PE&RS

January 2024

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PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

The official journal for imaging and geospatial information science and technology

ANNOUNCEMENTS

Dewberry, www.dewberry.com, has announced it was selected by the Florida Department of Environmental Protection (FDEP) and Office of Resilience and Coastal Protection (ORCP) to support the Florida Seafloor Mapping Initiative (FSMI), an effort to capture statewide bathymetric lidar to the 20-meter isobath and acoustic/sonar soundings from the 20-meter isobath to the 200-meter isobath.

Dewberry was selected to provide topobathymetric lidar mapping for the entire Gulf Coast of Florida, beginning in the western Panhandle and continuing south through Naples. This area includes Southwest Gulf – Region IV, Big Bend – Region V, and Panhandle – Region VI.

"We're excited to support the state of Florida on this important initiative," says Dewberry Senior Associate and Project Manager Emily Klipp. "The data we collect with our CZMIL SuperNova sensors will be a valuable tool to guide resilience and coastal protection officials as they navigate the increasing environmental challenges faced by the state."

For more information on the FSMI, visit https://floridadep.gov/, https://floridadep.gov/orcp, and www.floridagio.gov/ (FGIO) for timelines and anticipated schedules. Find a StoryMap with collection regions, progress updates, and processing status www.floridagio.gov/pages/fsmi.

The **U.S. Geological Survey** has tasked **Woolpert**, www.woolpert.com, with acquiring topographic Quality Level 1 lidar data and providing ground control survey across eastern Arkansas in support of the 3D Elevation Program, www.usgs.gov/3d-elevation-program, and The National Map, https://apps.nationalmap.gov/viewer/.

Led by the USGS National Geospatial Program, 3DEP offers the nation's first baseline of seamless, high-resolution topographic elevation data, which is then incorporated into The National Map. These data are free and publicly available to local, state, and national agencies. They are used to inform decisions that impact the immediate safety of life, property, and the environment, and they are critical to effective, long-term infrastructure planning.

In Arkansas, lidar data has proved beneficial in supporting numerous business activities, including agriculture and precision farming, and has advanced flood-risk management, urban and regional planning, natural resources conservation, and critical mineral assessment, www.usgs.gov/publications/3d-elevation-program-supporting-arkansass-economy.

Under this task order, Woolpert will collect 24,533 square miles of aerial lidar data, including parts of the Ozark-St. Francis and Ouachita National forests, using a Leica TerrainMapper. Woolpert Project Manager Megan Blaskovich said that the size and complexity of the area of interest required extensive planning. She expects the lidar data to be acquired by fall 2024 and delivered in summer 2025. QL1 data are collected at 8 points per square meter.

"This is one of the largest Quality Level 1 lidar acquisition projects our team has been tasked with. We will be flying 996 flight lines and collecting over 940 ground control survey points," Blaskovich said. "We are excited to get started."

Woolpert has supported 3DEP since its launch nearly a decade ago. The firm has collected data across multiple states, tested sensors for optimal acquisition, and provided training for state and local government officials. Most recently, Woolpert delivered 13,000 square miles of aerial lidar data collected across southwest Ohio and completed lidar data acquisition across Colorado and Oregon under additional task orders for the USGS.

"It has been an honor supporting the U.S. Geological Survey and its efforts updating and enhancing The National Map," Woolpert Program Director John Gerhard said. "The importance of this work extends far beyond the project's completion. From disaster preparedness and emergency response to long-term infrastructure planning, these data will help inform decisions to improve the lives of individuals for years to come."

By learning about mapping skills and geography, students, teachers, and others can gain a better understanding of how the world's most crucial issues, challenges, and opportunities fit into the context of place. In celebration of GIS Day, www.gisday.com/en-us/overview, and as part of Geography Awareness Week, **Esri**,www.esri.com, the global leader in geographic information system (GIS) technology, and the National Geographic Society (NGS), www.nationalgeographic.org/society/, the global nonprofit organization, have launched the reimagined National Geographic MapMaker, https://mapmaker.nationalgeographic.org/.

Developed in partnership with Esri, MapMaker is National Geographic's online mapping tool that uses the latest in GIS software to connect classrooms and individuals with essential geographic information and technology for exploration and education. With this web-based 2D and 3D app, anyone can visually experience and interact with geospatial information about Earth's interconnected social and physical systems while also exploring the art of mapmaking.

"We are honored to continue our partnership with the National Geographic Society to bring MapMaker 4.0 to K–12 students around the world," said Jack Dangermond, Esri president. "We believe that mapping is a powerful tool for learning, communication, and change, and we hope that MapMaker will inspire the next generation to better understand and care for our world."

Updates to MapMaker 4.0 reach beyond the scope of a traditional map and provide users with interactive data on a variety of important topics that enrich learning and better illustrate how maps act as powerful devices that allow us to find our way, analyze and visualize complex datasets, solve problems, and tell stories.

"The [National Geographic] Society has a long history of supporting geographic education, and we are so excited to have our relationship with Esri work further to foster a sense of wonder and curiosity about the world through data-driven mapping technology," said Deborah Grayson, chief education officer at the National Geographic Society. "National Geographic MapMaker is an engaging educational tool with the power to inspire the next generation of geographers, cartographers, and National Geographic Explorers that show how geography influences their lives and work every day, as well as how passion around the geographic approach can address challenges and drive real change around the world."

The new MapMaker allows users to form patterns and relationships by layering maps; adding notes and sketches to maps; and saving images for use in papers, presentations, or other applications. These layers can be created to educate users; represent various biomes, populations, and environments; and view different geographic effects of climate change for innovative learning and exploring.

Students can also explore current and historical maps on topics like earth science (e.g., earthquakes, volcanoes, climate) or human geography (e.g., population characteristics, land cover, public health), and educators can view additional learning resources created by Esri and National Geographic Learning as well. MapMaker runs on online and mobile platforms and lightweight devices, and it is touch screen friendly for an easy experience for users at any age or level of familiarity with geography.

To learn more, explore the National Geographic MapMaker, www.esri.com/en-us/industries/k-12-education/mapmaker.

ACCOMPLISHMENTS

NV5 Geospatial, www.nv5.com, and its partner **Aerial Services Inc. (ASI)**, www.AerialServicesInc.com, recently received the Conservation Innovation Partner Award from the Missouri Conservation Heritage Foundation, https://mochf.org/, and the Missouri Department of Conservation. The companies were honored for their work to map streams, rivers, lakes and ponds in southern Missouri. The culmination of this work delivers 3D elevation derived hydrography (EDH) data that supports the state's conservation efforts and aligns with the United States Geological Survey (USGS) 3D Hydrography Program (3DHP).

"We are proud to be recognized for the important work we are doing with ASI," said Andrew Brenner, Ph.D, vice president of Solutions Engineering, NV5 Geospatial. "This partnership with the Missouri Department of Conservation and ASI has a vision of developing current and accurate water data across the state that will support multiple agencies, organizations and municipalities. The data will provide detail that did not exist before and support decision makers managing Missouri's vital water resources and the ecosystems they support."

