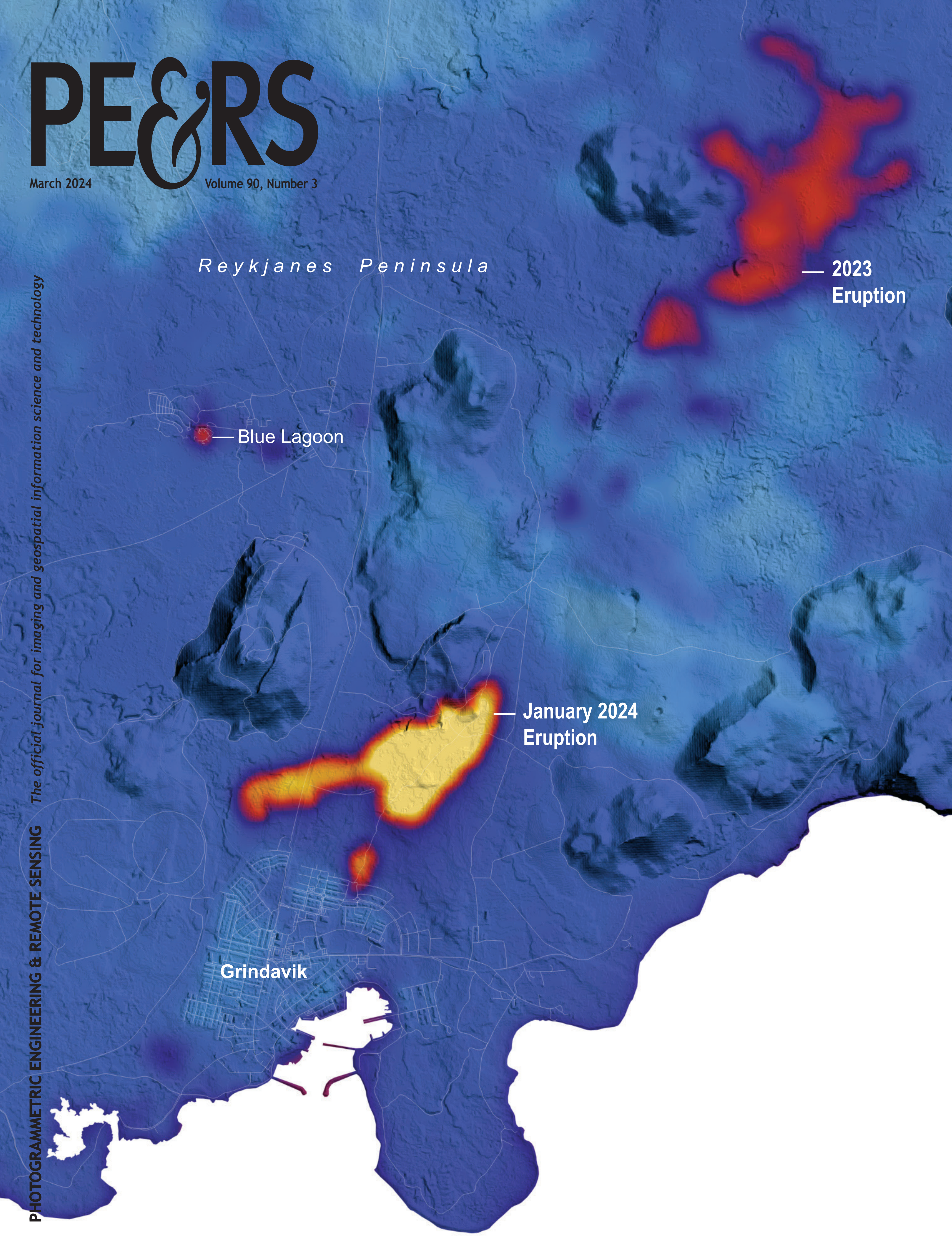
PE&RS
March 2024 Volume 90, Number 3
PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING
The official journal for imaging and geospatial information science and technology



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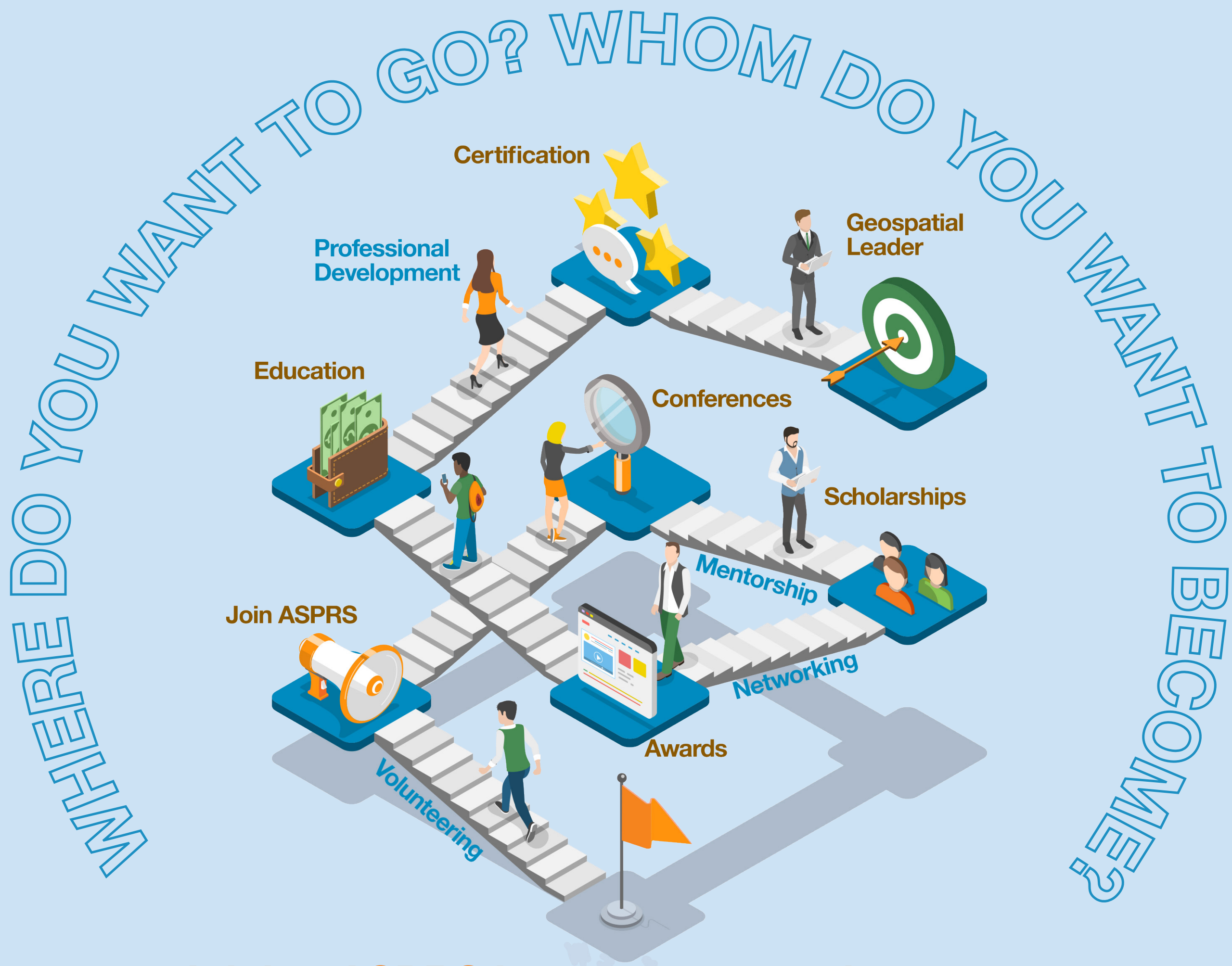

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PE&RS

Our monthly journal, is packed with informative and timely articles designed to keep you abreast of current developments in your field. Now available in e-format.

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ANNOUNCEMENTS

January 23, 2024 marked the launch of Maps.com, a platform dedicated to showcasing and celebrating the world's most beautiful and remarkable maps. The innovative website is set to redefine the way people perceive the power of cartography and data visualization.

Created by **Esri**, www.esri.com, the new website is a platform for sharing and discussing visually engaging maps that inspire, challenge, educate, reward, and provoke across a range of topics and formats. The site will serve as a celebration of science and art, presenting maps that captivate not only with their insights but also with their aesthetics.

Maps.com is focused on spotlighting distinctive, powerful maps and those who make them. As a creator-focused platform, Maps.com encourages individuals as well as organizations to submit their maps to be featured on the site. Submissions that are visually engaging, dramatic, and bold but understandable, with both style and substance, have already been highlighted on the site during soft launch.

Featuring analysis and dynamic visualizations, videos, and 3D models, Maps.com explores topics such as climate change, the digital divide, and even the exploration of Mars. Intended as a way to bring the power of mapping to a wider audience, the website is approachable to non-professionals curious about cartography. But it is also valuable for academics and professionals seeking to access new and useful data resources or insightful real-world narratives.

"Maps can help us tell stories about what's happening on our planet, experience new ideas, and guide us where we want to go," said Jack Dangermond, Esri president. "With Maps.com, we are proud to partner with some of the most innovative map makers to celebrate how they can show us the future we're facing, bad or good, and which can help us to build a better world."

Maps.com is now live and accessible to anyone. Join us there to explore the latest and most fascinating maps–and if you have a great map that the Maps.com editorial team should know about, submit it for consideration at maps.com/submit-map/.

