated platforms like serverless cloud computing.

As I mentioned before, these platforms enable developers to run apps and services without having to manage and operate costly and complicated server infrastructure. One interesting development is the increased use and attention to the Microsoft platform Azure. Azure is a cloud platform that contains more than 200 products and cloud services designed to enable businesses to build, run and manage applications across multiple clouds, on-premises and at the edge, with the tools and frameworks of their choice.

One very positive characteristic of Azure is that it is not limited to Microsoft software and applications. It supports off-the-shelf and open-source technologies, so a user can employ the tools and technologies that suit their needs. Azure supports the virtual work environment, enabling businesses to run any centrally hosted applications using their data source and operating system and device. Because it is virtual, the Azure environment eliminates the need to set up a workstation with company applications and software for every employee individually.

As for geospatial application-based AI within the industry, on the commercial software level, Esri continues to push the envelope to help users streamline workflows with AI tools within ArcGIS. For example, in 2021, Esri added three ready-to-use geospatial AI models in the ArcGIS Living Atlas of the World. The first two models, which use satellite imagery, extract building footprints and perform land-cover classification. The third model classifies point clouds. The interesting thing about these models and algorithms, besides their ability to deal with huge amounts of data, is that they are self-trained and require no additional data training by the user.

On the AI-based services side, only modest activities were observed this year. Companies like Airwork offered a cloud-based solution for extracting information from imagery and lidar point clouds. Although this Airwork offering has been welcomed by the surveying and mapping industry, massive work still needs to be done with AI, machine learning and deep learning to marry automation with GIS and geospatial applications to support mining the tremendous amount of data today's sensors acquire. In my opinion, without federal and public funding to entice creativity in this field, GIS and the geospatial applications will see slow adaptations of AI, ML and DL capabilities.

Lidar for Everyone

During 2021, lidar use and technologies continued to advance. But, aside from the bathymetric development noted earlier, there was not the big breakthrough from a major lidar system manufacturer I had hoped for this year in the development of AI-based applications. This development would help system users derive information from the massive and growing number of point clouds with minimal manual processing. However, this lack of investment may have been a casualty of the pandemic and its impact on the economy.

The miniature lidar system was the segment that advanced the most in 2021, driven by car manufacturers, gadget manufacturers like smartphones and drone use. Most upscale models of cars are now equipped with lidar sensors, which are important for autonomous vehicles. This is leading car manufacturers to invest heavily in miniaturized lidar by acquiring manufacturing companies that produce small lidar or indirectly supporting its development.

Our industry reaps the benefits from this investment, as Velodyne is one of the biggest providers of miniature lidar for the automobile companies. Velodyne revealed during Auto Guangzhou 2021, held in China in November, that its latest innovations support advanced driver assistance systems (ADAS), autonomous vehicles, robotics, smart city infrastructure, delivery, industrial applications and more. Fortunately, Velodyne has not yet been acquired by a car manufacturer and still offers affordable lidar systems for our drones.

Shadow of the Pandemic

This is my fifth annual trends article, which began as a blog on the Woolpert website in 2018. In the last couple of years, the pandemic has adversely affected many segments of our industry while providing some relief to others. This has made it more difficult to accurately predict where our industry and technology are heading. However, one thing has become even clearer during this difficult time: Our success as an industry requires the collaboration of multiple tiers of government, the private sector, public utilities, community activists, building owners, average citizens, etc., to truly advance.

We will get through this, and we will be stronger for it individually and together. Happy New Year!

Woolpert Vice President and Chief Scientist Qassim Abdullah, Ph.D., PLS, CP, has more than 40 years of combined industrial, R&D and academic experience in analytical photogrammetry, digital remote sensing, and civil and surveying engineering. When he's not presenting at geospatial conferences around the world, Qassim teaches photogrammetry and remote sensing courses at the University of Maryland and Penn State, authors a monthly column for the ASPRS journal PE&RS, *and mentors R&D activities within Woolpert.*

This article is running in both PE&RS, Lidar Magazine, *and the* Geo Week Newsletter.

GIS

Tips & Tricks

Al Karlin, Ph.D. CMS-L, GISP

Sometimes You Need to Turn the World Upside-Down

As a frequent user of lidar- and IfSAR-derived digital elevation models (DEMs), on multiple GIS software platforms, I have come to standardize the "look and feel" of the rendering of these datasets on each platform. Because I am usually looking at DEMs to help me understand terrain characteristics and where to find water, I typically make lower elevations blue and higher elevations browns and/or reds. While each GIS platform offers several pre-designed color ramps, often none are quite to my liking. So. here are a few tips and tricks that I use to "standardize" between platforms.

My workflow includes, using the DEM to make a hillshaded-surface, usually with a 5X exaggeration, then making the DEM transparent, usually between 35 – 45 %, and finally choosing a color ramp and invert it to make the blue colors represent the lower elevations. Here's how:

In GQIS Desktop

After you load a DEM into the Layers, in the Processing Toolbox open the "Raster terrain analysis" tools and double-click on "Hillshade" to open the dialog as below. You can customize the Azimuth and Vertical angle, but I use the defaults here, and only modify the Z factor (set it to 5) to produce a 5X vertical exaggeration.

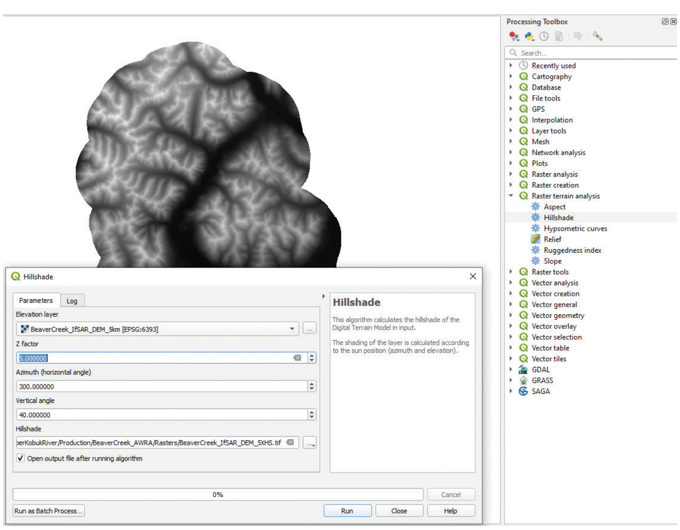


Figure 1. QGIS dialog for constructing a Hillshaded Surface raster.

When complete, move the hillshaded-surface below the DEM in the Layers.

Next, double-click on the DEM in the Layers window to start the Layer Properties dialog box and use the Transparency tab to set the "Global Opacity" to 35%. You can do this by either moving the slider, clicking the up/down arrows, or typing 35 into the window.

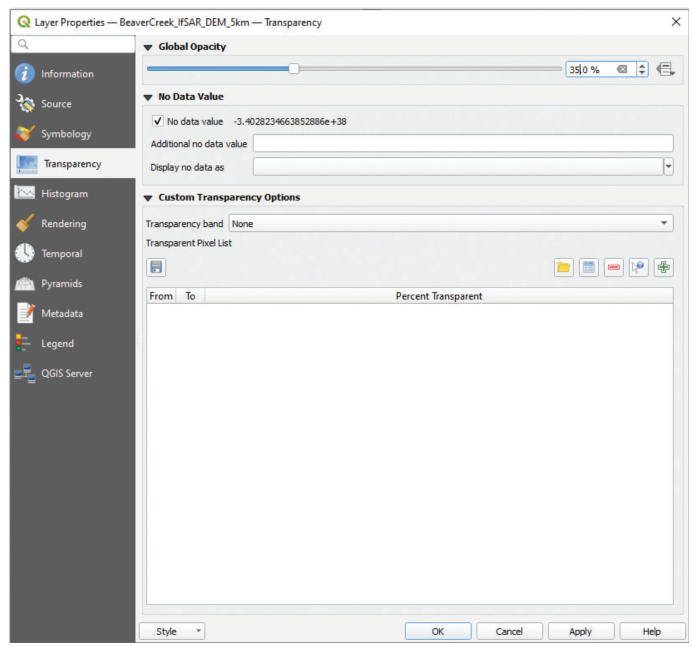


Figure 2. Use the Transparency Tab on the Layer Properties to set the Global Opacity.