NV5 Geospatial is a leader in developing EDH, having worked with the USGS from the initial concept and pilot program in 2016 covering five geographically distinct sites across the lower 48 states through current specifications. NV5 Geospatial has completed numerous EDH projects, including mapping more than 75,000 square miles in Alaska, producing the first operational CONUS EDH dataset for the USGS in Texas, supporting Michigan's development of statewide 3DHP, mapping six watersheds in Pennsylvania and integrating the 3DHP overland/surface flow line with the District of Columbia's storm sewer network. In 2023 alone, NV5 Geospatial was awarded eight 3DHP projects.

In Missouri, NV5 Geospatial has undertaken ground-breaking work to create the next generation of hydrography starting with five watersheds and mapping the network connecting the streams, rivers, lakes and ponds in this region. Using lidar collected as part of USGS's 3D Elevation Program (3DEP), NV5 Geospatial created the new hydrography that will replace the National Hydrography Dataset (NHD), transferred attributes to the dataset, and created drainage basins for each stream segment. These data were created to align with the 3DHP specifications.

In addition to the standard 3DHP specifications, NV5 Geospatial has worked closely with Missouri Department of Conservation, which is leading the efforts to enhance the dataset to; accommodate shallow sinks caused by the Karst geology, create a dataset of bankfull approximation polygons for all mapped river valleys that will support ecological and flood analysis, and demonstrate how the data can be used to support the update of spring locations and wetlands for the state .

For more information on NV5 Geospatial's EDH work, www.nv5.com/geospatial/solutions/edh/.

CALENDAR

- 11-13, February 2024, **Geo Week**, Denver, Colorado; https://www.geo-week.com.
- 2-4 May 2024, **GISTAM 2024**, Angers, France; https://gistam.scitevents.org.
- 13-16 May 2024, **Geospatial World Forum**, Rotterdam, The Netherlands; https://geospatialworldforum.org.
- 11-14 June 2024, **ISPRS Technical Commission II Symposium — The Role of Photogrammetry for a Sustainable World**, Las Vegas, Nevada; www.isprs.org/tc2-symposium2024.

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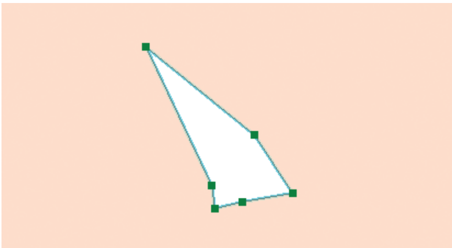

COLUMNS

ANNOUNCEMENTS

DEPARTMENTS

See the Cover Description on Page 4

COVER DESCRIPTION

To human eyes, glacial ice typically looks white tinged with blue. But in this false-color satellite image, the rippled ice of Alaska's Malaspina Glacier appears more fiery than frosty.

This view of Malaspina Glacier on the southeastern coast of Alaska was captured by the OLI-2 (Operational Land Imager-2) on Landsat 9 on October 27, 2023. The coastal/aerosol, near infrared, and shortwave infrared bands are displayed here: a band combination of 1-5-7. In this configuration, watery features are displayed in reds, oranges, and yellows; vegetation appears green; and rock is shown in shades of blue.

The sprawling Malaspina Glacier—or Sít' Tlein, Tlingit for "big glacier"—is located mostly within Wrangell-St. Elias National Park. At approximately 1,680 square miles (4,350 square kilometers) in size, it is the world's largest piedmont glacier and covers an area larger than the state of Rhode Island. Its main source of ice is the Seward Glacier, which spills out of the St. Elias Mountains onto a broad coastal plain. Several other glaciers, such as the Agassiz, also fan out onto this plain and coalesce to form the larger Malaspina.

The dark blueish-purple lines on the ice are moraines—areas where soil, rock, and other debris have been scraped up by the glacier and deposited along its edges. The zigzag pattern of the debris is caused by changes in the ice's velocity. Glaciers in this area of Alaska periodically "surge" or lurch forward for one to several years. As a result of this irregular flow, the moraines can fold, compress, and shear to form the characteristic textures seen on Malaspina.

At the terminus, or end, of the glacier, a thin strip of land creates a barrier between the ice and the Gulf of Alaska. A comparison of satellite imagery over time has revealed a lagoon system forming along that barrier over the past few decades. Small patches of open water are visible here in a rusty red color. Some of this water is nearly as salty as the ocean, according to recent research, meaning that comparatively warm ocean water is making contact with the ice. This could lead to large-scale calving and hasten the glacier's retreat.

NASA Earth Observatory image by Wanmei Liang, using Landsat data from the U.S. Geological Survey. Story by Lindsey Doermann. The entire image can be viewed online by visiting the Landsat Image Gallery, https://landsat.gsfc.nasa.gov/, image id 152121.

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All written correspondence should be directed to the American Society for Photogrammetry and Remote Sensing, PO Box 14713, Baton Rouge, LA 70898, including general inquiries, memberships, subscriptions, business and editorial matters, changes in address, manuscripts for publication, advertising, back issues, and publications. The telephone number of the Society Headquarters is 225-408-4747; the fax number is 225-408-4422; web address is www.asprs.org.

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MEMBERSHIP. Membership is open to any person actively engaged in the practice of photogrammetry, photointerpretation, remote sensing and geographic information systems; or who by means of education or profession is interested in the application or development of these arts and sciences. Membership is for one year, with renewal based on the anniversary date of the month joined. Membership Dues include a 12-month electronic subscription to *PE&RS*. Annual Individual Membership dues are $175.00 USD and Student Membership dues are $50.00 USD. A tax of 5% for Canada's Goods and Service Tax (GST #135123065) is applied to all members residing in Canada.

GIS

Tips & Tricks

By Savannah Carter, CMT-L and Al Karlin, Ph.D., CMS-L, GISP

Slivers be Gone!

One of the most annoying aspects of building large polygon datasets by heads-up digitizing occurs when there are small overlaps and/or gaps where the polygons meet. Edge-matching to eliminate slivers between digitized polygons can be a laborious and tedious task. These "slivers", especially voids, can be very difficult to detect by visual means, so the GIS workflow to resolve these issues generally involves building topology, constructing a ruleset, and running advanced GIS tools; a heady operation for a beginning GIS analyst and particularly cumbersome when tracking a few slivers. This month's GIS Tip demonstrates a quick and effective workflow to avoid the build topology route.