The **Sanborn Map Company, Inc.**, www.sanborn.com, is pleased to announce the establishment of its Canadian subsidiary, Sanborn Geophysics, ULC located just outside of Toronto. Sanborn Geophysics will focus on geophysical survey services and equipment sales, opening a new market to Sanborn.

With a commitment to advancing geospatial data collection and aerial survey capabilities, Sanborn Geophysics builds upon Sanborn's extensive geospatial data expertise. John Copple, CEO of Sanborn, remarked, "The creation of Sanborn Geophysics expands Sanborn's already extensive geospatial data collection and aerial survey capabilities. We're uniquely positioned to not only collect specialized data but to do so with our own state-of-the-art equipment."

Sanborn Geophysics was enabled by the purchase of assets from Nuvia Dynamics, Inc. Sanborn was also able to hire employees who have a proven track record in geophysics survey technology to staff Sanborn Geophysics. Some of Sanborn Geophysics employees have over 25 years of experience and previously worked for Nuvia Dynamics Inc (formerly known as Pico Envirotec Inc). Both prior companies have a distinguished record of accomplishment in developing geophysics survey technologies for mineral/oil exploration and geotechnical applications. Sanborn was supported by The Environmental Financial Consulting Group, LLC (EFCG). Terms were not disclosed.

"Sanborn Geophysics will create new opportunities for the company both domestically and internationally. This investment is to provide the best geospatial solutions for our clients," said Copple.

The Wyoming Geographic Information Science Center (WyGISC) at the University of Wyoming (UW) has tasked **Woolpert**, www.woolpert.com, with producing a higher-resolution digital terrain model and contours covering the entire land area of the state of Wyoming. The project is supported by an appropriation made to the university by the State of Wyoming Legislature during its 2023 General Session.

To develop these products, Woolpert will use statewide topographic lidar data the firm collected through the 3D Elevation Program (3DEP) under a separate, ongoing, shared capacity contract for the U.S. Geological Survey. A digital terrain model is a datafile that produces digital modeling of surface terrain and incorporates break lines as needed for large bodies of water. Woolpert will use photogrammetric software to generate contours specific to the newly revised ASPRS Positional Accuracy Standards for Digital Geospatial Data. Woolpert Vice President and Chief Scientist Qassim Abdullah was integral to the drafting of these standards.

Woolpert Program Director Brian Stevens said that the topographic contours will primarily be generated at 2-foot intervals except for areas with extreme elevation change, which may be generated at 10-foot intervals.

WyGISC is an interdisciplinary research and engagement center within UW's School of Computing that supports state and local mapping and GIS needs through geospatial data and software development, and by connecting collaborators across the state to advanced research support within the university.

WyGISC Director Jeff Hamerlinck said the center is enthusiastic about partnering with Woolpert to build new capacity statewide in the use of lidar data and related products. He said plans are also underway for WyGISC to build a new lidar-specific component to its Wyoming Geospatial Hub and connecting it to UW's Wyoming Innovation Partnership research data integration platform.

Stevens said these products will help advance WyGISC's research and application capabilities, as well as support future statewide mapping initiatives including the USGS 3D National Hydrography Program (3DHP). He expects the products to be delivered this summer.

"The digital terrain model will provide Wyoming with an up-to-date, highly detailed, and more comprehensive understanding of its land," Stevens said. "From improving water drainage and floodplain mapping to assisting with preliminary engineering and design for agriculture, forestry, transportation, pipelines, water storage, or energy infrastructure projects, the model will serve as an invaluable resource for the Wyoming Geographic Information Science Center and other state agencies as they help move the state of Wyoming forward."

Numerous nonprofit organizations use geographic information system (GIS) technology to support their operations worldwide, addressing challenges such as climate change, public health, and social equity. GIS helps these organizations better understand complex issues by placing them in the critical context of location. To further support the nonprofit sector, **Esri**, www.esri.com, the global leader in GIS, has partnered with TechSoup to make the purchase of Esri software simpler for 501(c)(3) nonprofit organizations.

TechSoup is a nonprofit international network of nongovernmental organizations that provides technical support and technological tools to other nonprofit organizations. The partnership with Esri will expose more nonprofit organizations to GIS technology, a major business system that helps improve the world.

"TechSoup is excited to partner with Esri, providing our nonprofit members with access to Esri's ArcGIS mapping products," said Conor Mulherin, general manager of validation services at TechSoup. "Esri provides great tools for [nonprofit organizations] because [its] ArcGIS mapping products enable [them] to transform data into actionable insights, advancing their missions and driving real change in the communities they serve."

Today, hundreds of 501(c)(3) nonprofit organizations from a wide variety of disciplines join the Esri Nonprofit Program every month, receiving special pricing. Esri has witnessed an explosion of nonprofit organizations embracing a geographic approach to improving their operations in addressing civic and social equity, the environment, conservation, homelessness, social services, and more. These organizations also use GIS to better communicate their cause through storytelling; increase their understanding of the communities with which they are trying to connect; improve resource and staff allocation; and better measure, report, and adjust their approaches.

"Nonprofit organizations are part of Esri's DNA. For decades, Esri has worked with organizations of all sizes, ranging from the American Red Cross and Audubon Society to the YMCA and NAACP," said Emily Swenson, Esri Nonprofit Program manager. "Each nonprofit we have worked with has used GIS to further its mission through the lens of geography. We have strived to be part of the nonprofit community and to have nonprofit organizations be part of the GIS community as well."

The partnership with TechSoup will help its 1.4 million members gain easier access to the Esri suite of offerings. TechSoup will verify eligibility among its members for Esri discounted software, confirm nonprofit status, and help streamline the application process. In turn, Esri will work with TechSoup to produce educational webinars, provide best practices for organizations implementing GIS, introduce Esri product offerings, and highlight educational opportunities.

To learn more about the use of GIS for nonprofit organizations, go to esri.com/nonprofitsolutions.

EVENTS

SUNY ESF is hosting the Systems and Technologies for Remote sensing Applications Through Unmanned Aerial Systems (STRATUS) 2024 Conference on May 20-22, 2024, in Syracuse, NY.

The emergence of low-cost and easy-to-use Unmanned Aerial Systems (UAS), commonly referred to as drones, has led to an expansion of their use for numerous applications. In particular, these new platforms have enabled new imaging and earth remote sensing technologies and applications previously unavailable due to the high cost of manned aircraft or satellites. This is the 7th conference of STRATUS that will bring together international academics, government, industry representatives, and domain specialists to share perspectives on this rapidly evolving topic.

The Conference includes Keynote Speakers, Panels, Workshops, UAV Flight Demos, K-12 involvement, Oral and Poster Presentations, and Industry Exhibits. This event is sponsored by multiple organizations including IEEE.

More information is available at http://stratus-conference.com/event-details/.

CALENDAR

- 18-20 March, **CalGIS**, Visalia, California; https://urisa.org/page/CalGIS.
- 2-4 May, **GISTAM 2024**, Angers, France; https://gistam.scitevents.org.
- 13-16 May, **Geospatial World Forum**, Rotterdam, The Netherlands; https://geospatialworldforum.org.
- 20-22 May, **STRATUS 2024**, Syracuse, New York; https://stratus-conference.com/home/

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COLUMNS

ANNOUNCEMENTS

DEPARTMENTS

The density and uniformity of lidar data play crucial roles in the corresponding data processing steps. One factor influencing point density and spacing in lidar data is the presence of empty pulses, where no return is detected. Missing returns can occur due to atmospheric absorption, specular and diffusive reflection, etc. To address this issue and enhance point density, this article introduces a novel method for approximating missing returns in airborne lidar data collected over urban areas.

This article presents recommendations and corresponding detailed procedures for the assessment of a geolocation system's accuracy, as well as the specification of accuracy requirements and their subsequent validation when they are available. This article also presents similar recommendations for the predicted accuracy of a geolocation system, based on samples of geolocation error, as well as corresponding predicted error covariance matrices associated with the geolocations.

In this article, we propose a novel approach for the extraction of high-quality frames to enhance the fidelity of videogrammetry by combining fuzzy frames removal and baseline constraints. We first implement a gradient-based mutual information method to filter out low-quality frames while preserving the integrity of the videos. After frame pose estimation, the geometric properties of the baseline are constrained by three aspects to extract the keyframes: quality of relative orientation, baseline direction, and base to distance ratio. The three-dimensional model is then reconstructed based on these extracted keyframes.

To extract terraced fields in hilly areas on a large scale in an automated and high-precision manner, this article proposes a terrace extraction method that combines the Digital Elevation Model (DEM), Sentinel-2 imagery, and the improved U-Net semantic segmentation model. The U-Net model is modified by introducing Attention Gate modules into its decoding modules to suppress the interference of redundant features and adding Dropout and Batch Normalization layers to improve training speed, robustness, and fitting ability. In addition, the DEM band is combined with the red, green, and blue bands of the remote sensing images to make full use of terrain information.

See the Cover Description on Page 132

COVER DESCRIPTION

Volcanic activity reawakened on the Reykjanes peninsula in southwestern Iceland with a pulse of eruptions in mid-January 2024. Over the course of about two days, new fissures released lava near the town of Grindavík. A human-constructed barrier diverted some of the flow from one fissure away from town, but lava from one closer to Grindavík engulfed several homes. The eruption occurred less than a month after another fissure opened several kilometers to the northeast. It was the fifth eruption on the peninsula since 2021.