Finally, before your hit <Apply> and <OK> of the bottom of the Layer Properties, use the Symbology tab to set the Render type to "Singleband pseudocolor", select the color ramp, "Spectral" from the dropdown choices, (and here comes the trick)… right-click on the Color rap and choose "Invert Color Ramp". At this point, you can change the Mode to "Equal Interval" and specify 10 (or some number of) Classes (I generally choose 10 Classes):

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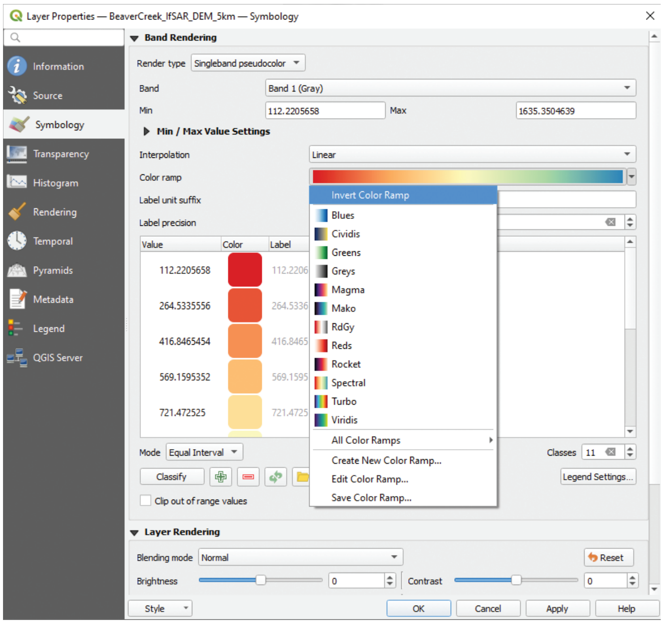

Figure 3. Band Rendering settings on the Layer Properties dialog box.

Finish by pressing <Apply> and <OK> to get the final Band Rendering.

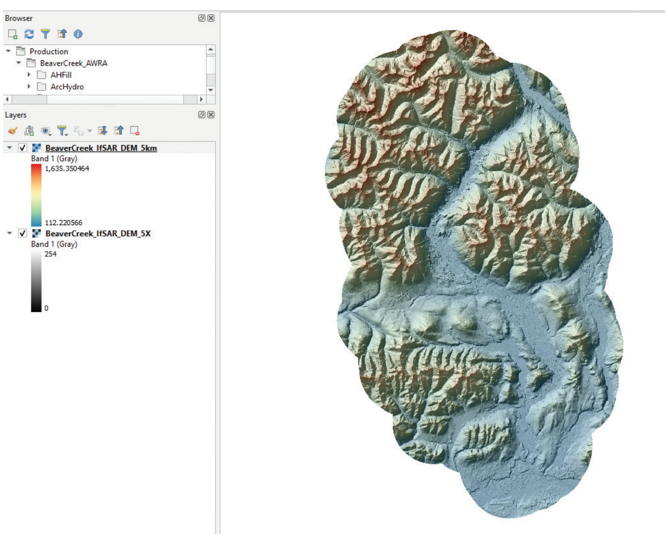

Figure 4. DEM with hillshaded-rendering in QGIS.

For ArcGIS Desktop

After you load the DEM into the Table of Contents, open ArcToolbox and use the Spatial Analyst Tools | Surface | Hillshade tool to construct the Hillshaded surface. In this dialog, use the Z factor (optional) parameter to specify the 5X exaggeration as seen in Figure 5.

Again, move the hillshaded-surface below the DEM in the Table of Contents, and double-click on the DEM layer to open the Layer Properties dialog. On the Display Tab, enter 45 (%) for the Transparency and on the Symbology Tab, choose the Red to Blue color ramp (and here comes the trick again…), check the Invert Box as in Figure 6.

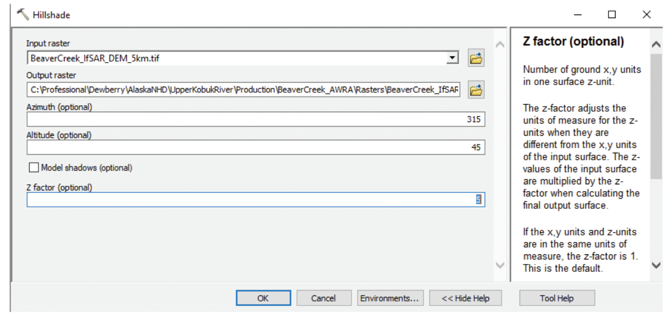

Figure 5. ArcGIS Desktop Spatial Analyst | Hillshade dialog box showing 5X vertical exaggeration.

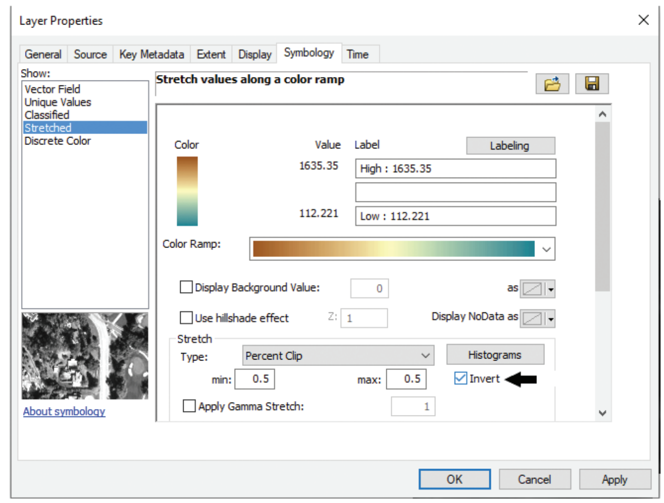

Figure 6. The Layer Properties | Symbology Tab showing the Invert (color ramp) check box.

Pressing <Apply> and <OK> produces the same visualization as in QGIS.

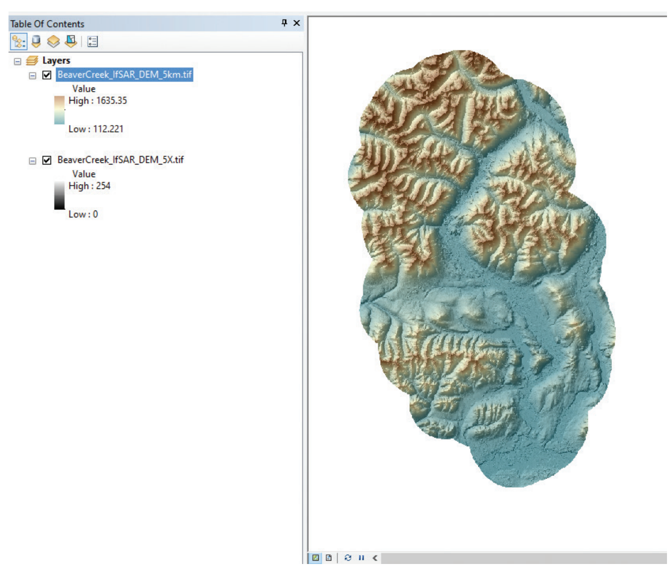

Figure 7. DEM with hillshaded-rendering in ArcGIS Desktop.

For ArcGIS Pro

A nearly identical workflow can be used in ArcGIS Pro using the Spatial Analyst Toolbox to construct the 5X exaggerated hillshade-surface. As before, move the hillshaded-surface to under the DEM in the Contents. Click on the DEM surface and use the Raster Layer | Appearance and choose the "Symbology" tab to start the Symbology dialog. In the Symbology Dialog, select the Red to blue color scheme, and check the Invert box. This will result in the same hillshaded-rendering as in ArcGIS Desktop and QGIS.