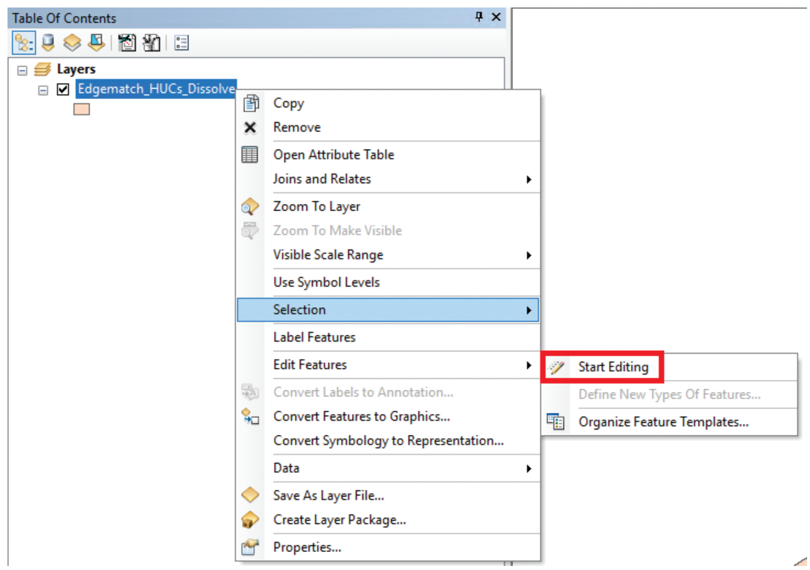

Figure 2. Starting an editing session in ArcMap by right-clicking in the Table of Contents.

TIP #1 — In ArcGIS Desktop using Shapefiles (will also work with Feature Classes)

Step 1 – Data Preparation: Ensure all polygons that must edge-match are in a single shapefile. If the polygons are in multiple shapefiles, use the Data Management | Merge tool to construct a single shapefile.

Step 2 – Use the Data Management | Dissolve tool (Figure 1) and output to a new shapefile. Uncheck the box for "Create multipart features" so the output is a single, dissolved feature. Add the new dissolved shapefile to the map.

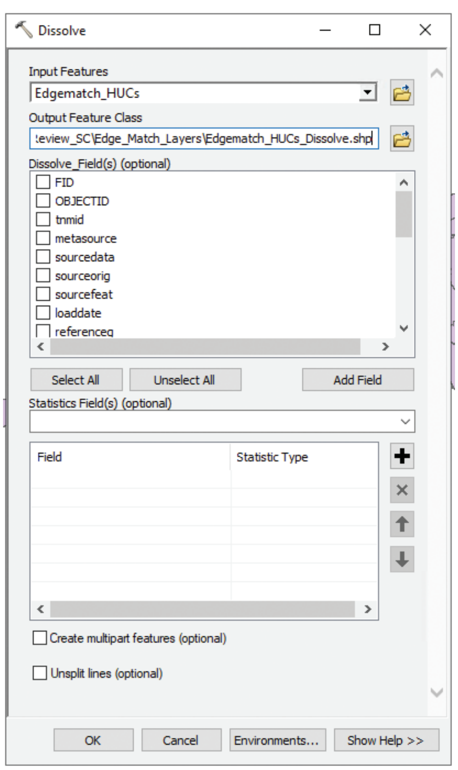

Figure 1. "Data Management | Dissolve" tool setup in ArcMap.

Step 3 – Start an editing session for the dissolved shapefile. In ArcMap, this can be accomplished by right-clicking on the layer in the Table of Contents (Figure. 2), or by using the editing toolbar (Figure. 3).

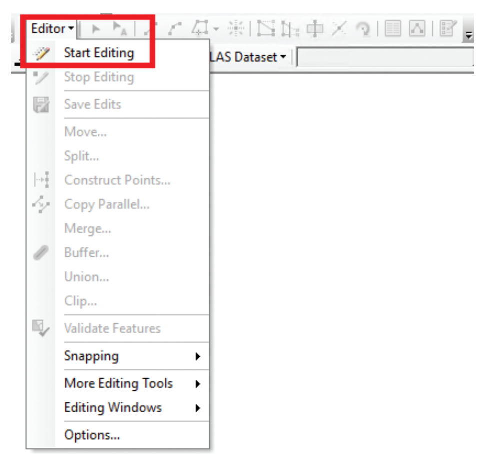

Figure 3. Starting an editing session in ArcMap using the "Editor" toolbar.

Step 4 – Edit vertices of the dissolved shapefile to display all vertices. Using ArcMap, double-click on the feature using the editor selection arrow (Figure 4).

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If the original, individual features edge-match and contain no gaps, vertices should only exist on the outer edge of the dissolved shape. If there were any small gaps between features, a small "hole" will be formed, and vertices will display in the interior of the dissolved shape (Figure 4). Any interior vertices should be investigated for potential gaps (Figure 5).

Step 5 – Using the "Dissolved Polygon" layer to identify the potential edge-matching errors, edit the "Merged Polygon" layer to resolve the sliver issues.

TIP #2 — In ArcGIS Pro using Shapefiles or Feature Classes

The workflow follows much the same steps as in ArcGIS Desktop, but the dialog boxes for the tools have been updated in ArcGIS Pro. Some may find it easier to use feature classes in a file-Geodatabase than using shapefiles.

Step 1 – Prepare the data: if necessary, use the Data Management | Merge tool to merge multiple polygon feature classes into one feature class.

Step 2 – Use the Data Management | Dissolve tool to dissolve the (merged) polygons into a single polygon. Again, be careful to make certain the "Create multipart features" is NOT checked (Figure 6).

Step 3 – Edit the Dissolved Polygon feature class

In ArcGIS Pro, navigate to the "Edit" tab on the top ribbon (Figure 7).

Step 4 – In ArcGIS Pro, select the feature and choose "Edit Vertices" **(Figure 8)** from the "Edit" tab

Step 5 – Using the "Dissolved Polygon" feature class to identify the potential edge-matching errors, edit the "Merged Polygon" layer to resolve the sliver issues. Remember to save edits when completed.

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

Savannah Carter, CMT-L is a geospatial analyst III with Dewberry's Geospatial and Technology Services Group. Savannah works with aerial photo interpretation, topographic and bathymetric LiDAR classification, digital elevation modeling, and sedimentological analyses.

Al Karlin, Ph.D., CMS-L, GISP is a senior geospatial scientist with Dewberry's Geospatial and Technology Services group in Tampa, FL. Al works with all aspects of lidar, remote sensing, photogrammetry, and GIS-related projects. Al also teaches Mapmaking for the Social Sciences and Geographic Information Systems at the University of Tampa.

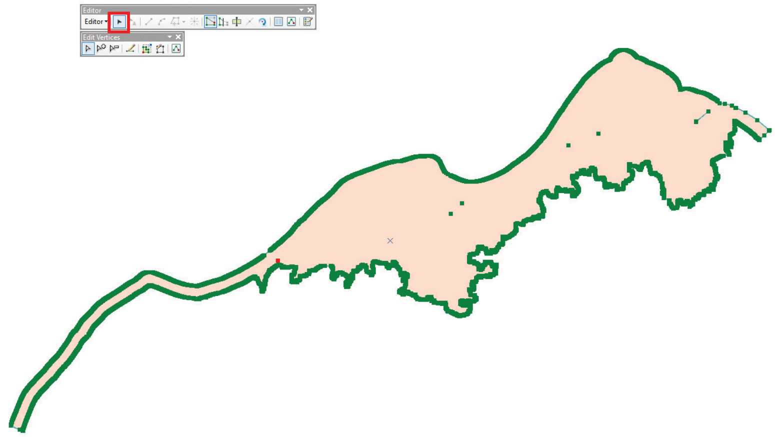

Figure 4. Editing vertices by double-clicking in an editing session.