The map above indicates the location and extent of the recent activity. Data for the map were acquired by the TIRS-2 (Thermal Infrared Sensor 2) on the Landsat 9 satellite on January 16, 2024, and overlaid on a digital elevation model of the area. TIRS-2 detects thermal radiation in two wavelengths, revealing the amount of heat emanating from surfaces on Earth. Lava flows from the January 2024 eruption appear the warmest (yellow), while the still-warm December 2023 flows and the Blue Lagoon geothermal pool also stand out from the relatively cooler surrounding land. Scattered clouds (light blue) account for areas with the coolest temperatures.

A fissure eruption began at 7:57 a.m. local time on January 14, 2024, approximately 1 kilometer away from Grindavík. It followed several hours of increased seismicity, according to the Icelandic Met Office. Some lava from this fissure flowed toward town, while some was diverted to the west by barriers of earth and rock constructed starting in November 2023 when the risk of imminent hazard became apparent.

At 12:20 p.m. local time, a second, smaller fissure opened outside of the barrier at the edge of town and oozed lava that burned three homes. Drone footage from that day captured both flows, which turned out to be relatively short-lived. By the morning of January 16, the Icelandic Met Office reported that activity was no longer visible and that seismicity had decreased.

Stopping hot, viscous rock is a difficult feat, and past efforts have been met with mixed results. Famously on Iceland's Heimaey island 51 years ago, workers sprayed millions of tons of seawater on a lava flow's edge to cool and slow it, preventing it from destroying a harbor. Most recent efforts have taken the barrier approach like at Grindavík, aiming to redirect lava onto a less destructive path.

More battles with lava may follow on the Reykjanes peninsula, as hazards remain high. Modelling showed that magma has moved beneath Grindavík and deformed the ground by as much as 1.4 meters (4.6 feet). Experts have told news sources that bursts of activity could continue in a cyclical pattern.

NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the U.S. Geological Survey. Story by Lindsey Doermann.

he entire image can be viewed online by visiting the Landsat Image Gallery, https://landsat.gsfc.nasa.gov/, image id 152344.

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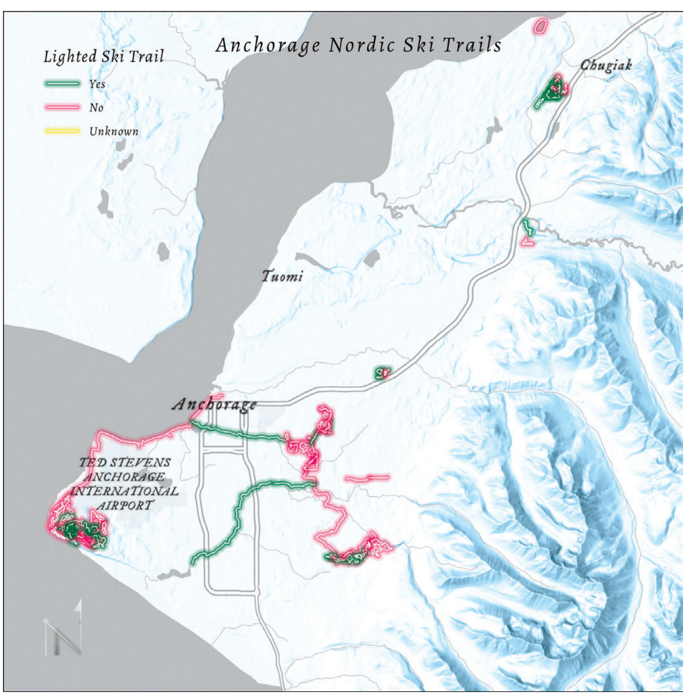
GIS Tips & Tricks

By Shira A. Ellenson and
Al Karlin, Ph.D., CMS-L, GISP

Winter-themed Mapping Tricks

As many who follow this column know, I (Al Karlin) live in sunny Tampa, Florida. This summer was an extremely hot one, and the heat extended beyond the typical summer schedule. By the time Hurricane Idalia came through the area in late August, I should have started thinking of a winter-holiday themed column. Unfortunately, with the hot weather continuing long after the kids went back to school, a winter-themed column completely skipped my mind throughout September. October finally brought daytime temperatures in the low 70's, what we might call winter here in Tampa, and I remembered my intent to write a winter-themed column. Since those of us in low-lying sunny locations, might rarely encounter mapping at high latitudes, I reached out to a colleague, Shira Ellenson, who lives in Alaska, to help with this month's Tips and Tricks column on how to make your maps look more wintery.

MAKING A SNOWY BASEMAP



Here is the Step-by-Step workflow to make this "snowy" winter-themed map:

STEP 1 — Open a new map in ArcGIS Pro.

STEP 2 — CHANGE THE BASEMAP Add the Human Geography Detail" layer from "Living Atlas"

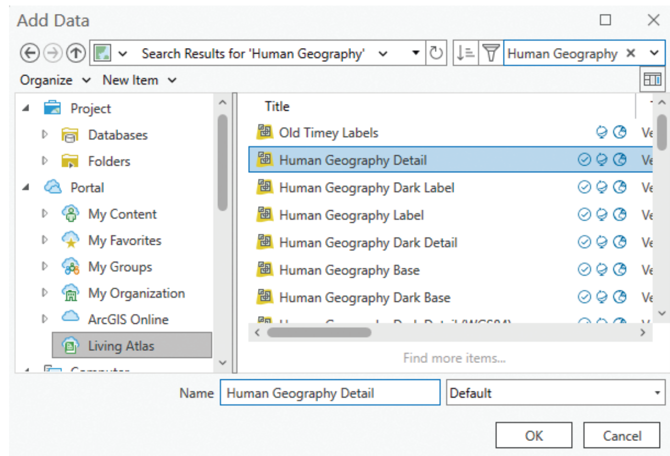


Figure 1. Using the Add Data button in ArcGIS Pro to add the Human Geography Detail layer from "Living Atlas" to the map.

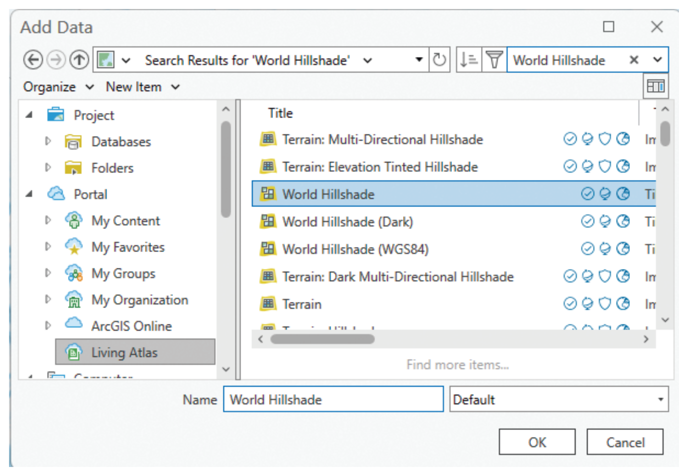


Figure 2. Using the Add Data button in ArcGIS Pro to add the World Hillshade layer from "Living Atlas" to the map.

STEP 3 — ADD "WORLD HILLSHADE Add the World Hillshade from "Living Atlas".

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0099-1112/22/133-136

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Place the World Hillshade on the bottom (under the Human Geography layer) of the Drawing Order in the Contents Pane.

Step 4 — Change the Map's Background Color to Light/ Powder Blue Under Map Properties > General, change the background color to Power Blue, #D9ECFF (remember from previous columns how to adjust colors using the Color Editor). This will add a blue background to your map.

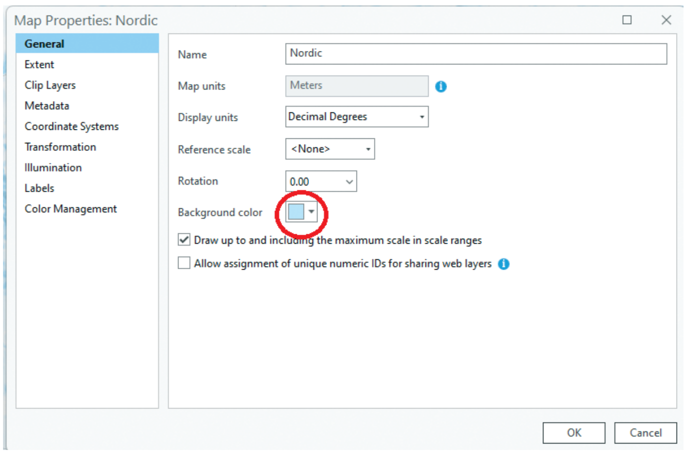

Figure 3. Changing the background map color using the Map Properties dialog box.

Step 5 — Adjust the World Hillshade Layer With World Hillshade layer selected, adjust the Effects settings under the "Tile Layer" tab, set the Layer Blend to Luminosity and the Transparency to 0 (zero).

Map Tip #1 — This preserves the color of the background while maintaining the texture of the Hillshade. Zoom in and take a look around! You've quickly made a wonderful winter basemap!