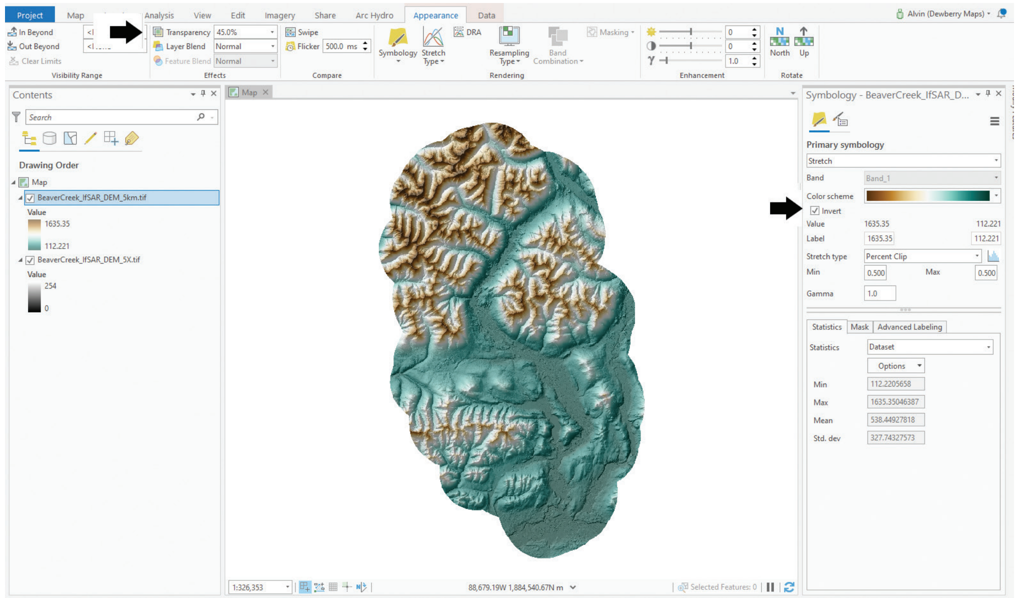

Figure 8. DEM with hillshaded-rendering in ArcGIS Pro.

And that's all there is to inverting the color ramp in these GIS packages.

Send your questions, comments, and tips to GISTT@ASPRS.org.

Al Karlin, Ph.D., CMS-L, GISP is with Dewberry's Geospatial and Technology Services group in Tampa, FL. As a senior geospatial scientist, Al works with all aspects of Lidar, remote sensing, photogrammetry, and GIS-related projects.

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Grids & Datums

Republic of Botswana

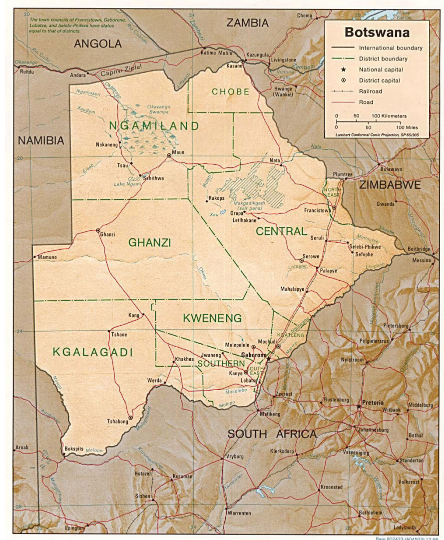
By Clifford J. Mugnier, CP, CMS, FASPRS

The Grids & Datums column has completed an exploration of every country on the Earth. For those who did not get to enjoy this world tour the first time, *PE&RS* is reprinting prior articles from the column. This month's article on the Republic of Botswana was originally printed in 2004 but contains updates to their coordinate system since then.

The Boskop People inhabited southern Africa for thousands of years during the Middle Stone Age, and their descendants include the present-day San (Bushmen) People of Botswana. Most of the present population (95%) is known as the "Batswana." The region was occupied by the British at the instigation of the colonial administrator, Sir Cecil Rhodes in 1884. It was organized as a British Protectorate the following year, and was divided into the British Bechuanaland and the Bechuanaland Protectorate. Botswana gained independence in 1966 and is a member of the British Commonwealth. The discovery of diamonds and copper has allowed Botswana to become one of the most economically stable countries in Africa.

The Republic is landlocked and is slightly smaller than the State of Texas: bordered by Namibia (1,360 sq. km), by South Africa (1,840 sq. km), and by Zimbabwe (813 sq. km) (*PE&RS*, November 2003). The terrain of Botswana is predominately flat to gently rolling tableland with the Kalahari Desert in the southwest. The lowest point is the confluence of the Limpopo and Shashe Rivers (Elevation: 513 m), and the highest point is Tsodilo Hill (Elevation: 1,489 m).

In *GIM International,* September 1994, B.B.H. Morebodi, director of Surveys and Lands reported: "The history of cadastre in Botswana can be traced back to 1890 when the Foreign Jurisdiction Act in Great Britain established and regulated the power of Queen Victoria's Government in the then territory of British Bechuanaland." Subsequently, various acts defined the boundaries of the Crown Lands in Botswana, the territories occupied by tribes and land vested in the British South Africa Company. The earliest registration of deeds was put into effect at Vryburg in South Africa, but was moved to Mafeking in 1908 following the establishment of the Office of Registrar of Deeds for the Bechuanaland Protectorate in 1907. From 1908 to independence in 1966, the Registrar of Deeds Office remained in Mafeking.



Throughout its history, the cadastre has been numerical. Surveying was under the control of the Surveyor General in Cape Town until the 1959 Land Survey Act established the Office of Director of Surveys and Lands in Botswana. In 1960, an act was passed establishing the Office of Registrar of Deeds to regulate the transfer of land in Botswana. The Department of Surveys and Lands was physically moved from Mafeking to Gaborone in 1969.

There is no cadastral mapping in Botswana as such. The registration of title to property is affected by a system of registration of deeds. To be capable of registration, a deed must be supported by a survey diagram (deed plan) approved by the Director of Surveys. Data from numerical cadastral surveys is compiled into a number of plans called "Compilations" which are regularly updated to show the current land parcel situation. This is not however equivalent to a registry index map.

The Department of Surveys and Mapping exercises statutory control over all surveying for cadastral purposes and

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national mapping but not over surveying for engineering purposes. Surveys for the cadastre re-effected in two ways:

a. New township surveys in which a large number of new stands are surveyed simultaneously. This is generally done by the Department but sometimes registered surveyors are given this work on contract.
b. Surveys of single plots and mutations. In this case, most of the work is done by private surveyors.

The Land Survey Act of 1959 provides that all data generated for cadastral purposes whether by government surveyors or private surveyors must be subjected to an examination approval process by the Department. Only approved diagram and general plans are accepted by the Registrar of Deeds for registration."

The Mapping Division is responsible for the National Mapping Program, and tasks are carried out in-house as well as through contract services. The Division provides topographic maps at small, medium, and large scales in hardcopy and digital formats. The first maps by the British Directorate of Colonial Surveys were published in 1955 at a scale of 1:125,000. By the time the series was discontinued in 1966, a total of 104 sheets had been printed in two colors with black for detail and blue for hydrographic features. Contours were not compiled, but formlines were used to depict prominent features . The British Directorate of Overseas Surveys published the first map series at a scale of 1:50,000 in 1967. This edition was conventional line and symbol topographic maps with a contour interval of 50 feet, covered the more densely populated eastern portion of the Country, and were printed in five colors. These map sheets are referenced to the Gauss-Krüger Transverse Mercator projection. The astronomic coordinates of the initial point of the Cape Datum near Port Elizabeth are for Buffelsfontein where $\Phi_o = 33^o\ 59'\ 32.000''$ S and $\Lambda_o = 25^o\ 30'\ 44.622''$ E. In 1944, D.R. Hendrikz of the South African Trigonometrical Survey wrote, "For the computation of the geographical coordinates of the stations of the Geodetic Survey, Sir David Gill adopted the numerical values of the semi-major and semi-minor axes of Clarke's 1880 figure or a = 20,926,202 ft and b = 20,854,895 ft. At that time this result was the most recent determination of the figure of the Earth. But, because the baselines were reduced to S.A.G. (*South African Geodetic* – ed.) feet, the computations were really carried out on a 'Modified Clarke 1880 Spheroid' defined by a = 6,378,249.145 326 int metre and b = 6,356,514.966 721 int metre. It may be remarked that this value of the flattening for this spheroid is $^1/_f$ = 293.466 307 656 which differs slightly from the value 293.465 given by Clarke himself." There are five belts for the Botswana Transverse Mercator Projection where the Central Meridians are: 21ºE, 23ºE, 25ºE, 27ºE, and 29ºE. The scale factor is unity, and there appears to be no False Easting or False Northing for any of these belts.