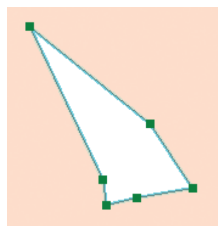

Figure 5. Zooming into one of the interior patches of vertices shows there is a small hole, indicating a gap between features. The gap is very small and only visible around 1:100.

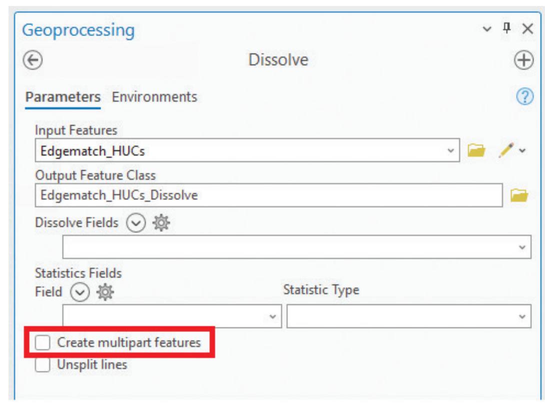

Figure 6. "Data Management | Dissolve" tool setup in ArcGIS Pro.

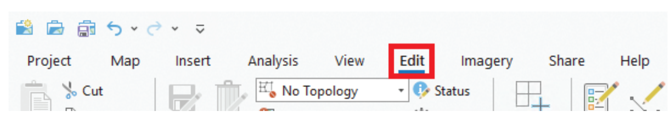

Figure 7. Edit in ArcGIS Pro by selecting the "Edit" tab.

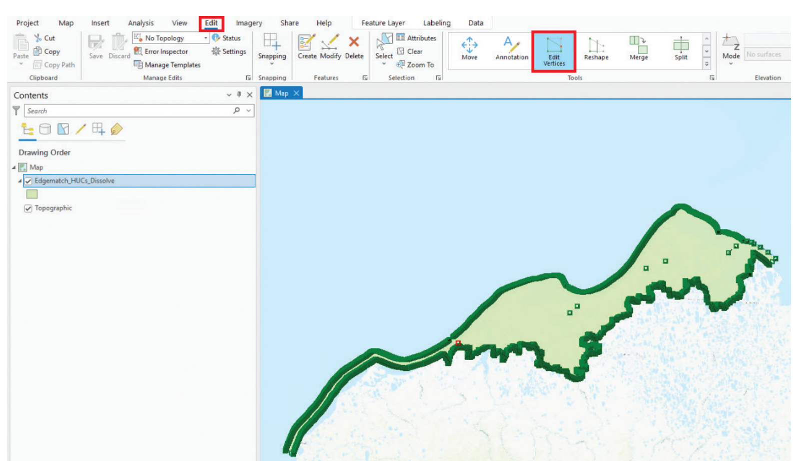

Figure 8. "Edit Vertices" tool in ArcGIS Pro.

The layman's perspective on technical theory and practical applications of mapping and GIS

MAPPING MATTERS

YOUR QUESTIONS ANSWERED

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

- **Have you ever wondered about what can and can't be achieved with geospatial technologies and processes?**
- **Have you been intimidated by formulas or equations in scientific journal articles and published reports?**
- **Would you like to understand the geospatial industry in layman's terms?**
- **Do you have a challenging technical question that no one you know can answer?**

If you answered "YES" to any of these questions, then you need to read Dr. Qassim Abdullah's column, Mapping Matters.

In it, he answers all geospatial questions—no matter how challenging—and offers accessible solutions.

Send your questions to Mapping_Matters@asprs.org

To browse previous articles of Mapping Matters, visit http://www.asprs.org/Mapping-Matters.html

"Your mapping matters publications have helped us a lot in refining our knowledge on the world of Photogrammetry. I always admire what you are doing to the science of Photogrammetry. Thank You Very much! the world wants more of enthusiast scientists like you."

"I read through your comments and calculations twice. It is very clear understandable. I am Honored there are experienced professionals like you, willing to help fellow members and promote knowledge in the Geo-Spatial Sciences."

YOUR COMPANION TO SUCCESS

2024 ASPRS ANNUAL WORKSHOPS AT GEO WEEK!

ASPRS is offering eight thought-provoking in-person workshops during Geo Week.

- Register for workshops through the Geo Week portal, www.geo-week.com.
- Cost is $225 for a 4-hour workshop and $175 for a 2-hour workshop.
- All in-person workshops will be taught in a traditional face-to-face classroom setting. There is no provision for virtual attendance.
- If you have questions about registration, contact GeoWeek@xpressreg.net. If you have questions about content, contact programs@asprs.org.

Introduction to Geographic Object Based Object Analysis (GEOBIA) Utilizing eCognition Developer

February 11, 2024, 8 AM to 12 NOON

Presenters

Dr. JB Sharma, *University of North Georgia*, Department of Physics and Astronomy, Emeritus Retiree; Penn State University, Dutton Adjunct Professor and

John McCombs, *Lynker* for *NOAA Office of Coastal Management*, GIS Team Lead

High spatial resolution remotely sensed data streams from multiple sensors present an increasing challenge and opportunity for mapping applications. eCognition Developer software is a leader in GEOBIA based automated feature extraction capability for high spatial resolution multi-sensor based mapping. This workshop will introduce the participants to the fundamental concepts of GEOBIA mapping workflows and provide a hands-on exploration of eCognition Developer software. This includes an overview of the eCognition interface, exploration of segmentation algorithms, creating workspaces and projects, object exploration, interpretation keys, ruleset development and a simple classification. The fusion of spectral and spatial Remotely Sensing (RS) data in mapping applications will be emphasized. There are several resources available for learning about additional capabilities of eCognition which will be discussed. GEOBIA workflows replicate human visual cognition which are based not just on spectral information, but include object attributes like geometry, location, size, texture, pattern, context, shadows and relations to neighbors. Traditional RS image classification approaches are solely based on the spectral properties of pixels of moderate resolution (>10 m) multispectral (MSI) satellite data. In the past two decades there has been a proliferation of MSI from satellite and aerial platforms at a high spatial resolution (<1 m). Lidar collects are increasing nationwide where the point clouds can be processed to <1 m rasterized elevation models. Unmanned Aerial Systems (UAS) are data collection platforms at an ultra-high spatial resolution to the order of centimeters. Pixel based spectral classification approaches do not work for high and ultra-high spatial resolution data. These high spatial resolution and exponentially increasing RS data streams give a particular contemporary importance to the multi-sensor mapping capabilities of the eCognition Developer software. This workshop will introduce GEOBIA principles and ruleset development in an interactive and hands-on manner. Participants will be provided with instructions for installing the eCognition Developer software and the provided RS data on their laptops, prior to the workshop.