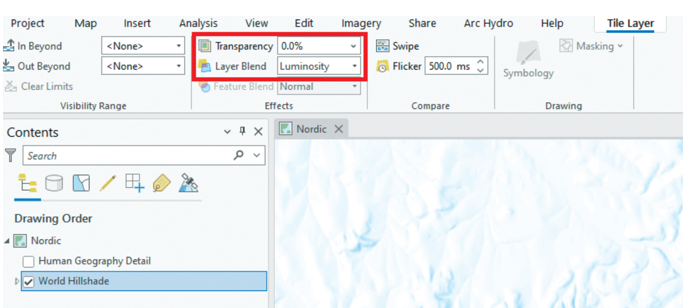

Figure 4. Adjusting the rendering of the World Hillshade under the Tile Layer tab.

Step 6 — Adjust the Human Geography Detail layer With Human Geography Detail layer selected, adjust the different blend modes until you achieve a look you like.

Map Tip #2 — In this example, we used the "Linear Burn" and increased the transparency to 60%. This softens all the roads, water bodies, and other features.

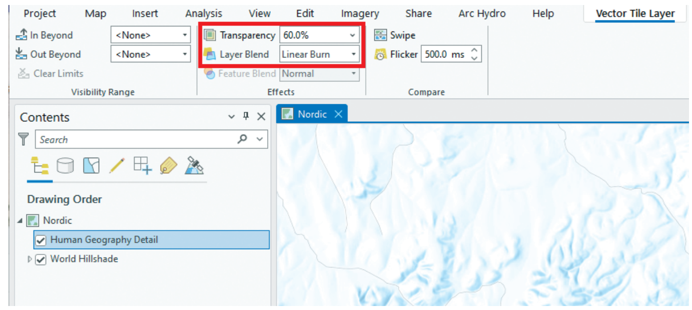

Figure 5. Adjusting the rendering of the Human Geography Detail layer under the Vector Tile Layer tab.

Step 7 — Add some ski trails to the map To go along with our winter wonderland theme, lets add some ski trails! Search for "NordicTrails" in ArcGIS Online.

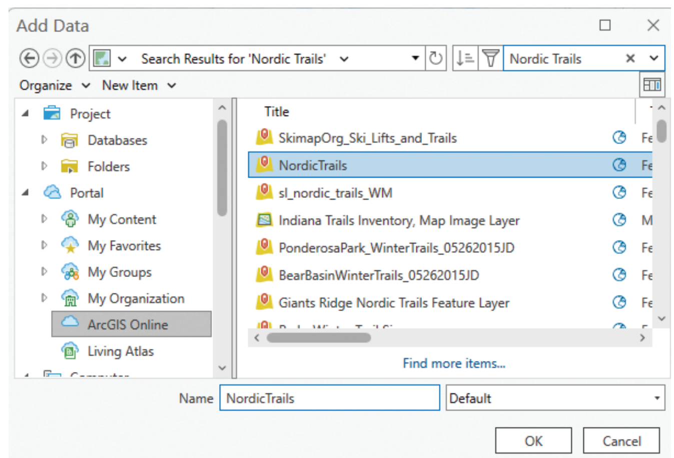

Figure 6. Using the Add Data button in ArcGIS Pro to add the Nordic Trails layer from "ArcGIS Online" to the map.

This layer is managed by the Municipality of Anchorage and shows Cross-Country Ski Trails around Anchorage, Alaska. It also includes information about grooming status, difficulty level, and which trails are lighted. With about five hours of sunlight during the peak of Alaska winter, knowing which trails have lights is super useful for night skiing!

NOTE: IF you are working through this map as a tutorial, because we're working with data in Anchorage, AK, we changed the map projection to a local coordinate system, "NAD 1983 StatePlane Alaska 4 FIPS 5004 (US Feet)".

Step 8 — Adjust the symbology of the trails Change the primary symbology to "Unique Values" by "Lighted_Trail". We can now see which trails are lighted and which are not.

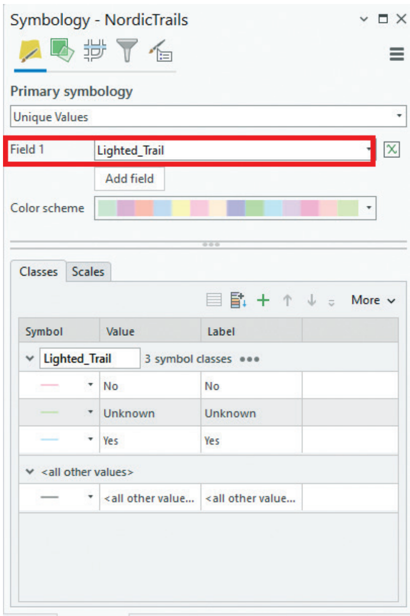

Figure 7. Changing the symbology of the Nordic Trails to "Unique Values" and selecting "Lighted_Trail" as the value.

Step 9 — Adjust the Symbology for the Selected Trails For the lighted trails ("Yes"), lets dig into the symbology a bit deeper.

Map Tip #3 — Under Properties > Structure, duplicate the layer three times.

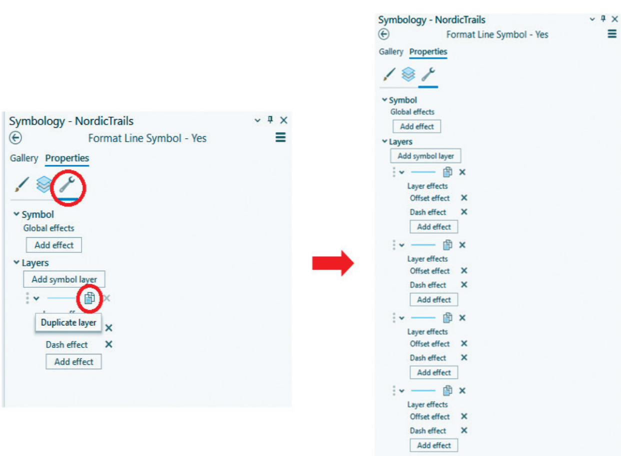

Figure 8. Making multiple/duplicate copies of a feature.

Back under LayerTab, select each copy of the layer and adjust each as:

- Layer 1 – Solid Stroke | Width = 0.5 | Color to White
- Layer 2 - Solid stroke | Width = 2.5 | Color to # 00734C | Transparency = 60%
- Layer 3 - Solid stroke | Width = 4.0 | Color to # 00734C | Transparency = 85%
- Layer 4 - Solid stroke | Width = 6.0 | Color to # 00734C | Transparency to 85%, as

Map Tip #4 — By stacking increasing stroke widths and transparencies, we've hacked a forest green lighted feel to the lighted loops!

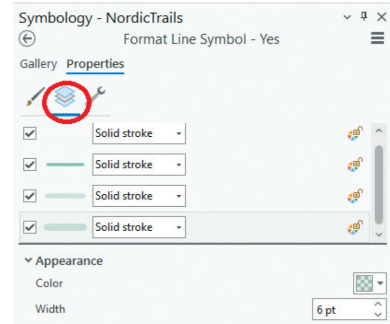

Figure 9. Stacking the multiple/duplicate features.

Repeat this same process for other trails, choosing colors that look good to you! I went with a Candy Red (#FF6685) for the unlighted trails, and a gold (#FFE44A) for the unknown trails.

Figure 10. Adjusting the color and transparency of each stacked feature.

Step 10 — Adjust the Font The map is looking very wintery, but the font doesn't really match the theme here.

Map Tip #5 — Search Living Atlas for "Old Timey Labels". To tone down the labels, I increased the transparency to 30%.

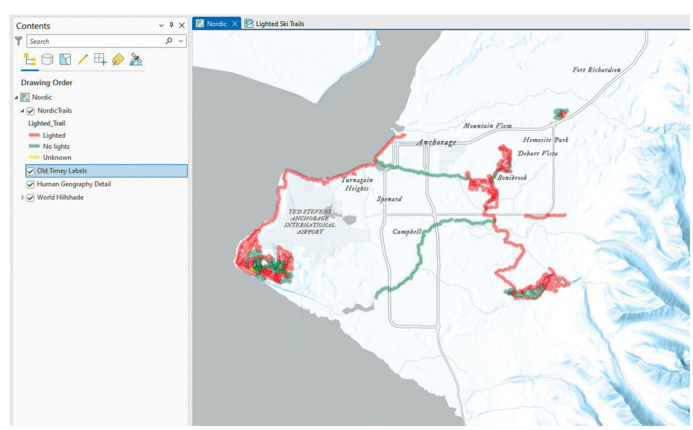

Figure 11. Final map with "Old Timey Labels" font replacing the default labels.

With nearly 40 miles of trails, browsing moose, and views of Denali, Kincaid is one of my favorite places to go skiing!

Step 10 — (optional, but fun) Use Adobe Illustrator to put a Candy cane border around the map and add a cute graphic to make a holiday-themed winter map.

The winter-themed map can be taken another step to make a winter holiday-themed map, by taking the map into Adobe Illustrator (or another graphic editor) and adding holiday-themed decorations.

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

Shira Ellenson is a senior geospatial analyst with Dewberry's Anchorage, AK office. She specializes in remote sensing and cartography. 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.

Figure 12. Winter holiday-themed "Lighted Ski Trails" Map. Note: The cartoon moose is the creation of YoLani Martin, a frequent contributor to this column.

Michael S. Renslow

1946-2023

It is with great sorrow that we announce that Michael S. Renslow passed away in his beloved log home in Eugene, Oregon surrounded by his family on November 22, 2023 looking out at the birds and fields surrounding his home. The Beatles song "Come Together" was playing as he took his last breath. Mike is survived by his wife Linda and two children Jason and Adrienne along with their families and many grandchildren. A celebration of Mike's life will take place on July 20, 2024 for all friends and family.