In April 1990, Professor Merry and J. Rens of the University of Cape Town published a paper in Survey Review that described their solution for datum shift parameters in southern Africa that included Botswana. Although they achieved a seven-parameter solution for nine points in Botswana, they found that a combined solution of 28 points for Botswana, Lesotho, the eastern half of South Africa, and Swaziland yielded a simpler solution. They recommended three trans-formation parameters for the region that includes the Republic of Botswana from the Cape Datum to the WGS 84 Datum is $\Delta X = -136.0$ m ±0.4 m, $\Delta Y = -105.5$ m ±0.4 m, $\Delta Z = -291.1$ m ±0.4 m. The Hartebeesthoek 94 Datum is now the official coordinate system of the Republic of South Africa and presumably, may someday become official for the Republic of Botswana.

Botswana Update

In regards to the Botswana National Geodetic Reference System 2002 (BNGRF 2002), "A new Geodetic Reference System WGS584 was established in 2002 as a necessary step to ensure not only that the cadastral survey, and mapping were based on it, but also that for Global and regional environment and other purposes, seamless topographic and cadastral mapping could be attained. The Geodetic System whilst established on already monumented old Trigonometrical stations was carried out systematically across the country to allow for a strong network that would allow minimal deviations and progressive densification. Suffice it to say that whilst the cadastral survey is still being compiled in both WGS84 and the old datum system, the conversion to WGS84 has been fully provided for. An integrated system will thus ensure dexterity in information enhancement through over laying of variable data sets, especially as the high accuracy of the system, gained through the use of GPS and modern sophisticated software, far surpasses that of the past. The Land Survey Act requires that each parcel of land for cadastral survey in both urban and rural areas be tied to the Geodetic Network. The resultant erection of reference marks and Geodetic Stations in and around all settlements and other areas across the country, has also acted in favour of increased surveying for registration of title especially in rural areas" (*Botswana – Department of Surveys and Mapping (DSM) Cadastral Information System*, Bryson B. H. Morebodi, Promoting Land Administration and Good Governance 5th FIG Regional Conference Accra, Ghana, March 8-11, 2006).

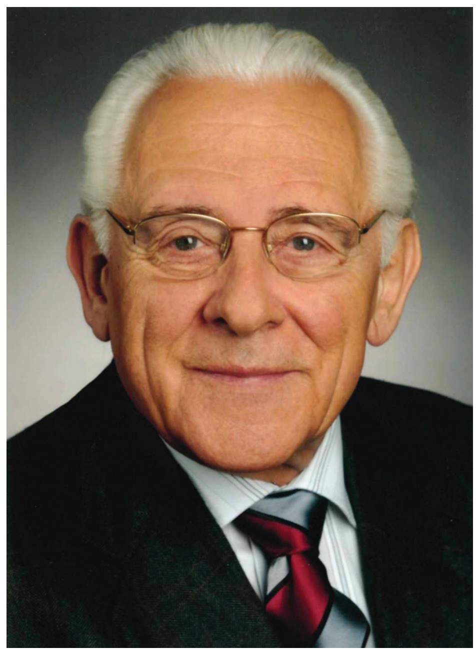
In Memoriam

Friedrich Ackermann

1929-2021

ASPRS mourns the loss of Friedrich (Fritz) Ackermann who passed away at the age of 92 on December 4, 2021. Professor Ackermann was an Honorary Member of ASPRS and known as the “Father of Modern Photogrammetry” for his research in analytical and digital photogrammetry.

We mourn the loss of our dear colleague and institute founder Friedrich (Fritz) Ackermann, who passed away on December 4, 2021. He founded the Institute for Photogrammetry with his appointment to the University of Stuttgart on April 1, 1966, and was its director until March 31, 1992. With his research and development work in the field of analytical and digital photogrammetry, he significantly influenced the developments and progress in these two fields and helped the Institute of Photogrammetry to achieve a worldwide reputation. For many younger photogrammetrists he was always a role model and stood for the close connection between basic research and application. With the software developments he initiated with his spin-off inpho GmbH, Stuttgart (today Trimble), he was able to drive very successful technology transfer from research to practice.



Friedrich (Fritz) Ackermann, Professor Emeritus of Photogrammetry and Surveying and Former Director of the Institute for Photogrammetry at the University of Stuttgart

Fritz Ackermann was born on November 1, 1929 in Moosbeuren (Ehingen) on the Danube. As a result of the Second World War, his school education, like that of many of his generation, was not entirely easy. He attended the elementary schools in Moosbeuren and Ehingen (1936-1940) and then the grammar school in Ehingen, where he graduated in 1949. Few knew of his inclination towards physics - he enrolled in the same year at the University of Tübingen to study physics. A year later, he began studying surveying at the Technical University of Stuttgart - a stroke of luck for photogrammetry. He finished his studies in 1954 and decided to get his first taste of practical experience as a young graduate engineer. For this purpose, he joined Zeiss-Aerotopograph, Munich, and was able to help developing film-based aerial photogrammetry and photogrammetric evaluation equipment in analog photogrammetry. After almost four years of practical experience, he decided to enter international photogrammetry research and development and in 1958 applied to the International Training Center for Earth Sciences (ITC), which at the time was located in Delft (now Enschede and part of the University of Twente).

Here he also completed a master’s degree in photogrammetry and got to know other recognized companions of photogrammetric research such as H.G. Jerie and C.M.A. Van den Hout, who at this time had already entered the field of analytical photogrammetry. The analytical formulation of the bundle block adjustment had just been worked out by D.C. Brown and published by H.H. Schmid, who used it to perform the first world-wide photogrammetric triangulation for geometric determination of the Earth's figure at the National Oceanic and Aeronatics Administration (NOAA) Institute. The analytical block adjustment also fascinated the young researcher Fritz Ackermann, who was able to write a doctoral thesis at the ITC on "Error-Theoretical Investigations on the Accuracy of Photogrammetric Strip Triangulations" (DGK Series C, Issue No. 87) and defended it at the University of Stuttgart in 1964 - supervisor was Prof. E. Gotthardt. For this dissertation he was awarded the Otto-von-Gruber Award of the International Society for Photogrammetry (ISP). When Prof. E. Gotthardt was appointed to the Technical University of Munich in 1965, his professorship in Stuttgart was vacant and Fritz Ackermann was able to demand the foundation of a new Institute for Photogrammetry in his appointment negotiations - he took over its direction on April 1, 1966.

In research and development Fritz Ackermann has set standards worldwide. In analytical photogrammetry, the block adjustments according to the method of independent models (software PAT-M) and the ray bundle (software PAT-B) are associated with his name. It was he who published the method of image correlation by the method of least squares and transferred it into application (later software MATCH-T). In the late 1980s, he worked to integrate GPS into photogrammetry, thus introducing GPS-based aerotriangulation to measure directly projection centers by DGNSS - now a matter of course. With the advent of airborne laser profiling, high-accuracy laser profiles were successfully acquired and analyzed. In the early 1990s, he worked on digital aerotriangulation and transformed it into a fully automated workflow (software MATCH-AT). In total, 26 PhD students and 3 post-doctoral students were supervised by him, who went on to successful careers in administration, universities and colleges, and industry. No wonder that he was often called the "father of modern photogrammetry". In addition to research and development, technology transfer was always important to him: from 1973 to 1991, he organized the Photogrammetric Week symposia at the University of Stuttgart every two years, in cooperation with Carl Zeiss, Oberkochen.

With so many successes, honors were not lacking. In 1988, for example, the Helsinki University of Technology honored him with an honorary doctorate Dr. tek. h.c., and four years later the Vienna University of Technology awarded him the dignity of Dr. tech. E.h. The University of Wuhan awarded him an honorary professorship Prof. h.c. in 1989 - a distinction comparable to the honorary doctorates here. At the University of Hanover, he was awarded the Dr.-Ing. E.h. degree in 1995, and in 2009 he received the Dr.-Ing. E.h. award from the Moscow State University of Geodesy and Cartography (MIIGAiK). Furthermore, he was an honorary member not only of the German Society for Photogrammetry and Remote Sensing and the ISPRS, but also in the corresponding professional societies in the USA and Great Britain.

With Fritz Ackermann we and the Institute for Photogrammetry at the University of Stuttgart lose an extremely successful scientist, academic teacher and a kind, friendly and humble colleague. He was always humorous in his dealings and, in addition to photogrammetry, especially loved music, including playing the piano. We fondly remember the 50th anniversary celebration of the Institute of Photogrammetry in April 2016, which he introduced with a piano sonata - at the age of more than 86. Besides his fondness for music, mountain hiking and skiing were important to him; he was almost 80 years old when he climbed Kilimanjaro. Until the end he tried to keep up professionally. At the photogrammetric weeks he was an honorary participant until the end. We will miss him very much and cherish his memory.