Practical Approach to Using the ASPRS Positional Accuracy Standards for Digital Geospatial Data

February 11, 2024, 8 AM to 12 NOON

Presenter

Dr. Qassim Abdullah, *Woolpert*, Vice-President and Chief Scientist; ASPRS Positional Accuracy Standards Working Group, Chair

This workshop provides an in-depth look at the ASPRS Positional Accuracy Standards to categorize positional accuracy of products derived from digital aerial cameras, manned and unmanned aerial systems, and all types of lidar including terrestrial, mobile, and airborne. The workshop will explain the basis for each accuracy measure adopted in the standards. Instructors will demonstrate practical application of these standards using a web-based application deployed by Esri.

Remote Sensing Data for Climate Change Analysis

February 11, 2024, 8 AM to 10 am

Presenter

Dr. Indu Jeyachandran, *San Jose State University*, Department of Civil and Environmental Engineering, Assistant Professor

This workshop will focus on applications of remote sensing for climate change analysis. A case study of Land Surface Temperature(LST) variation across a decade using Landsat LST data will be demonstrated during the workshop. Participants will learn to analyze LST data and study the variation of LST across various years.

Geospatial Deep Learning with ArcGIS
February 11, 2024, 10 AM to 12 NOON

Presenters
Vinay Viswambharan, *Esri*, Imagery and Remote Sensing, Principal Product Manager
Canserina Kurnia, *Esri*, Senior Solution Engineer

Deep Learning is an AI technique that uses deep neural networks to solve complex problems. One area of AI where Deep Learning has done exceedingly well is computer vision, or the ability for computers to see. This makes it especially suitable for imagery tasks such as pixel classification, object detection, and categorizing features. ArcGIS provides a rich suite of tools and APIs to perform end-to-end deep learning workflows with a variety of data types. In this session users will learn how deep learning can be applied to perform feature extraction and classification in the ArcGIS Platform. You will see how Deep Learning tools, Pre-trained deep learning models and AI-infused apps make deep learning easier to use – within ArcGIS Pro, the online Map Viewer and ArcGIS Notebooks designed for the data scientists and developers.

Professional Mapping Using Drones
February 11, 2024, 1 PM to 3 PM

Presenter
Dr. Qassim Abdullah, *Woolpert*, Vice-President and Chief Scientist; ASPRS Positional Accuracy Standards Working Group, Chair

The use of small drones is becoming an integral part of the daily activities for construction sites monitoring and project planning and design. As the market flooded with different types of drones and the sensors it can carry, many surveyors and mappers are confused about the right path to follow acquire drones and sensors for their operations. The proposed training and education session focus on providing the participants with the foundational knowledge on important topics such as licensing, airframes, sensors, planning, processing software, data accuracy, etc.

Preparation for ASPRS Certification
February 11, 2024, 1 PM to 5 PM

Presenter
Harold Rempel, *ESP Associates, Inc.*, Senior Geospatial Manager

This workshop covers the common knowledge areas comprising a large portion of exam content for ASPRS Certification. It is valuable preparation for those who have never taken an ASPRS exam, as well as for those who have expertise in a particular specialty, such as lidar or UAS, but feel less prepared for the general knowledge component of the exam. This workshop will also explain the certification application process and the importance of certification in career development.

Advanced Remote Sensing Data Processing and Deep Learning with PyTorch
February 11, 2024, 1 PM to 5 PM

Presenter
Dr. Tao Liu, *Michigan Technological University*, College of Forest Resources and Environmental Engineering, Assistant Professor in Remote Sensing and GIS

Attendees will learn how to utilize deep learning techniques to process remote sensing (RS) data in a 4-hour workshop. The first three hours will be dedicated to learning PyTorch (and other Python tools), an open-source deep learning development platform. Participants will be introduced to the fundamentals of deep learning, learn how to create deep learning models from scratch, and explore customized applications such as image classification using PyTorch Image Models (TIMM) and image segmentation with Segmentation Models PyTorch (SMP). The final hour will focus on 3D RS data generation and processing. Using PyTorch3D, we will introduce the implementation of the structure-from-motion (SfM) algorithm based on 2D images to generate georeferenced point clouds. With brief exposure to digital surface and terrain model generation using point cloud or LiDAR data, advanced semantic 3D classification and segmentation models will be introduced. Upon completion of the workshop, attendees will possess the necessary skills to develop customized applications using Python tools for advanced RS data processing.

Airborne Bathymetric Lidar
February 11, 2024, 3 PM to 5 PM

Presenters
Chris Parrish, *Oregon State University,* Department of Civil and Construction Engineering, Associate Research Professor; ASPRS, Immediate Past President
Amar Nayegandhi, *Dewberry*, Senior Vice President

Airborne bathymetric lidar is one of the most exciting and rapidly-advancing technologies in the geospatial sector. Its uses range from safety of marine navigation (i.e., hydrographic surveying and nautical charting), to sediment transport modeling, benthic habitat mapping and monitoring, marine ecological assessments, flood inundation modeling, river morphology, coastal engineering, and more. This workshop is designed for geospatial professionals, students, and even those new to the field who are interested in learning more about lidar bathymetry. We will start with a brief history and theory of bathymetric lidar, including terminology, system components, and acquisition principles. We will then cover operational concepts, including mission planning, data processing and workflows, calibration, QA/QC, and accuracy assessment. We will conclude with a view of the future of airborne bathymetric lidar, including emerging trends and anticipated advances over the next decade.

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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.

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Terrain Complexity and Maximal Poisson-Disk Sampling-Based Digital Elevation Model Simplification

Jingxian Dong, Fan Ming, Twaha Kabika, Jiayao Jiang, Siyuan Zhang, Aliaksandr Chervan, Zhukouskaya Natallia, and Wenguang Hou

Abstract

With the rapid development of lidar, the accuracy and density of the Digital Elevation Model (DEM) point clouds have been continuously improved. However, in some applications, dense point cloud has no practical meaning. How to effectively sample from the dense points and maximize the preservation of terrain features is extremely important. This paper will propose a DEM sampling algorithm that utilizes terrain complexity and maximal Poisson-disk sampling to extract key feature points for adaptive DEM sampling. The algorithm estimates terrain complexity based on local terrain variation and prioritizes points with high complexity for sampling. The sampling radius is inversely proportional to terrain complexity, while ensuring that points within the radius of accepted samples are not considered new samples. This way makes more points of concern in the rugged regions. The results show that the proposed algorithm has higher global accuracy than the classic six sampling methods.