Mike was born on October 5, 1946 and grew up in the San Francisco Bay area. He graduated with an AA in Civil Engineering in 1967 from Solano College and began his career as a civilian land surveyor for the US Department of Defense. Following a BS in Geography from San Francisco State University in 1971, Renslow became a surveyor, cartographer, photogrammetrist, and project leader for the US Forest Service where he worked for 11 years. He was instrumental in the development and implementation of the FIRESCOPE Project in Southern California and the Incident Command System for disaster response to wildland fires. In 1983, Renslow left government service and entered the private sector as the general manager of Pacific Aerial Surveys and vice-president of Hammon, Jensen, and Wallen in Oakland, California where he worked until 1989. While there he was responsible for contract implementation, proposals, daily operations, two flight crews; conducting and publishing research on modern-generation aerial films for Kodak and Agfa products; and performing research for the USGS on aerial film(s) resolution.

His next position, in 1989, was with the Oregon-based WAC Corporation in market development and operations management of Digital Geographic Systems writing digital aerial imagery on CD-ROM. Renslow started his first mapping firm in 1995, Renslow Image Mapping, which specialized in digital imagery and orthophotography. After one year, he sold the company to Spencer B. Gross Engineering and became the firm's vice-president managing the Eugene office. It was at this time that Mike's interest in lidar began. His job also included being senior technical advisor for the Applications of Advanced Technologies group; providing GIS support operations; using Map Objects, and co-authoring "SBG View" a stand-alone viewer for geo-referenced imagery and ESRI shapefiles. In 1997, Renslow took a position at the University of Oregon, Geography Department as adjunct faculty, teaching a class in Fundamentals of Remote Sensing for the next five years. In 2007, he established Renslow Mapping Services specializing in consulting for emerging technologies and map accuracy QA/QC validation procedures. In 2009, he accepted a position with Penn State University, John A. Dutton e-Education Institute as a senior lecturer in the Geography Department teaching a new course on Lidar Technology and Applications (GEOG497D). Most recently, Renslow has been very active in research and development for applications of lidar mapping technology and has an established reputation for expertise in this field. He also participated in lidar research projects with Oregon State University, the University of Oregon, and the University of Washington. He published several papers on the subject and has presented numerous workshops and technical sessions at local and national conferences throughout the country. In 2012, the Manual of Airborne Topographic Lidar was published in which Mike was the editor and a contributing author.

I can think of no one who has contributed more to ASPRS than Mike Renslow. He joined ASP in 1973 and was a member for over 50 years. He served nationally on numerous committees and technical divisions, on the Board of Directors, on the Executive Committee, and as National President in 1999-2000. In addition, he was technical editor for Photogrammetric Engineering & Remote Sensing from 2004 – 2018. During the transition between ASPRS Executive Directors in late 1997 and early 1998, Mike took on the role of controller as the Society struggled with a financial crisis. Mike's focus on financial reporting and his commitment to transparency was critical to resolving the crisis and his monthly financial report, dubbed the Renslow Report, served as the basis for continuing financial stability over the next 16 years. In recognition of his financial acumen, Mike was appointed as the first volunteer Treasurer for ASPRS from 2000-2004, after which he was the first Treasurer of the ASPRS Foundation (2004 – 2015) and then served as its Vice President (2015 – 2020). He was the Chair of the ASPRS Evaluation for Certification Committee beginning in 2002, Chair of the ASPRS Professional Examination Development Committee (serves NCEES for assessment items for the national photogrammetrist exam), and formerly the ASPRS Representative to the Council of Engineering and Scientific Specialty Boards (accreditation of science-based certification programs). He was also the technical editor of the ASPRS Manual of Remote Sensing, 6th edition.

In addition to all the ways that Mike served nationally, he was also extremely active in whichever ASPRS Region he lived (Northern California and Columbia River). Mike hosted the Board and Officers meetings for the Northern California Region at his office for most of the 1980's. During this time, the region planned and hosted the first large GIS conference of its kind (GIS '87) in San Francisco in which more than 1000 people attended. Mike was in charge of getting a hotel for this conference and did an amazing job considering the first time we looked at the hotel it was under construction with just girders in place.

Mike received many awards and recognition for his contributions to ASPRS and the geospatial community. He was elected an ASPRS Fellow (2002) and was a Certified Photogrammetrist (#1073) and an Oregon Registered Professional Photogrammetrist (#78313RPP). He received the Birdseye President's Citation – 1999; a Conference Management Award for GIS'87 in 1988; Presidential Citations for Meritorious Service- 1988, 1989, 1991; ASPRS Merit Award - 1994, 1997,1998; ASPRS Presidential Citations - 1998, 2003, 2004; and was the first recipient of the ASPRS Outstanding Workshop Instructor Award, 2007; the ERDAS Award for Best Scientific Paper in Remote Sensing, 2001, 3rd Place and the ASPRS Outstanding Service Award, 2005 and 2015. Finally, Mike received ASPRS' highest award, the Lifetime Achievement Award, in 2018.

Mike was also extremely active within ISPRS serving as a Working Group Chair 2000 to 2004, active member of Commission I, and was elected to the International Council as the Treasurer from 2008-2012. He was the 2011 recipient of the ISPRS Carl Pulfric Award.

If you knew Mike or if you are just reading about him here, it is clear that he was a busy guy with boundless energy who was willing to work hard and loved his career and his family. To me, Mike was an amazing friend and mentor. He very unselfishly brought me into ASPRS when I was a new assistant professor at the University of California, Berkeley. He graciously shared his hotel room with me in those early days when I did not yet have the funding to afford all the costs of a national conference. He took me around and introduced me to all the big names in the field and he got me involved in the regional activities as well. Mike was always smiling and always willing to offer encouragement and help to whoever needed it. Mike was an excellent winemaker, and many special social events were even more enjoyable when Mike brought along a few bottles to share with his friends. He was truly a special individual and I only wish there were many more like him. I know that we all miss him.

Russell G. Congalton
Professor of Remote Sensing and GIS
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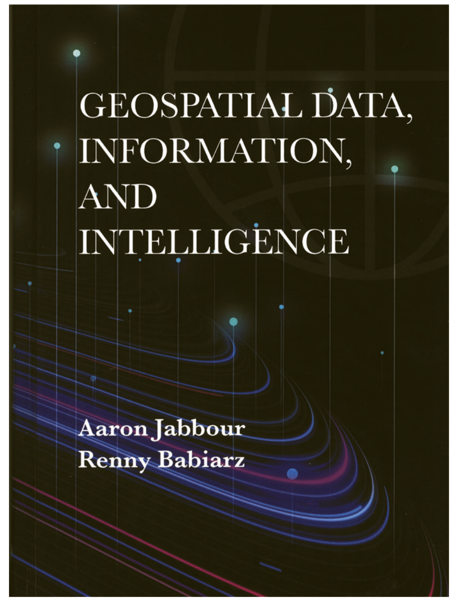

Geospatial Data, Information, and Intelligence, First Edition.

Aaron Jabbour and Renny Babiarz

xx+229 pages. 2023. Artech House, Boston|London.
ISBN 13: 978-1-63081-979-8 (hardcover)

Reviewed by Demetrio P. Zourarakis, PhD, GISP, CMS (GIS, RS, Lidar). Adjunct Assistant Professor, University of Kentucky, CAFE. Visiting Lecturer, Kentucky State University, CACS.

Rich in content and densely packed with information, this remarkably well-written and succinct book – only 229 pages long, should be essential reading for the layperson and practitioner alike. The title of the book is in and by itself an acknowledgement of the causality linking data, information, and intelligence - or knowledge. This first edition of the work represents an excellent primer for anyone who desires to apply geospatial intelligence (also known by its popular name of "GEOINT") analysis to the tradecraft, in which it plays a leading and defining role. The central theme of the book is the conceptualization of human-based processes of geospatial observation, analysis, inference, and communication, and their application to "geospatial intelligence", as defined on page 4 ("*… a term that describes specialized collection, processing, analysis, production, and dissemination of Earth-referenced entities, events, and phenomena, usually by government entities.*").

It is necessary, however, to remind ourselves of the obvious and implicit subject matter of the book, embodied by the term tradecraft, which has a specific meaning and widespread usage within the intelligence community, and is defined elsewhere as: "*the techniques and procedures of espionage*" (https://www.merriam-webster.com/dictionary/tradecraft) ." The term tradecraft appears prominently in the book, such as in Section 7.2 ("*Geospatial Analysis as a Profession: Imagery and Spatial Analysis Tradecraft*"), and subsections therein (*Chapter 7 — "The Skillset: Geospatial Analysis Practices*"). On page 120, the authors re-define the term, giving it a broader sense: "*… Tradecraft refers to the specific skills and practices required to work in a given job or trade, …*". The authors, do however, provide examples of *geospatial tradecraft* (pages 95-103), but paradoxically, the term – *sensu stricto* is not present by itself in the index. In essence, the authors' meticulous and masterful exposition centers around the premise that the human being - with its attendant sensory perceptions, brain and mind is the main seat for the process of geospatial observation and analysis. In support of this view, however, the authors could have used an already existing term - "*wetware*" which is defined elsewhere as: "*the human brain or a human being considered especially with respect to human logical and computational capabilities.*" (https://www.merriam-webster.com/dictionary/wetware).