~ Dieter Fritsch and Uwe Soergel
Institute for Photogrammetry of the University of Stuttgart

ASPRS REGIONAL ELECTION RESULTS

Thank you all for participating in ASPRS Regional Elections. The results are in and we would like to announce the results of the elections.

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Call for *PE&RS* Special Issue Submissions

Monitoring Earth Hazard with Remote Sensing Techniques

Natural and human disasters are increasingly affecting global communities worldwide in recent decades. With the increasing human population and urbanization, the earth is inevitably more susceptible to manmade hazards. Global warming and its associated environmental instability increase the frequency and severity of the disaster. Rapid Climate change is linked with meteorological events with a high degree of risk probability causing flood disasters. Implementation of proper hazard management such as disaster prevention, disaster preparedness, and adequate disaster relief would reduce the impact of natural disasters. Usage of the convectional earth observation model helps hazard management with a reliable solution but cannot provide early prediction of disaster occurrence, saving people's lives. However, using remote sensing techniques would enable warning systems by building futuristic codes that predict the hazards and warn people on time with greater accuracy. Remote sensing imagery provides a quick method for assessing the variation of hazard impacts, coastal inundation, erosion, and majority affected flood plains using intelligent, visionary technology. The data gathered from sensors provide valuable insights about the spatial phenomena that aid scientists in making accurate decisions about the forecast patterns. Above all satellites, remote sensing is used to detect global environmental problems, explore resources, and monitor disasters by capturing the earth's surface during altered weather conditions. This helps in the early detection of disaster patterns with futuristic mitigation procedures.

The sensors technology captures images of fires, flooding, and volcanic eruption can create a visual impact during the response phase that aids in readiness actions when people are viable to disaster risk. Earth observation systems and GIS helps professionals to make effective project planning with a more accurate analysis. The utilization of various spectral bands such as Visible, infrared, thermal infrared, and synthetic aperture radar provides adequate coverage of environmental patterns and allows technology enhancement to analyze data. Meteorological satellites use High-resolution transmission sensors for cyclone monitoring, intensity assessment, and storm surges. Geo-stationary satellites use global coverage sensors for flood and drought management by collections of multi-date imaginary data for rainfall and river stages. Using its unique spectral signature, it identifies the water standing areas, the sand casting of agricultural lands, and marooned villages to enable hazard recovery plans. SAR sensing system is used to detect forest fires and forest monitoring using microwave techniques to acquire sensory images. There are some challenges about using sensors for hazard prediction where research prospects are needed. As smart sensors use advanced technologies and complex data for prediction, data breaches would lead to misinterpretation of results, increasing the risk to human lives. An adequate skilled workforce is required to analyze the collected sensor data. In the future, integrating IoT and artificial intelligence would create autonomous drones that aid in inspecting the geographical patterns in multi-dimensional views to accelerate high definitions imagery for efficient prediction of results. This special issue enumerates the role of remote sensors for earth hazard predictions and future advancements. We welcome scholars and practitioners of this platform to emphasize this topic and present submissions that fall within the scope of remote sensing techniques for the accurate prediction of environmental hazards.

The topics of interest include:

- Role of Artificial intelligence in generating patterns in sensor data
- Disaster management cycle and it's important in hazard mitigation
- Advantages of geometrics in disaster risk management
- Usage and applications o GIS in flood forecasting
- Advanced Earth observation system tools for project planning
- RadarSat and use cases in detecting oil seeps
- Big data and its uses for accurate data collection in sensors
- Role of climate change in creating environmental risk
- Advancement in satellite sensors for earth's behavioral prediction
- Role of autonomous drones in capturing multispectral images

Deadline for Manuscript Submission
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Guest Editors

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Spatiotemporal Temperature Fusion Based on a Deep Convolutional Network

Xuehan Wang, Zhenfeng Shao, Xiao Huang, and Deren Li

Abstract
High-spatiotemporal-resolution land surface temperature (LST) images are essential in various fields of study. However, due to technical constraints, sensing systems have difficulty in providing LSTs with both high spatial and high temporal resolution. In this study, we propose a multi-scale spatiotemporal temperature-image fusion network (MSTTIFN) to generate high-spatial-resolution LST products. The MSTTIFN builds nonlinear mappings between the input Moderate Resolution Imaging Spectroradiometer (MODIS) LSTs and the output Landsat LSTs at the target date with two pairs of references and therefore enhances the resolution of time-series LSTs. We conduct experiments on the actual Landsat and MODIS data in two study areas (Beijing and Shandong) and compare our proposed MSTTIFN with four competing methods: the Spatial and Temporal Adaptive Reflectance Fusion Model, the Flexible Spatiotemporal Data Fusion Model, a two-stream convolutional neural network (StfNet), and a deep learning-based spatiotemporal temperature-fusion network. Results reveal that the MSTTIFN achieves the best and most stable performance.

Introduction
Land surface temperature (LST), a key parameter for the exchange of energy, water, and carbon between the land surface and the atmosphere (Sellers *et al.* 1997; Kustas and Anderson 2009; Xu *et al.* 2011), is of considerable importance to various fields of study, including the surface energy balance (Anderson *et al.* 2011; Chen *et al.* 2014), surface moisture and evapotranspiration (Gillies *et al.* 1997; Carlson 2007; Natsagdorj *et al.* 2017), global climate change (Hage 2003), vegetation dynamics (Zhao *et al.* 2016), drought monitoring (Gillies and Carlson 1995; Li *et al.* 2015), fire monitoring (Lentile *et al.* 2006), and the urban thermal environment (Anderson *et al.* 2008; Imhoff *et al.* 2010; Phelan *et al.* 2015). At present, urban heat islands are widely acknowledged to be one of the prominent factors that affect urban climate, quality of life, and ecological diversity (Zeng *et al.* 2010; Yang *et al.* 2020). A better understanding of LST and its spatiotemporal variations benefits the investigation of the developing trend of urban heat islands and provides theoretical guidance for alleviating the heat-island effect, thus promoting the healthy development of cities (Deilami *et al.* 2018; Zhou *et al.* 2019). Thermal infrared images from satellites are a widely adopted LST data source. The progress of satellite observation technology makes it possible to monitor urban thermal environments at various spatiotemporal scales. However, there is a trade-off between the temporal and spatial resolutions of satellite remote sensing images, and the spatial resolution and scanning bandwidth need to be balanced in designing sensors (Gao *et al.* 2006; Xia *et al.* 2019; Shao *et al.* 2021). The limited spatial or temporal resolution of thermal infrared images has largely limited the applicable potential of LST products in urban environments. To address this challenge, scholars started to explore the possibility of fusing multi-temporal and multi-source satellite sensor data.

The spatiotemporal fusion method was initially designed to fuse shortwave reflectance images. It aims to fuse the spatial features of high-spatial-resolution images with the temporal features of low-spatial-resolution images, aiming to generate reflectance images with a high spatiotemporal resolution. Existing spatiotemporal fusion models can be divided into three categories: weighted function-based models, unmixing-based models, and learning-based models. Weighted function-based models assign reflectance changes of similar pixels to the center pixel and generate the prediction image at the target time by considering the spectrum, time, and distance weights. Popular models in this category include the Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM; Gao *et al.* 2006), the Enhanced STARFM (Zhu *et al.* 2010), and the Spatial and Temporal Adaptive Algorithm for Mapping Reflectance Change Model (Hilker *et al.* 2009). The core idea of unmixing-based models, such as the Spatial Temporal Data Fusion Approach (M. Wu *et al.* 2012) and Flexible Spatiotemporal Data Fusion (FSDAF; Zhu *et al.* 2016), is to predict the unknown fine image by spectral unmixing of the existing coarse image. In comparison, learning-based models such as the Sparse Representation Based on a Spatiotemporal Reflectance Fusion Model (Huang and Song 2012), the Error-Bound-Regularized Semi-Coupled Dictionary Learning Model (B. Wu *et al.* 2015), and a two-stream convolutional neural network (StfNet; X. Liu *et al.* 2019) establish a nonlinear mapping between images using sparse representation and deep-learning technology.