Introduction

Light Detection and Ranging (lidar) has been widely used in geology, archaeology, geography, geomorphology, remote sensing, and other related fields. In general, the point cloud obtained by lidar is redundant, as such, the raw Digital Elevation Model (DEM) is dense and can represent the scanned object with high accuracy. However, in some applications, dense and high-precision DEM is not necessary (Ren *et al.* 2017; Li and Nan 2021). Such as, in case of our navigation, the three-meter resolution DEM is enough. Moreover, the huge point cloud data will be subject to subsequent processing, storage, transmission, and display, which will far exceed the capabilities of computer graphics workstations (Śliwiński *et al.* 2022). Specifically, it is very difficult to achieve real-time rendering in interactive mode. DEM simplification can make the analysis and modeling to be more efficient, especially in mobile and web-based applications where computational resources and bandwidth are limited. For offline applications, DEM simplification can generate pyramid downsampling files, enabling users to efficiently perform interactive operation. Furthermore, fewer samples are needed because there is less terrain variations in flat areas, and vice versa (Yu *et al.* 2021). Therefore, it is of practical significance to simplify the terrain point cloud by preserving the feature points or retaining the terrain features to the maximum extent in the case of the given sampling rate (Zhu *et al.* 2019; Li *et al.* 2022; Sun *et al.* 2022).

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Terrain complexity evaluation and sampling strategy are the cores of terrain simplification. Whether a point is sampled or not depends on the complexity of the local terrain, where the point is located. Generally, more points appear in the rugged parts, and vice versa. Meanwhile, the samples' density should be locally uniform. Traditional terrain complexity mainly includes slope, curvature, relief degree, and so on. Recently, some scholars design DEM sampling algorithms on the basis of single or complex terrain features including elevation difference of the eight-nearest-neighborhood as the Very Important Points (VIP) method (Chen 1987), the dispersion of topography (Xu *et al.* 2008), curvature (Song and Feng 2009; Leal *et al.* 2021; Sun *et al.* 2022), terrain slope (Li *et al.* 2012), normal vector (Han *et al.* 2015); Vuillamy *et al.* 2022), and comprehensive complexity (Zhou *et al.* 2015). Generally, the sampling algorithms for DEM are mainly based on threshold or bounding box-based methods. In Chen (1987), Xu *et al.* (2008), Song and Feng (2009), Li *et al.* (2012), and Han *et al.* (2015), a threshold of terrain complexity is estimated according to different applications. The defect lies in that many samples are concerned in the rugged regions and fewer points appear in the flat parts. In Zhou *et al.* (2015) and Zhang *et al.* (2018), the point cloud is classified according to the bounding box method, and a different number of feature points are retained for different boxes according to the terrain complexity.

These methods are simple and efficient, but their accuracies are poor. Threshold or bounding-based sampling methods cannot obtain simplified points with the fine distribution. The unbalanced distribution means that the reconstruction is not accurate. The threshold-based simplification method may result in a hole phenomenon due to the absence of points in a large region (Mahdaoui and El Hassan 2020). On the other hand, the box-based method is inflexible and relies on predefined bounding boxes. These methods only consider the terrain features without taking into account the samples' distribution (Xu *et al.* 2008; Song and Feng 2009; Fei and He 2009). The samples' distribution should be the balance between terrain feature-based and uniform. As such, some scholars (Cook 1986; Ebeida *et al.* 2011) introduced the maximum Poisson-disk sampling (MPS) to point cloud simplification. The core idea is that the distance between any two samples is greater than the disk radius. Its principle is shown in Figure 1. The main process of classic MPS is as follows. A point is randomly selected from the original point cloud through dart throwing. When the distance between the selected point and any of the accepted samples is greater than the disk radius, this selected point is accepted as a new sample. The above steps are repeated until the Poisson disk covers all areas or there is no space to accommodate a new sample. This method can generate uniform but irregularly distributed samples. Recently, some researchers proposed adaptive point cloud sampling based on MPS (Wu *et al.* 2020). Their main idea is to dynamically adjust the disk radius according to the local characteristics. The disk radii in rugged regions are small, while the disk radii are large in the plate parts. The main problem is that the

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In-Press

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I^2-FaçadeNet: An Illumination-invariant Façade Recognition Network Leveraging Sparsely Gated Mixture of Multi-color Space Experts for Aerial Oblique Imagery

Shengzhi Huang, Han Hu, and Qing Zhu

Abstract

Façade image recognition under complex illumination conditions is crucial for various applications, including urban three-dimensional modeling and building identification. Existing methods relying solely on Red-Green-Blue (RGB) images are prone to texture ambiguity in complex illumination environments. Furthermore, façades display varying orientations and camera viewing angles, resulting in performance issues within the RGB color space. In this study, we introduce an illumination-invariant façade recognition network (I^2-FaçadeNet) that leverages sparsely gated multi-color space experts for enhanced façade image recognition in challenging illumination environments. First, RGB façade images are converted into multi-color spaces to eliminate the ambiguous texture in complex illumination. Second, we train expert networks using separate channels of multi-color spaces. Finally, a sparsely gated mechanism is introduced to manage the expert networks, enabling dynamic activation of expert networks and the merging of results. Experimental evaluations leveraging both the International Society for Photogrammetry and Remote Sensing benchmark data sets and the Shenzhen data sets reveal that our proposed I^2-FaçadeNet surpasses various depths of ResNet in façade recognition under complex illumination conditions. Specifically, the classification accuracy for poorly illuminated façades in Zurich improves by nearly 8%, while the accuracy for over-illuminated areas in Shenzhen increases by approximately 3%. Moreover, ablation studies conducted on façade images with complex illumination indicate that compared to traditional RGB-based ResNet, the proposed network achieves an accuracy improvement of 3% to 4% up to 100% for overexposed images and an accuracy improvement of 3% to 10% for underexposed images.

Introduction

Building structures are vital components of the three-dimensional (3D) urban system (Xiao *et al.* 2012). In this context, façade elements are fundamental and pivotal sources for tasks like 3D modeling (Fathi *et al.* 2015; Oskouie *et al.* 2017; Liu *et al.* 2023), mesh refinement (Tyle_ek and Šára 2010; Romanoni and Matteucci 2019), and damage assessment (Vetrivel *et al.* 2016; Duarte *et al.* 2020; Gonsoroski *et al.* 2023). Consequently, correctly identifying building façade patches from source images, particularly multi-view oblique images, becomes essential. This accuracy is imperative in façade parsing (Liu *et al.* 2020; Wang, Xu *et al.* 2021), multi-view verification (Zhu *et al.* 2021), urban scene modelling (Peters *et al.* 2022; Geng *et al.* 2022), and texture mapping (Zhou *et al.* 2020).