Once past the introduction (*Chapter 1 — "Introduction to the Geospatial Mindset, Toolset, and Skillset*"), in which they present the structure of their work and summarize the contents of the rest of the chapters, the authors identify the human mind as the seat for the analytical process, a central tenet and starting point as they embark on a deep exploration of the elements of human psychology relevant to making spatial thinking possible (*Chapter 2 — "The Location Mindset*"). The authors' message is basically that the geospatial analytic tradecraft is the amalgamated process encompassing human psychology, a panoply of sciences - the cornerstones being geography, cartography, GIS, geospatial analysis, and communication. Uncompromising in its thorough and systematic layout and exposition of the vital role which principles and practices of geospatial intelligence and knowledge play in the process of tradecraft, the book is organized in ten chapters. Except for Chapter 1 and 10, all Chapters have a Conclusions section. All Chapters, except for Chapters 8 and 10 provide a manageable core of relevant references as a subsection to the Conclusions section. In a writing style which is appealing, clear, precise, and articulate, the authors present and illustrate specific

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techniques developed as part of the workflow required by the process of geospatial intelligence gathering. In-depth treatment is given to the principles and practices of intra-personal pondering of the geo-observational data through thinking and reasoning, the choice of modeling and visualization techniques, and generation of analytical results. The inter-personal communication principles and practices deal with how to communicate findings to peers and audiences, while documenting the associated hypotheses, assumptions, models, inference methodologies, and uncertainties.

Frequent examples of the application of geospatial observations, analysis and reporting to specific incidents and case studies are provided throughout, and terms associated with tradecraft and their acronyms are defined. Some examples are: *Pattern of Life* (*Chapter 3 — "The Geospatial Toolset*") *Observation, analysis and communications* (OAC) (*Chapter 4 — "The Geospatial Skillset: Observation Principles*"); *Structured Analytical Techniques* (SAT) and the *Target Method* (*Chapter 7 — "The Skillset: Geospatial Analysis Practices"*); *Broad Area Search* (BAS) (*Chapter 5 — "The Geospatial Skillset: Observation Practices"; Chapter 8 — "The Geospatial Skillset: Communication Principles*"); *Structured geospatial observation techniques* (SGOT) (*Chapter 9 — "The Geospatial Skillset: Communication Practices*"); and *Denial and deception* (*Chapter 6 — "The Geospatial Skillset: Analysis Principles*").

Focusing on geospatial skill sets, the authors give them distinct treatment depending on whether they are part of observation, analysis, or communication. Subsumed within each of these, principles and practices are treated separately in chapters 4 through 9. The authors present the Four Cornerstones Method (Location, Color, Shape, Context) which when applied to observations, is clearly based on photointerpretation (*Chapter 5 — "The Geospatial Skillset: Observation Practices*" but can also be applied to communication practices (*Chapter 9 — "The Geospatial Skillset: Communication Practices*".)

The topics explored are cast against a backdrop of modern developments such as the escalating and dramatic changes of the Information Age, including mention of the relevance and promise of the Geospatial Data Act of 2018. The authors provide an all-encompassing view of the principles and practices, resorting to abundant illustrations and examples, a few even steeped in historic tradition from the domains of science, geography, and spatial analysis. Such are: Galileo's quote about the observational power granted to him by the use of the telescope effectively nullifying any wordy arguments about the nature of the Galaxy, which he inferred to be clusters of stars; John Snow's cholera map given as an example of superb contextual analysis in action, which resulted in drastic changes in the epidemiological mindset of his time; and Tobler's Law regarding waning similarities between observed geospatial entities as distances separating them grow, a warning to analysts as they engage in BAS.

As they explore the relevance of Geographic Information Systems (GIS) is defined in (*Chapter 3 — "The Geospatial Toolset*"), the authors make the valid and often forgotten point that despite the ever-growing multitude of data, software, and hardware – or toolset, people and their attendant skill sets are a necessary and essential component of GIS (page 48; *Section 3.7; "The Importance of People in the Geospatial Toolset*"). The implication and message of this book is that – in the end, tradecraft is and will remain a human endeavor, regardless of the tools and resources brought to bear. As the authors best put it, " *Humans will remain the most important tool in the toolset, providing reason, nimbleness and mentorship in ways that computers will never provide"* (*page 217; Chapter 10; "Outlook"*).

We all should look forward to a needed and new edition of this book, in which the authors will hopefully incorporate the now pervasive plethora of geospatial artificial intelligence (geo-A.I.) toolsets, while giving them the proper and correct contextual placement in the process of geospatial information intelligence. Based on the developmental structure of this first edition, a treatment of the way these new geo-A.I.-based toolsets are co-evolving with and impacting human skill sets and communication is also to be expected. Hopefully, the focus will still be on the role of human intelligence as both the primordial source and location, and ulterior target of the geospatial tradecraft process.

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Scan Angle Analysis of Airborne Lidar Data for Missing Return Approximation in Urban Areas

Hamid Gharibi and Ayman Habib

Abstract

The density and uniformity of lidar data play crucial roles in the corresponding data processing steps. One factor influencing point density and spacing in lidar data is the presence of empty pulses, where no return is detected. Missing returns can occur due to atmospheric absorption, specular and diffusive reflection, etc. To address this issue and enhance point density, this paper introduces a novel method for approximating missing returns in airborne lidar data collected over urban areas. This technique focuses on approximating returns for empty pulses that hit spots near abrupt slope changes on building and ground surfaces. The proposed methodology is validated through experiments using a lidar data set from downtown Dublin, Ireland. The collected data contained numerous gaps associated with wet surfaces, as well as missing returns on vertical and oblique surfaces.

Introduction

Airborne laser scanning or light detection and ranging (lidar) is a mapping technology to collect rapid, accurate, and high-resolution 3D data. Over the last two decades, airborne lidar has been used to acquire point data useful for applications such as flood plain mapping (Cobby *et al.* 2003; Cook and Merwade 2009; Malinowski *et al.* 2016) and forestry (Hollaus *et al.* 2006; Shi *et al.* 2018; Yu *et al.* 2011). Airborne lidar has also been used to collect mapping data over urban areas for diverse applications such as 3D city modeling, map updating, urban growth analysis, and disaster management. The acquired lidar points do not possess semantic information, leading to the development of various data processing methods to extract meaningful information for applications such as automated building extraction (Awrangjeb *et al.* 2013; Gilani *et al.* 2016), 3D building modeling (Arefi and Reinartz 2013; Habib *et al.* 2010), and urban scene classification (Gerke and Xiao 2014; Guo *et al.* 2011). An important workflow step in urban applications is the segmentation for which most techniques examine a 2D or 3D neighborhood of each point to fragment its data into geometric objects (Lari and Habib 2014; Kwak and Habib 2014; Vosselman 2013). Thus, the performance of the segmentation process is highly dependent on the sampling density/spacing of the input lidar data. Some of the developed data processing techniques have used the lidar systems' scan pattern, which can be in the form of zigzag, parallel, or elliptical scan lines (Vosselman and Mass 2010). Some researchers have used the parallel scan pattern to devise processing methods for ground filtering and classification of lidar data. Shan and Sampath (2005) and Hu *et al.* (2013) processed lidar data in the form of individual scan lines for filtering the ground points by analyzing geometric quantities such as slope, distance, and height difference between adjacent points. Moreover, Han *et al.* (2007) and Hebel and Stilla (2008) proposed methodologies for the classification of lidar data in urban areas also based on the geometric similarities between adjacent points along individual scan lines. Thus, the sampling density and regularity of lidar data is a crucial factor in the performance of both the scan line–based and 2D/3D neighborhood–based filtering and segmentation techniques.

An issue that degrades the sampling density of lidar data is the problem of missing returns, which occur when no/weak echoes of the emitted laser pulses reach the lidar system. This issue can happen due to atmospheric absorption or absorption at the target surface (i.e., low reflectance), specular reflection associated with smooth surfaces (e.g., water, glass), diffusive reflection of the targets with rough surfaces (e.g., rocks, tree trunks), multiple reflecting areas causing weak return echoes (e.g., tree canopies), and large distance between the lidar system and the target surface (Höfle 2007). The airborne lidar systems typically operate at between 800 and 1550 nm, wavelengths at which the reflectivity of water is low, causing the emitted laser pulses that hit water or wet surfaces to not reflect toward the flying platform (Vosselman and Mass 2010). Still water (i.e., not disturbed by wind) and horizontal wet surfaces can also cause specular reflection at off-nadir scan angles, resulting in low amplitude return echoes undiscoverable by the lidar system (Harding 2017). An example of missing returns along water/wet surfaces is shown in Figure 1, in which Figure 1a shows an aerial image of an urban area, and Figure 1b shows the acquired lidar data for the same area. The aerial imagery and lidar data presented in Figure 1 were captured over Dublin, Ireland, from the same platform, simultaneously. As indicated by the red arrows in Figure 1a, some parts on the building roofs are covered by the water remaining from recent rain. Some of the emitted laser pulses that hit those wet surfaces were either not reflected or weakly reflected toward the operating lidar system. For diffusively reflective surfaces such as a rock, tree trunk, and asphalt with pebbles, the laser reflection pattern is hemispherical, with the maximum reflectance perpendicular to the target plane and the reflectance amplitude weakening rapidly to each side (Petrie and Toth 2017). Therefore, the interaction of laser pulses with such surfaces at small incident angles may result in the absence of return echoes. Moreover, missing returns can occur on glassy surfaces (e.g., windows, skylights), where the emitted laser pulses are either refracted or specularly reflected.