As LST and reflectance are both continuous surface variables, spatiotemporal fusion methods are used to generate high-spatiotemporal-resolution LST products (Yin *et al.* 2021). Considering the continuity of LST in the temperature space, Huang *et al.* (2013) proposed a spatiotemporal fusion model based on bilateral filtering. Ma *et al.* (2018) fused Moderate Resolution Imaging Spectroradiometer (MODIS) data with Landsat data to generate a simulated Landsat LST product to estimate land surface evapotranspiration at high spatial and temporal resolutions. H. Liu and Weng (2012) fused Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and MODIS data with the STARFM model to create a series of simulated ASTER data sets that contain various environmental variables such as LST and the normalized difference vegetation index.

Compared with reflectance, the dynamics of LST are more complicated. In addition, the LST from a given landscape patch is greatly dependent on the surrounding features (Oke 1982). In light of the characteristics of LST images, some improved algorithms have been proposed. Using a variation-based model, P. Wu *et al.* (2013) introduced a variation-based model to improve the accuracy of spatiotemporal fusion of LST. C. Wang *et al.* (2009) obtained high-spatiotemporal-resolution LSTs between land surface parameters estimated from visible and near-infrared data and thermal infrared data by means of an artificial neural network with genetic algorithms and self-organizing feature maps. Bai *et al.* (2015) integrated downscaling and spatiotemporal

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Call for Submissions

AI-Based Environmental Monitoring with UAV Systems

Photogrammetric Engineering and Remote Sensing (*PE&RS*) is seeking submissions for a special issue on AI-Based Environmental Monitoring with UAV Systems.

Global warming and climate change have become the most important factor threatening the world. Climate change results in dramatical environmental hazards and threatens the planet and human life. A wide variety of policies have been proposed to decrease the effects of global warming and climate change. The most important one is the Paris Agreement which aims to limit global warming to well below two degrees Celcius. Many countries have formulated long term low greenhouse gas emission development strategies related to the Paris Agreement which aimed to meet the essential strategies addressing issues with climate change, environmental protection and low carbon.

The astonishing developments on unmanned aerial vehicle (UAV) systems and artificial intelligence (AI) technologies enables a great opportunity to monitor the environment and propose reliable solutions to restore and preserve the planet and human health.

Data acquisition and processing paradigm has been changed as a result of technological developments. It is obvious that new solutions, innovative approaches will make significant contributions to solve the problems which our planet is facing. UAV data can be collected by various platforms (planes or helicopters, fixed wing systems, drones) and sensors for earth observation and sustainable environmental monitoring which are also utilized by the United Nations to support the delivery of its mandates, resolutions, and activities.

UAV based earth observation data and AI techniques have a wide range of applications such as risk management, disaster monitoring and assessment, environmental impact evaluation and restoration, monitoring agriculture and food cycles, urban analysis, digital twin and smart city applications and providing increased situation awareness. This growth of widely available UAV data associated with the exponential increase in digital computing power, machine learning and artificial intelligence plays a key role in the environmental monitoring and solution generation of geospatial information for the benefit of humans and the planet.

The proposed special issue aims to contributes ASPRS's key mission on 'Simplify and promote the use of image-based geospatial technologies for the end-user', 'Promote collaboration between end users and geospatial experts to match data and technology to applications and solutions' and 'promote the transfer of geospatial data and information technology to developing nations' by serving as an innovative knowledge exchange platform for authors from the globe to deliberate on the latest advancements, state-of-the-art developments and solutions that can help the community to solve many real-world challenges on the topic of "*AI-Based Environmental Monitoring with UAV Systems*."

This special issue aims to bring researchers to share knowledge and their expertise about state-of-art developments and contribute to the goal of a livable world by integrating human creativity with UAV and AI technologies for environmental monitoring to combat global threats on ecosystems. We wish to discuss the latest developments, opportunities and challenges that can solve many real-world challenges in environmental monitoring including but not limited to:

- AI-Based UAV and GIS Applications
- AI-Based Object Detection and Recognition from UAV Imagery
- AI-Based Digital Twin Applications
- AI-Based Smart City Applications

Papers must be original contributions, not previously published or submitted to other journals. Submissions based on previous published or submitted conference papers may be considered provided they are considerably improved and extended. Papers must follow the instructions for authors at http://asprs-pers.edmgr.com/.

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Three-Dimensional Point Cloud Analysis for Building Seismic Damage Information

Fan Yang, Zhiwei Fan, Chao Wen, Xiaoshan Wang, Xiaoli Li, Zhiqiang Li, Xintao Wen, and Zhanyu Wei

Abstract

Postearthquake building damage assessment requires professional judgment; however, there are factors such as high workload and human error. Making use of Terrestrial Laser Scanning data, this paper presents a method for seismic damage information extraction. This new method is based on principal component analysis calculating the local surface curvature of each point in the point cloud. Then use the nearest point angle algorithm, combined with the data features of the actual measured value to identify point cloud seismic information, and filter the points that tend to the plane by setting the threshold value. Based on the statistical analysis of the normal vector, the raw point cloud data are deplanarized to obtain the preliminary results of seismic damage information. The density clustering algorithm is used to denoise the initially extracted seismic damage information. Ultimately, we can obtain the distribution patterns and characteristics of cracks in the walls of the building. The extraction result of the seismic damage information point cloud data is compared with the photos collected at the site, showing that the algorithm steps successfully identify the crack and shed wall skin information recorded in the site photos (identification rate: 95%). Point cloud distribution maps of cracked and shed siding areas determine quantitative information on seismic damage, providing a higher level of performance and detail than direct contact measurements.

Introduction

Earthquake disasters can have a serious impact on people's lives and property, with damage to buildings being one of the main causes of death and injury. Rapid assessment of damage to buildings after an earthquake is essential for emergency response, rescue operations, and postdisaster reconstruction (Tu *et al.* 2016). China accounts for 7% of the world's land area and is responsible for about 33% of the world's continental earthquakes, resulting in more than 50% of the global earthquake death toll (Zhang *et al.* 2013; Zhou *et al.* 2017; Qiu *et al.* 2017a; Qiu *et al.* 2017b; Qiu *et al.* 2018; Li *et al.* 2018; Li *et al.* 2020). After a devastating earthquake, the seismic rating of a building's structural type plays a critical role in casualties. The extraction and analysis of seismic damage information of different types of structures can provide scientific basis and technical support for emergency rescue, damage assessment of buildings, extraction of deformation characteristics of other structures (bridges, tunnels, dams, etc.), and seismic reinforcement of buildings after an earthquake (Ye *et al.* 2017; Hao *et al.* 2016).

The postearthquake building damage assessment is determined by a postearthquake field team of experts sent by the Earthquake Emergency Response and Disaster Relief Command to assess and analyze the damage to buildings after the earthquake through measurement and visual interpretation. After the earthquake, the damage assessment of the buildings, time constraints, and heavy tasks. In the process of investigation, there are human errors, and the buildings with high degree of damage have the risk of secondary collapse, which brings great danger to the personal safety of the on-site scientific research staff (Zhang *et al.* 2019).

As an emerging technology, Terrestrial Laser Scanning (TLS) is gradually being applied to various fields such as surveying, modeling, and monitoring, which is the main way to obtain high-precision lidar data on geological targets (Ye *et al.* 2017). TLS is a new sensing technique that uses laser reflection signals to measure the distance between the target and the scanner by transmitting and receiving a laser beam and calculates the three-dimensional (3D) coordinates of all sampling points on the target surface from the attitude angle of the scanner at the time the laser beam is emitted. Compared with traditional remote sensing techniques, TLS has the ability to acquire accurate, rapid, and real-time data on the true shape of the surface of a target feature. It is based on active measurement and does not rely on visible light, allowing for more flexible operation (Makuch and Gawronek 2020; Markiewicz *et al.* 2020).

In recent years, TLS technology has been widely used in different fields such as three-dimensional modeling, heritage protection, deformation monitoring, and forest structure investigation (Li 2019). Experiments using TLS for continuous monitoring and analysis of building structural component damage demonstrate its effectiveness in structural modeling and analysis applications (Olsen *et al.* 2010; Ziółkowski 2015). TLS has also been used for scanning assessment and 3D modeling of ancient buildings to propose effective solutions for the conservation and maintenance of ancient buildings (Nowak *et al.* 2020). In civil engineering applications, high precision data obtained by TLS in combination with least squares are used for the quality assessment of building plane regularity (Li *et al.* 2020). Scholars apply "Alpha Shapes Algorithm" to lidar data contour line extraction and regularization for buildings, and demonstrate the accuracy of the algorithm in lidar point cloud data extraction for building contour lines (Shen *et al.* 2008; Wang *et al.* 2010).