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Most existing façade identification methods detect only structural features, such as window frames (Xiao *et al.* 2012, Hu *et al.* 2022) and vertical edges (Yang *et al.* 2015), or combine engineered features and train them to fit a set of parameters that achieve good performance. However, these techniques are largely adaptations from roof detection and do not sufficiently consider façade characteristics. Consequently, current façade extraction methods lack stability when applied to multi-view oblique façade images and fail to address poor illumination conditions, whether overly bright or excessively dark (Burdziakowski and Bobkowska 2021). The primary reason for these challenges is the considerably more complex illumination environment that façade surfaces experience compared to roof surfaces.

Existing methods for solving the multi-view illumination problem rely solely on selecting the optimal image based on geometric analysis of whether the building façade is fully facing the image projection plane (Zhou *et al.* 2020). However, these methods are insufficient. Firstly, based on the solar radiation model, the reflection model of normal urban façade usually does not adhere to Lambert's cosine law, which can affect the illumination intensity of façade oblique images. Secondly, simply discarding poorly illuminated images results in the loss of redundancy in multi-view oblique photogrammetry.

In fact, if inadequately illuminated images cannot be detected or classified correctly and lead the mixture of façade detection, then it is inevitable that the overall accuracy of building detection could be compromised. If the classification of poorly illuminated images is not detected correctly, and the resulting mixture of façade detection occurs, it can compromise the overall accuracy of building detection. Additionally, several studies have shown that RGB images may exhibit different characteristics under different color spaces (Bello-Cerezo *et al.* 2016). The three RGB components (R, G, and B) are strongly correlated and sensitive to variations in illumination, shadows, and other factors. Furthermore, some seminal works have been done on low-light or inconspicuous objects in RGB color space detection by transferring to alternative color spaces. These findings prompt us to explore addressing the challenge of poor illumination in façade image classification by transitioning to other color spaces. Nevertheless, certain situations require further analysis.

Complex Illumination Condition Caused by Different Façade Orientations

Given that building façades can be oriented in any direction, it is inevitable that they will exhibit diverse illumination statuses. In the earlier research stages, researchers manually selected images for texture mapping onto level-of-detail models (Luebke *et al.* 2003), a process that was both tedious and inefficient. Despite these efforts, the texturing outcomes did not always produce satisfactory results, as undulations

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Development of Soil-Suppressed Impervious Surface Area Index for Automatic Urban Mapping

Akib Javed, Zhenfeng Shao, Iffat Ara, Muhammad Nasar Ahmad, Md. Enamul Huq, Nayyer Saleem, and Fazlul Karim

Abstract

Expanding urban impervious surface area (ISA) mapping is crucial to sustainable development, urban planning, and environmental studies. Multispectral ISA mapping is challenging because of the mixed-pixel problems with bare soil. This study presents a novel approach using spectral and temporal information to develop a Soil-Suppressed Impervious Surface Area Index (SISAI) using the Landsat Operational Land Imager (OLI) data set, which reduces the soil but enhances the ISA signature. This study mapped the top 12 populated megacities using SISAI and achieved an overall accuracy of 0.87 with an F1-score of 0.85. It also achieved a higher Spatial Dissimilarity Index between the ISA and bare soil. However, it is limited by bare gray soil and shadows of clouds and hills. SISAI encourages urban dynamics and inter-urban comparison studies owing to its automatic and unsupervised methodology.

Introduction

Impervious surface area (ISA) mapping is crucial for urban and related studies (Lu *et al.* 2011; Van de Voorde *et al.* 2011; Weng 2012), such as urban flood (Sohn *et al.* 2020), groundwater recharge (Ghimire *et al.* 2021), urban heat island (Yuan and Bauer 2007), environmental studies (Arnold Jr and Gibbons 1996; Chithra *et al.* 2015), climate studies (Bierwagen *et al.* 2010), hydrological studies (Brabec *et al.* 2002; Shao *et al.* 2020; Shuster *et al.* 2005), and land use land cover classification (Lu and Weng 2006). ISA can be natural or manmade. Slonecker *et al.* (2001) defined impervious surfaces as materials that prevent water infiltration into soil. This definition encompasses all types of impervious surface. Jennings *et al.* (2004), on the other hand, defined anthropogenic or artificial impervious surfaces as roads, rooftops, parking lots, driveways, sidewalks, etc.

Spectral index-based urban mapping approaches can include the use of index-based built-up index (IBI) (Xu 2008), the improved normalized difference of built-up index (He *et al.* 2010), vegetation index built-up index (Stathakis *et al.* 2012), built-up area extraction method (BAEM) (Bhatti and Tripathi 2014), ratio normalized difference soil index (RNDSI) (Deng *et al.* 2015), normalized urban areas composite index (NUACI) (Liu *et al.* 2015), combinational built-up index (CBI) (Sun *et al.* 2016), combinational biophysical composition index (Zhang *et al.* 2018), enhanced normalized difference impervious surface index (ENDISI) (Chen *et al.* 2019a), nighttime lights adjusted impervious surface index (NAISI) (Chen *et al.* 2019b), and binary built-up index (BBI) (Zhou *et al.* 2014).

Earlier indices worked well for comparing urban areas with similar geography but were not tested for ISA with diverse geography. Nighttime lights can overcome this limitation, but they are not accurate for predicting ISA and lack spatial resolution (Ch *et al.* 2021; Duque *et al.* 2019). These are still useful in ISA studies.

One of the common problems with mapping ISA is mixed pixel problems, especially with bare soil, owing to their spectral similarity (Deng *et al.* 2019; Lu and Weng 2004). Compared to the ISA, the spectral signatures of bare soil fluctuate phenologically more in infrared regions (near infrared, shortwave infrared (SWIR)1, and SWIR2), particularly in summer (Wang and Li 2019). Some bare soil studies have also used temporal information to minimize bare soil signatures (Chen *et al.* 2004; Mzid *et al.* 2021).

Earlier urban indices were used to map built-up and bare soil areas together. Such indices are the enhanced built-up and bareness index (EBBI) and BBI. Previous spectral indices extracted urban ISA and bare soil area together, such as the EBBI (As-syakur *et al.* 2012) and BBI (Zhou *et al.* 2014). The biophysical composition index (BCI) is a significant attempt to address this problem and uses a tasseled cap transformation to minimize the bare soil signature from the ISA (Deng and Wu 2012). Other indices have been developed to address the mixed pixel problem, such as the RNDSI (Deng *et al.* 2015), modified normalized difference soil index, and normalized ratio urban index (Piyoosh and Ghosh 2017).

Some urban indices are sensitive to waterbodies. The Water Eraser-Normalized Difference Built-Up Index (WE-NDBI) was developed to exclude water areas (Bai *et al.* 2020). Many urban indexing studies have removed water bodies during preprocessing (Deng and Wu 2012). Except for water, the three main Land Use/Land Cover (LULC) elements are vegetation, impervious surfaces, and soil, which were popularized as the vegetation-impervious surface-soil (V-I-S) model by Ridd (1995). Using the V-I-S model, vegetation and bare soil areas were removed to extract impervious surfaces. These include the BCI (Deng and Wu 2012).