The approximation of missing returns can increase the density and uniformity of lidar data, and thereby, it can improve the performance of data processing and segmentation methods. Some researchers have focused on the identification and approximation of missing returns by using the temporal or angular pattern of emitted laser pulses (Höfle 2007; Hinks 2011). A laser pulse for which no return echo is detected is referred to as an empty pulse herein. In the missing return approximation method proposed by Höfle (2007), the time differences between sequential laser pulses in each scan line are computed and compared with the pulse repetition rate of the corresponding lidar system to identify empty pulses. For each empty pulse, a return is then approximated by linear interpolation between the returns of a laser pulse before and a laser pulse after the empty pulse. However, the point spacing between the last returns of consecutive laser pulses varies with scan angle and is not constant as assumed within the linear interpolation process. To mitigate

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Contributed by Tolga Bakirman, March 2, 2023 (sent for review August 16, 2023; reviewed by George Vosselman).

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Assessment, Specification, and Validation of a Geolocation System's Accuracy and Predicted Accuracy

John Dolloff, Henry Theiss, and Brian Bollin

Abstract

This article presents recommendations and corresponding detailed procedures for the assessment of a geolocation system's accuracy, as well as the specification of accuracy requirements and their subsequent validation when they are available. Applicable metrics and related processing are based on samples of corresponding geolocation errors. This article also presents similar recommendations for the predicted accuracy of a geolocation system, based on samples of geolocation error, as well as corresponding predicted error covariance matrices associated with the geolocations. Reliable error covariance matrices enable optimal use of a geolocation system's products, such as the optimal fusion of multiple geolocations or multiple products for higher confidence and increased accuracy. The recommendations presented in this article enable reliable estimates of accuracy and reliable predicted accuracies, both of which are critical to many geolocation-based applications. The recommendations associated with predicted accuracy are also relatively new and innovative.

Introduction

In this article, a geolocation system is synonymous with an arbitrary but specific type or class of geolocation products that it generates and outputs, such as 3D point clouds generated from electro-optical imagery within a specified time span and available from a specified organization or vendor. These products are nominally defined to contain explicit geolocations or data that can be used to extract such geolocations, such as stereo pairs of images with image support data and an Application Programming Interface (API) provided by the geolocation system to related functions, such as an image-to-ground function, adjustable parameters, and uncertainty information relative to sensor pose. A geolocation system also generates and outputs numerous instances or realizations of corresponding individual products, all from the same explicit class or type of product.

Today, there is an ever-increasing number of geolocation systems that produce and output geolocation products. As such, a reliable estimate of a geolocation system's accuracy is a critical metric, such that corresponding geolocations can be applied in an informed and appropriate fashion. This metric is defined as applicable to an arbitrary geolocation contained in an arbitrary product and characterizes the accuracy of the Geolocation System as a whole. This article advocates the use of an applicable scalar accuracy metric, such as the 90th percentile linear error (*LE*90), the 90th percentile circular error (*CE*90), and 90th percentile spherical error (*SE*90), which correspond to vertical, horizontal, and 3D geolocation errors, respectively. For example, *CE*90 is defined as the radius of a circle, such that it is 90% probable that an arbitrary horizontal geolocation error resides within it.

Not only are the above metrics relatively simple and easy to understand, but they also have a built-in probability (e.g., 90%) associated with them. As such, they contain more information than, for example, a root-mean-square (rms) metric. Another benefit of these metrics is that a reliable estimate of their value can be computed using order statistics, with no information required about the corresponding probability distribution of the underlying geolocation errors, which is a robust and desirable feature. In addition, a rigorously derived least-upper-bound (lub) relative to their true (but unknown) value can also be computed at a specifiable confidence level.

An assessment of accuracy is a process that provides such estimates and is based on samples of geolocation error relative to highly accurate "ground truth." Other related metrics and processes include the specification of accuracy requirements for the geolocation system by those responsible for the system, as well as the validation that those requirements are met. All of the above metrics and processes are under the category of geolocation system accuracy, a major section in this article.

This article also advocates that a geolocation system include a reliable predicted accuracy metric with each geolocation or include the metadata with a product to rigorously generate it. The recommended metric is the predicted error covariance matrix. As such, although there is essentially only one accuracy metric value for the geolocation system, there is potentially an unlimited number of predicted accuracy metric (predicted error covariance matrix) values. Each geolocation in each product has its own unique predicted error covariance matrix tailored to that geolocation; for example, if the geolocations are 3D, they should have their own unique 3 × 3 predicted error covariance matrix. Unfortunately, a significant number of existing geolocation systems do not have or support the generation of predicted error covariance matrices. One goal of this article is to advocate for their generation and use. Examples of articles in the photogrammetric literature that provide approaches for computing predicted accuracy include the work of Eren *et al.* (2019) and Mezian *et al*. (2016).

If the geolocation system is image-based, a predicted error covariance matrix is typically computed, along with an estimate of the corresponding geolocation, as a multi-image geolocation (MIG) optimal weighted-least-squares solution or as a single-image geolocation (SIG) that includes an external estimate of the vertical coordinate. Both the geolocation (estimate) and its predicted error covariance are subsequently "placed" in the corresponding product. These solutions account for image-to-ground geometry, as well as other factors that affect the specific geolocation's solution and its uncertainty. Hence, the need for a unique predicted error covariance matrix for each geolocation. Similar processes, such as a block adjustment, perform similar solutions.

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Call for *PE&RS* Special Issue Submissions

Ushering a New Era of Hyperspectral Remote Sensing to Advance Remote Sensing Science in the Twenty-first Century

Great advances are taking place in remote sensing with the advent of new generation of hyperspectral sensors. These include data from, already in orbit sensors such as: 1. Germany's Deutsches Zentrum fur Luftund Raumfahrt (DLR's) Earth Sensing Imaging Spectrometer (DESIS) sensor onboard the International Space Station (ISS), 2. Italian Space Agency's (ASI's) PRISMA (Hyperspectral Precursor of the Application Mission), and 3. Germany's DLR's Environmental Mapping and Analysis Program (EnMAP). Further, Planet Labs PBC recently announced the launch of two hyperspectral sensors called Tanager in 2023. NASA is planning for the hyperspectral sensor Surface Biology and Geology (SBG) to be launched in the coming years. Further, we already have over 70,000 hyperspectral images of the world acquired from NASA's Earth Observing-1 (EO-1) Hyperion that are freely available to anyone from the U.S. Geological Survey's data archives. These suites of sensors acquire data in 200 plus hyperspectral narrowbands (HNBs) in 2.55 to 12 nm bandwidth, either in 400-1000 or 400-2500 nm spectral range with SBG also acquiring data in the thermal range. In addition, Landsat-NEXT is planning a constellation of 3 satellites each carrying 26 bands in the 400-12,000 nm wavelength range. HNBs provide data as "spectral signatures" in stark contrast to "a few data points along the spectrum" provided by multispectral broadbands (MBBs) such as the Landsat satellite series.

The goal of this special issue is to seek scientific papers that perform research utilizing data from these new generation hyperspectral narrowband (HNB) sensors for a wide array of science applications and compare them with the performance of the multispectral broadband (MBB) sensors such as Landsat, Sentinels, MODIS, IRS, SPOT, and a host of others.

Papers on the following topics are of particular interest:

1. Methods and techniques of understanding, processing, and computing hyperspectral data with specific emphasis on machine learning, deep learning, artificial intelligence (ML/DL/AI), and cloud computing.
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3. Building hyperspectral libraries for purposes of creating reference training, testing, and validation data.
4. Utilizing time-series multispectral data and hyperspectral data over many years to build data cubes and apply advanced computational methods of ML/DL/AI methods and approaches on the cloud.
5. Discussions of hyperspectral data analysis techniques like full spectral analysis versus optimal band analysis.
6. Developing hyperspectral vegetation indices (HVIs) for targeted applications to model and map plant biophysical (e.g., Yield, biomass, leaf area index), biochemical (e.g., Nitrogen, anthocyanins, carotenoids), plant health/stress, and plant structural quantities.
7. Classification of complex vegetation and crop types/species using HNBs and HVIs and comparing them with the performance of multispectral broadband data.

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A Keyframe Extraction Approach for 3D Videogrammetry Based on Baseline Constraints

Xinyi Liu, Qingwu Hu, and Xianfeng Huang

Abstract

In this paper, we propose a novel approach for the extraction of high-quality frames to enhance the fidelity of videogrammetry by combining fuzzy frames removal and baseline constraints. We first implement a gradient-based mutual information method to filter out low-quality frames while preserving the integrity of the videos. After frame pose estimation, the geometric properties of the baseline are constrained by three aspects to extract the keyframes: quality of relative orientation, baseline direction, and base to distance ratio. The three-dimensional model is then reconstructed based on these extracted keyframes. Experimental results demonstrate that our approach maintains a strong robustness throughout the aerial triangulation, leading to high levels of reconstruction precision across diverse video scenarios. Compared to other methods, this paper improves the reconstruction accuracy by more than 0.2 mm while simultaneously maintaining the completeness.