In the aspect of building maintenance, the scholars proposed an automatic inspection scheme based on TLS data using the principal component analysis and area growth algorithm, which improves the accuracy and efficiency of building facade measurement and provides a reference for geometric feature analysis of local surface restoration (Makuch and Gawronek 2020). In postearthquake building loss analysis, scholars proposed a building shape analysis model based on ground-based lidar data, which effectively solved the problems in building contour polygon sequence extraction, shape discrete parameter extraction, irregular building block division, earthquake damage analysis, and so on (Jiao *et al.* 2019). For crack extraction in postearthquake building walls, scholars use planar triangular dissection modeling to construct triangular irregular network data sets, inverse distance-weighted point cloud rasterization method based on crack width to generate raster surfaces, and to extract relevant information according to the crack shape features (Jiang *et al.* 2017; Jiang *et al.* 2018). A method for earthquake disaster loss assessment using other

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Toshihiro Sakamoto, Daisuke Ogawa, Satoko Hiura, Nobusuke Iwasaki. Alternative procedure to improve the positioning accuracy of orthomosaic images acquired with Agisoft Metashape and DJI P4 Multispectral for crop growth observation.

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Effectiveness of Deep Learning Trained on SynthCity Data for Urban Point-Cloud Classification

Steven Spiegel, Casey Shanks, and Jorge Chen

Abstract

3D object recognition is one of the most popular areas of study in computer vision. Many of the more recent algorithms focus on indoor point clouds, classifying 3D geometric objects, and segmenting outdoor 3D scenes. One of the challenges of the classification pipeline is finding adequate and accurate training data. Hence, this article seeks to evaluate the accuracy of a synthetically generated data set called SynthCity, tested on two mobile laser-scan data sets. Varying levels of noise were applied to the training data to reflect varying levels of noise in different scanners. The chosen deep-learning algorithm was Kernel Point Convolution, a convolutional neural network that uses kernel points in Euclidean space for convolution weights.

Introduction

Urban 3D remote sensing has opened up new opportunities for modeling cities on a massive scale, but the size and geometric properties of these point clouds—collections of *xyz* measurements and other attributes, such as intensity or color—pose challenges that are not amenable to conventional data-processing techniques. Urban settings introduce a new set of challenges and demands not seen in other forms of study. Urban point clouds often have varying densities, occlusion, and large data sizes. Due to technological advances and cost reductions, there has been a dramatic increase in demand for these data sets (Aijazi *et al.* 2013). With the explosion of data that can be collected, new demands for labeled data have increased. Low-level semantic segmentation provides the ability to obtain high-accuracy measurements from the data, as the error threshold for laser scanners is low. However, since laser scans are typically taken from high elevation, this is still relatively new technology and data. For this study, we consider low-elevation data collected using one of three methods: static terrestrial laser scanners such as the one collected by Hackel *et al.* (2017) named Semantic 3D, or mobile laser scans, where the lidar scanner is attached to a vehicle and uses a localization method, which use either a SLAM (simultaneous localization and mapping) algorithm or a sensor suite that includes a global navigation satellite system (GNSS) and inertial measurement unit (IMU) system. As seen in the aforementioned Semantic 3D data set, these point clouds can have up to billions of points, with a high level of resolution and detail (Hackel *et al.* 2017).

Classification and segmentation of point clouds have historically faced similar challenges to those of image classification. Traditional machine-learning algorithms have proved effective with point-localized features such as surface normals, planarity, and linearity. These properties are often calculated via point-normal vectors about a radial neighborhood or *k*-nearest neighbors. For example, consider a point cloud $P \in \mathbb{R}^3$ with N points. A point normal for $p \in P$ is determined by calculating a covariance matrix about a neighborhood $\mathcal{N}_p$. This neighborhood could be a radial neighborhood about p or a count of the closest neighboring points, also called *k*-nearest neighbors. The corresponding covariance matrix is defined as

$$\mathcal{C}_p = \frac{1}{k}\sum_{i=0}^{k}\left(p_i - \tilde{p}\right)\cdot\left(p_i - \tilde{p}\right)^{\mathrm{T}} \tag{1}$$

where $p \in \mathcal{N}_p$ is a point coordinate described as a 3×1 column vector and $\tilde{p} = \left(1/k\right)\sum_{i=0}^{k} p_i$. From the resulting 3×3 covariance matrix, we can determine primitive features of the point cloud by looking at the resulting eigen values and eigen vectors. Resulting eigen values $\lambda_1 > \lambda_2 > \lambda_3$ and corresponding eigenvectors e_1, e_2, e_3 can be used to determine features of points. For example, the normal vector for the best-fit plane in $\mathcal{N}_p$ is e_3 (Rusu 2010). We can also calculate point primitives using the eigen values and eigen vectors (M. Chen *et al.* 2019):

- planarity = $\dfrac{\left(\lambda_2 - \lambda_3\right)}{\lambda_1}$
- sphericity = $\dfrac{\lambda_3}{\lambda_1}$
- linearity = $\dfrac{\left(\lambda_1 - \lambda_2\right)}{\lambda_1}$
- anisotropy = $\dfrac{\left(\lambda_1 - \lambda_3\right)}{\lambda_1}$
- curvature = $\dfrac{\lambda_3}{\sum_{n=1}^{3}\lambda_n}$
- verticality = $1 - \left|\left\langle\left[0,0,1\right], e_3\right\rangle\right|$

Traditionally, these primitives are fed into a machine-learning algorithm such as a support vector machine or random-forest classifier. Other approaches convert point clouds into 2.5D space and use image-processing techniques to further segment them (Griffiths and Boehm 2019a). A specific approach proposed by K. Zhang *et al.* (2003) uses a mathematical morphological filter to segment ground returns.

There are several factors that make traditional machine-learning algorithms less effective than deep-learning algorithms. Random-forest classifiers and support vector machines can achieve high accuracy over small areas where there is little occlusion and overlap (Griffiths and Boehm 2019a). Moreover, the features are selected by using local descriptors from the user. Deep-learning algorithms learn local feature descriptors themselves.

More recent approaches have used deep-learning (DL) techniques that combine multiple layers of classifiers into a single algorithm, making it possible to define a broader range of categories, each having

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Estimating the Aboveground Biomass of Urban Trees by Combining Optical and Lidar Data: A Case Study of Hengqin, Zhuhai, China

Linze Bai, Qimin Cheng, Yuxuan Shu, and Sihang Zhang

Abstract

The aboveground biomass (AGB) of trees plays an important role in the urban ecological environment. Unlike forest biomass estimation, the estimation of AGB of urban trees is greatly influenced by human activities and has strong spatial heterogeneity. In this study, taking Hengqin, China, as an example, we extract the tree area accurately and design a collaborative scheme of optical and lidar data. Finally, five evaluation models are used, including two deep learning models (deep belief network and stacked sparse autoencoder), two machine learning models (random forest and support vector regression), and a geographically weighted regression model. The experimental results show that the deep learning model is effective. The result of the stacked sparse autoencoder, which is the best model, is that R^2 *= 0.768 and root mean square error = 18.17 mg/ha. The results show that our method can be applied to estimate the AGB of urban trees, which greatly influences urban ecological construction.*

Introduction

In recent decades, urban areas have been expanding rapidly (Xu *et al.* 2019; Sumari *et al.* 2020; Shao, Sumari *et al.* 2021; Trinder 2021). The increase of urban population density and the expansion of roads and buildings have brought serious environmental problems (Shao, Ding *et al.* 2020; Shao, Tang *et al.* 2020; Li *et al.* 2021 ; Shao, Wu *et al.* 2021; Shao, Zhou *et al.* 2021). These problems include increased vulnerability to natural disasters, urban heat islands, and air pollution. In this context, remote sensing technology is increasingly applied to the study of the urban ecosystem (Shao *et al.* 2019; Liu *et al.* 2021; Trinder 2021). Trees, equivalent to a city's lungs, are an essential green landscape and precious carbon storage sources (Nowak and Crane 2002). The aboveground biomass (AGB) of urban trees refers to the weight of organic matter per unit area of trees in a city at a specific time, including the entirety of trunks, branches, and leaves. It determines the carbon sequestration capacity of urban trees. The estimation of AGB of urban trees is vital for exploring the carbon cycle of the urban ecosystem. It is also helpful to alleviate the urban heat island effect, repair the urban soil and water environment, purify the air, and alleviate urban disease.

The traditional estimation method of tree AGB is field logging measurement. It requires a lot of time and labor costs, so that it is difficult to apply to large-scale biomass surveys (Seidel *et al.* 2011; Wang *et al.* 2011). Because of the rapidity and extensiveness of remote sensing data, a lot of studies for AGB retrieval based on remote sensing have been carried out (Lu *et al.* 2012 ; Hays *et al.* 2020 ; Puliti *et al.* 2020). Optical remote sensing feature parameters, especially the multispectral vegetation index, are the most widely used feature for AGB retrieval, but they lack the mining of the three-dimensional vegetation structure. Lidar data can effectively estimate vegetation structure parameters, but it is challenging to provide sufficient spectral information (Dong and Chen 2020). The high complementarity of these two data sources has strong application potential for collaborative retrieval of AGB (Tian *et al.* 2012).

It contains various surface landscapes in urban areas, such as buildings, roads, water, bare soil, and vegetation. Urban trees exist in many places, such as urban forests, scenic landscapes, and public greenery. Unlike the AGB estimation of grassland and woods, the underlying surface of the city is complex, and the surface environment is highly heterogeneous (Rafiee *et al.* 2009). Vegetation environments in different urban landscapes may cause slight AGB changes. The primary purpose of early urban aboveground biomass inversion is to estimate urban carbon storage. Nowak and Crane (2002) used field measurement data to estimate carbon storage on a single tree scale in 28 cities in the United States. With the continuous development of urban landscape ecological research, urban aboveground biomass inversion has been applied to urban environmental monitoring. Strohbach and Haase (2012) retrieved the urban biomass of the Leipzig, Germany, area based on the canopy coverage of remote sensing images and the measured values. Aguaron *et al.* (2013) generated thematic maps of aboveground biomass in Los Angeles and Sacramento, California, based on remote sensing data and regression models. Unlike the study of forest biomass, urban areas consider the impact of a unique urban landscape. Christopher *et al.* (2015) explored the impact of human living mode on urban carbon density and added community density as an index to the evaluation model. Chan *et al.* (2021) estimated AGB in Hong Kong using airborne lidar data. In a word, there is little research on tree AGB estimation in urban areas, and most of the existing studies focus only on the landscape ecological qualitative analysis of urban vegetation. In the current AGB estimation models of urban trees, the spatial characteristics of urban trees are rarely considered.

Parametric methods, such as multiple regression analysis, are widely used in estimating the AGB of trees (Kulawardhana *et al.* 2014; Sheridan *et al.* 2015; Singh *et al.* 2015). Although the parametric model is simple and easy to use, it cannot describe the complex nonlinear relationship between forest attributes and prediction variables. Different from parametric models, many machine learning technologies, such as K-nearest neighbor (KNN), backpropagation neural networks, support vector regression (SVR), random forest (RF), and deep learning (DL), can fully describe complex nonlinear relationships (Fassnacht *et al.* 2014; Tian *et al.* 2014; Chen *et al.* 2015), and it can better deal with high-dimensional problems. Dong and Chen (2020) used a DL model to evaluate forest biomass through Worldview-2 data. Among many nonparametric methods, few studies compare the effect of the DL model with other machine learning methods, especially in the AGB evaluation of urban trees.

In this study, we take Hengqin, China, as an example. First, urban trees are accurately extracted. Second, we propose a sampling strategy

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Cloud Detection in ZY-3 Multi-Angle Remote Sensing Images

Haiyan Huang, Qimin Cheng, Yin Pan, Neema Nicodemus Lyimo, Hao Peng, and Gui Cheng

Abstract

Cloud pollution on remote sensing images seriously affects the actual use rate of remote sensing images. Therefore, cloud detection of remote sensing images is an indispensable part of image preprocessing and image availability screening. Aiming at the lack of short wave infrared and thermal infrared bands in ZY-3 high-resolution satellite images resulting in the poor detection effect, considering the obvious difference in geographic height between cloud and ground surface objects, this paper proposes a thick and thin cloud detection method combining spectral information and digital height model (DHM) based on multi-scale features-convolutional neural network (MF-CNN) model. To verify the importance of DHM height information in cloud detection of ZY-3 multi-angle remote sensing images, this paper implements cloud detection comparison of the data set with and without DHM height information based on the MF-CNN model. The experimental results show that the ZY-3 multi-angle image with DHM height information can effectively improve the confusion between highlighted surface and thin cloud, which also means the assistance of DHM height information can make up for the disadvantage of high-resolution image lacking short wave infrared and thermal infrared bands.

Introduction

With the rapid development of remote sensing technology, remote sensing images have been widely used in earth observation, resource investigation, natural disaster prediction, environmental pollution monitoring, and other fields (Anderson *et al.* 2017). However, due to the influence of environmental factors in the atmosphere, the sensor is greatly affected by the atmospheric density and cloud changes, leading to the problem of cloud pollution. According to statistics, more than 50% of the Earth's surface is covered by cloud (Chen *et al.* 2015), and the cloud areas seriously affect the interpretation of the remote sensing images. Therefore, the cloud detection plays an important role in data preprocessing to reduce the burden of data transmission and improve data use.

Considering spectral or spatial resolution, ground coverage, geometric stability, and other quality factors, the Moderate Resolution Imaging Spectroradiometer (MODIS), Medium Resolution Imaging Spectrometer (MERIS), Sentinel, Landsat, and other image data are widely used in the field of remote sensing research. For different satellite sensors, a variety of cloud detection methods in remote sensing images have emerged. Holz *et al.* (2008) used the MODIS Cloud Product Suite, described by Ackerman *et al.* (2008) and Frey *et al.* (2008) to realize the cloud detection and cloud top height (CTH) retrievals. Through a series of tests on the sun and infrared passive reflection observation, the MODIS cloud mask algorithm used up to 19 spectral bands to improve the reliability of cloud detection to the maximum extent. Based on the extraction of meaningful physical characteristics (brightness, whiteness) and the combination of atmospheric absorption features (oxygen and water vapor absorption) in unique band, Gómez-Chova *et al.* (2007) proposed a method of cloud screening for the MERIS multispectral image. Through the three highly correlated near-infrared bands observed with different view angles, Frantz *et al.* (2018) obtained the Cloud Displacement Index and used the parallax to separate cloud from bright ground objects reliably. As for the Landsat remote sensing images, the most widely known cloud detection method is Function of Mask (Fmask) (Zhu *et al.* 2015), which designs a series of indexes and rules for the physical characteristics of the cloud, and uses multiple threshold tests and location matching to obtain high-precision cloud and cloud shadow detection results.

Mostly, achieving the separation of cloud and ground surface in the above methods is mainly based on the physical properties of cloud to design corresponding rules. However, limited by the special spectral bands, the rule-based cloud detection methods are usually aimed at a particular type of satellite imagery. In addition, these methods often involve the commission of the bright noncloud object and the omission of the thin cloud. In order to overcome the problem of rule-based detection methods in the universality, the cloud detection methods based on machine learning classification model gradually occupy an important position. Zhang *et al.* (2013) combined the geometry-based method, threshold-based automatic training data extraction, and supported vector machine (SVM), to discriminate cloud shadow in MODIS images stepwise. After completing the initial detection based on the brightness features of the extracted subblock image, Li *et al.* (2015) combined its texture features and support vector machine model to realize the cloud classification. Hu *et al.* (2015) used the top-down visual saliency model to generate a rough cloud mask and combined the threshold to generate the final mask results of cloud and noncloud. Ma *et al.* (2014) proposed an approach to combine the multiple features based on texture and spectral features extracted from remote sensing images with the cascaded AdaBoost algorithm to build an automatic cloud detection model. In the method of cloud detection based on machine learning model, not only the spectral features of satellite image, but also the geometric and texture features are needed to enhance the feature diversity.

In the above methods, low-level spectral and spatial features are mainly used, but there is still some room for using high-level features to improve the cloud detection accuracy of satellite image (Li *et al.* 2018). As a subset of machine learning, deep learning has made rapid development in the field of remote sensing, especially in the high-resolution satellite images, such as *Gaofen* (GF), *Ziyuan* (ZY), etc. Benefiting from deep convolutional features, the deep learning model has been widely used in the task of high-precision image classification. Yang *et al.* (2019) proposed a cloud detection neural network with

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