Introduction

As a digital replication of the physical world, three-dimensional (3D) reconstruction is of great value in computer vision and photogrammetry (Yang *et al.* 2020a), with practical applications spanning various industries, including entertainment, cultural heritage preservation, and autonomous vehicles. Currently, there are three main techniques for generating 3D models: manual modelling, laser scanning, and photogrammetry using imagery or videos (Li 2016). Among these, videogrammetry stands out as a notably rapid and automated alternative, offering enhanced efficiency in data acquisition, ease of data collection, and improved temporal and spatial continuity (Herráez *et al.* 2016). Moreover, videogrammetry is acclaimed for its low cost, high efficiency, and ease of use, positioning it as the preferred technique for 3D reconstruction. This method not only facilitates more informed decision-making and streamlines workflows but also catalyzes innovation within numerous industrial domains (Kien 2005; Taneja *et al.* 2011; Torresani and Remondino 2019; Chang and Kehtarnavaz 2018; Chen 2019). Despite these advantages, using raw video frames for 3D reconstruction poses two significant challenges that need to be addressed.

Firstly, a major computational efficiency issue arises due to the significant similarity between consecutive frames, which leads to substantial data redundancy and high computational costs when processing all frames.

Secondly, the accuracy of reconstruction is compromised due to various factors. On one hand, the quality of video frames can be compromised by camera shaking and variations in movement speed during video recording. On the other hand, 3D reconstruction is affected by several factors such as baseline length, working distance, orientation angle, camera focal length, and pixel coordinate error (Wang *et al.* 2011). In videos, maintaining consistent, intrinsic factors such as camera focal length and pixel coordinate error is necessary. Hence, it is crucial to control the baseline and overlap between frames to ensure the accuracy of 3D reconstruction. Limited overlap or insufficient baseline length might lead to inaccuracies during the reconstruction process.

In this study, a gradient-based mutual information approach is used on video frames to identify high-quality frames. In addition, we introduce baseline constraints to extract keyframes, taking into account aspects such as relative orientation quality, baseline direction, and base to distance ratio to ensure sufficient overlap while avoiding excessively short baselines. With the proliferation of diversity of videos and the continuous expansion of data scale, our proposed approach demonstrates wide applicability across various video scenarios and attains high-precision video reconstruction.

Related Work

Videogrammetry

In the field of videogrammetry, there has been a great deal of research into the handling of various types of challenges. Pollefeys *et al.* (2008) used videos because of their high redundancy to effectively alleviate occlusion issues caused by trees in large-scale city scene reconstruction. Ponomaryov and Ramos-Diaz *et al.* (2011) proposed and implemented a video reconstruction technique based on wavelet atomic functions (WAF). Han *et al.* (2011) devised an extended deterministic annealing algorithm to tackle the problem of blank walls in video reconstruction. However, the resulting dense depth map often lacks smoothness, leading to the omission of authentic geometric features such as planar surfaces. Byrne *et al.* (2017) used videos shot by an unmanned aerial vehicle to capture additional images and increase overlap, facilitating reconstruction in scenarios characterized by unstable and highly dynamic lenses.

Recently, researchers have concentrated on developing end-to-end frameworks for complete two-dimensional (2D)-to-3D model reconstruction (Wang *et al.* 2021; Khorasani Ghassab and Bouguila 2021). Additionally, encouraging experimental results have been presented for deep learning methods (Yang *et al.* 2020b; Sun *et al.* 2021).

Keyframe Extraction

Existing keyframe extraction approaches can be classified into two primary categories: content-based and geometry-based.

The first group of approaches has broad practical use across multiple domains, such as video compression, video retrieval, and video classification. Two primary techniques are implemented for the extraction of keyframes in this category. Firstly, the feature-based approach detects keyframes through variations in visual attributes, such as color and texture, within each frame (Calic and Izuierdo 2002; Ding and Chen 2009). To overcome the limitations of depending on a single image feature, Ioannidis *et al.* (2016) proposed an approach that combines multiple features through weighted fusion. The second approach employs clustering-based strategies, in which cluster centers

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Extraction of Terraces in Hilly Areas from Remote Sensing Images Using DEM and Improved U-Net

Fengcan Peng, Qiuzhi Peng, Di Chen, Jiating Lu, and Yufei Song

Abstract

To extract terraced fields in hilly areas on a large scale in an automated and high-precision manner, this paper proposes a terrace extraction method that combines the Digital Elevation Model (DEM), Sentinel-2 imagery, and the improved U-Net semantic segmentation model. The U-Net model is modified by introducing Attention Gate modules into its decoding modules to suppress the interference of redundant features and adding Dropout and Batch Normalization layers to improve training speed, robustness, and fitting ability. In addition, the DEM band is combined with the red, green, and blue bands of the remote sensing images to make full use of terrain information. The experimental results show that the Precision, Recall, F1 score, and Mean Intersection over Union of the proposed method for terrace extraction are improved to other mainstream advanced methods, and the internal information of the terraces extracted is more complete, with fewer false positive and false negative results.

Introduction

Terrace construction is a widely adaptable agricultural management strategy in areas threatened by soil erosion, severe drought, and landslides (Lasanta *et al.* 2001). Multiple ecological functions are performed by terraces, including reducing water runoff (Chow *et al.* 1999; Montgomery 2007), controlling soil erosion (Sharda *et al.* 2002), improving land productivity (Homburg and Sandor 2011), ensuring food security (Dai *et al.* 2020; Rockström and Falkenmark 2015), and restoring biodiversity and ecosystems (Tokuoka and Hashigoe 2015; Wei *et al.* 2012). The accurate spatial distribution of terraces holds significant importance for agricultural management and soil and water conservation departments. It enables effective protection and management of terrace resources, providing valuable scientific decision support in these fields (Jijun *et al.* 2010; Liu *et al.* 2019).

Due to the large scale and complex distribution of terraces, it is difficult for traditional manual survey and mapping methods to meet the demand for rapid and accurate assessment and monitoring of terraces. Remote sensing is a technology with broad application prospects, which can meet rapid positioning and detection in different spatial scales (Xie *et al.* 2008). Deep learning, as a powerful machine learning method, has experienced rapid advancements in the field of remote sensing since 2014 (Zhu *et al.* 2017). In recent years, the application of deep learning-based methods for remote sensing image analysis has witnessed significant advancements. These techniques have demonstrated remarkable success in various tasks associated with remote sensing information extraction (Yu *et al.* 2018; Zhang *et al.* 2018; Zhang *et al.* 2020b), including object classification (Kussul *et al.* 2017; Yu *et al.* 2021), object detection (Cheng *et al.* 2021; Erdem *et al.* 2021), change detection (Zhang *et al.* 2020a), and other tasks. However, although there has been some research on terrace extraction, most of them are focused on the Loess Plateau in China. For instance, Yu *et al.* (2022) used a deep learning transfer method to automatically identify terraced fields specifically in the Loess Plateau region. Guo *et al.* (2023) used semantic segmentation based on deep learning and change detection to identify abandoned terraced fields in the Loess Plateau. Based on the comprehensive analysis above, there is currently limited research on the extraction of terraced fields in hilly areas, primarily due to the greater challenges associated with studying complex terrain regions (Wei *et al.* 2021). Consequently, it is crucial to explore extraction methods for terraced fields in southern hilly regions; as such, research holds both theoretical and practical significance. Additionally, previous studies have typically relied on high-resolution satellite images for data selection in the extraction of terraces, such as WorldView (Luo *et al.* 2020; Zhao *et al.* 2017), SPOT-5 (Li *et al.* 2013), Gaofen-1 (Zhang *et al.* 2017) and unmanned aerial vehicles (Diaz-Varela *et al.* 2014). High-resolution data is expensive and not universally accessible, which limits its usability for large-scale applications. Alternatively, medium-resolution data like *Sentinel-2* imagery, provides a more practical and freely available option for data in the extraction of terraces.

Initially, the extraction of terraces primarily relied on the spectral information of remote sensing images. Zhang *et al.* (2016) constructed extraction rules for terraced fields based on the texture, spectral, and spatial features of image objects. Although the extraction task of terraces can be completed to a certain extent by simply relying on spectral images, it is important to consider that the spatial distribution of terraces is also influenced by topographic factors. Therefore, many researchers have combined multispectral images with the Digital Elevation Model (DEM) to extract terraces. For instance, Dai *et al.* (2020) applied edge detection operators to detect terrace edge information from high-resolution remote sensing images and extracted terrace contour information from DEM and finally combined the results of the two to complete terrace extraction. Similarly, Hongming *et al.* (2018) combined with DEM slope information and Canny edge detection operator to extract terraces from unmanned aerial vehicle orthophoto images. However, the spatial resolutions of the image and DEM data used in these studies have reached the sub-meter level, which is not suitable for large-scale applications not suitable for large-scale applications.

Semantic segmentation based on the U-Net model (Ronneberger *et al.* 2015) is an efficient and accurate remote sensing image processing method, which has broad application prospects. The attention mechanism (Schlemper *et al.* 2019) simulates human visual behavior by assigning more weights to networks to focus on useful information in feature maps. Based on the semantic segmentation framework, an attention mechanism is introduced to assign different weights to different spatial positions or channels of the feature map through network learning. This allows for the acquisition of more discriminative feature representations. Kim *et al.* (2018) integrated the spatial pyramid pool module into the U-Net model and solved the problem of feature loss of surface features after multiple feature fusion in the U-Net model; Ranjan *et al.* (2020) applied the multi-residual attention (MRA) structure to the U-Net model to improve the accuracy of remote sensing image feature information extraction. Although many improved U-Net models show the great advantages of deep convolution neural networks

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