However, water indices are sometimes used to enhance the urban indices. For example, NDWI (McFeeters 2007) adds urban features to CBI (Sun *et al.* 2016). In addition, IBI, ENDISI, modified normalized difference impervious surface index (Sun *et al.* 2017), and BAEM are examples of the Modified Normalized Difference Water Index (MNDWI). The MNDWI is also sensitive to ISA after the water area (Xu 2010).

Bai *et al.* (2020) developed a different approach. This study proposed a WE-NDBI by excluding water areas (Bai *et al.* 2020). WE-NDBI significantly increased the urban mapping accuracy to a greater extent than BBI. Many urban indexing studies have removed water bodies during preprocessing (Deng and Wu 2012). Except for water, the three main LULC elements are vegetation, impervious surfaces, and soil, which were popularized as the V-I-S model by Ridd (1995). Zhang *et al.* (2021) proposed the Water-Impervious-Pervious (W-I-P) model, where feature spaces are used to develop an urban composition

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Dual-branch Branch Networks Based on Contrastive Learning for Long-Tailed Remote Sensing

Lei Zhang, Lijia Peng, Pengfei Xia, Chuyuan Wei, Chengwei Yang, and Yanyan Zhang

Abstract

Deep learning has been widely used in remote sensing image classification and achieves many excellent results. These methods are all based on relatively balanced data sets. However, in real-world scenarios, many data sets belong to the long-tailed distribution, resulting in poor performance. In view of the good performance of contrastive learning in long-tailed image classification, a new dual-branch fusion learning classification model is proposed to fuse the discriminative features of remote sensing images with spatial data, making full use of valuable image representation information in imbalance data. This paper also presents a hybrid loss, which solves the problem of poor discrimination of extracted features caused by large intra-class variation and inter-class ambiguity. Extended experiments on three long-tailed remote sensing image classification data sets demonstrate the advantages of the proposed dual-branch model based on contrastive learning in long-tailed image classification.

Introduction

Remote sensing is a comprehensive detection technology that uses sensors to obtain the characteristics of objects in various bands and changes in target objects through data processing and comprehensive analysis. The diversification of observation techniques and the development of imaging techniques have brought about the rapid development of high-resolution remote sensing image data, enabling remote sensing images to have higher spatial, temporal, and spectral resolutions (Gómez-Chova *et al.* 2015). In recent years, with the development of intelligent technology, a variety of remote sensing data (Liang 2005) has provided support for the wide application of remote sensing technology.

Traditional optical remote sensing image classification algorithms are mostly designed manually, but this type of algorithm is poor in robustness and weak in universality. With the emergence and development of deep learning, it has gradually replaced manual features due to its powerful deep feature representation ability, and it has become the mainstream method for remote sensing image classification (Reichstein *et al.* 2019).

With the research and development of convolutional neural networks (CNN), the performance of remote sensing image classification has made amazing progress (Jiang *et al.* 2018). Although CNN-based models perform well on balanced data sets (Zhang, Cheng, *et al.* 2023), they do not work well on imbalanced data sets (Liu *et al.* 2023). However, in most real-world data sets, a few head classes often include a large number of data sets, and most tail classes only include a small number of data sets—long-tailed distribution problems (Zhang, Kang, *et al.* 2023). Developing effective deep learning algorithms to automatically process data with long-tailed distribution characteristics is a long-standing and challenging research problem in the remote sensing field.

In the past 10 years, the related study on long-tailed data has attracted great attention from relevant researchers at home and abroad. According to different processing strategies, there are three well-known methods: re-sampling, re-weighting, and representation learning. The re-sampling method (Chen *et al.* 2023) is prone to overfitting or underfitting. The re-weighting method (Deng *et al.* 2021) distorts the original distribution.

In contrast, representation learning methods can effectively solve the problem of class imbalance at the feature level (Suh and Seo 2023). Contrastive learning is a major type of representation learning, and the rapid development of supervised contrastive learning brings hope to the research of long-tailed distribution problems. However, in existing contrastive learning methods, most of them overlook the discriminative features of images, and the feature space data is not well used. The accuracy of tail class data and the overall accuracy still need to be improved.

Based on the above analysis, this paper proposes a unified Dual-Branch Fusion Learning Classification model (DB-FLC) to better respond to the long-tailed distribution problem of remote sensing. In addition, a new hybrid loss function is proposed. In comparison to previous studies, our method improves the overall classification impact by better coordinating the learning of remote sensing data head samples and tail samples. Extensive comparative studies are conducted on several remote sensing classification data sets to confirm the effectiveness of the proposed strategy. The results of our experiments demonstrate that the proposed method has greater classification accuracy.

The paper's contributions are as follows:

(1) A DB-FLC model with specific and stronger feature representation capabilities is presented, which fuses the discriminative features and spatial data of remote sensing images extracted by dual branches. This method fully mines the feature characteristics of the image and elevates the status of the tail class.

(2) A new hybrid loss function is proposed to learn better image representation from imbalance data, obtain the feature space of intra-class compactness and inter-class separability, and improve the classification accuracy of remote sensing long-tailed images.

(3) The effectiveness of the proposed method is verified through comprehensive experiments on long-tailed versions of commonly used remote sensing classification data sets: NWPU-RESISC45, PatternNet, and VGoogle.

Related Work

Remote Sensing Image Classification

The original remote sensing image classification method is based on the extraction of shallow and middle information of the image.

Shallow features are used to describe the basic representation of an image. Commonly used shallow features include color, etc. (such as color histogram (Swain and Ballard 1991), gradient histogram (Dalal

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Comparison of 3D Point Cloud Completion Networks for High Altitude Lidar Scans of Buildings

Marek Kulawiak

Abstract

High altitude lidar scans allow for rapid acquisition of big spatial data representing entire city blocks. Unfortunately, the raw point clouds acquired by this method are largely incomplete due to object occlusions and restrictions in scanning angles and sensor resolution, which can negatively affect the obtained results. In recent years, many new solutions for 3D point cloud completion have been created and tested on various objects; however, the application of these methods to high-altitude lidar point clouds of buildings has not been properly investigated yet. In the above context, this paper presents the results of applying several state-of-the-art point cloud completion networks to various building exteriors acquired by simulated airborne laser scanning. Moreover, the output point clouds generated from partial data are compared with complete ground-truth point clouds. The performed tests show that the SeedFormer network trained on the ShapeNet-55 data set provides promising shape completion results.

Introduction

In recent years, point clouds have become easier to obtain thanks to the increased popularity of portable 3D laser scanners. Lidar sensors attached to unmanned aerial vehicles have enabled rapid acquisition of detailed representations of real-world objects such as terrain or buildings. While a low-altitude airborne survey can produce a complete point cloud of a single house, a high-altitude aerial scan will provide a data set representing entire city blocks, constituting an efficient method of acquiring big spatial data that can be used for various remote sensing applications, such as 3D object detection, classification, and surface reconstruction. Moreover, in many countries around the world, sparse point clouds from high-altitude terrain surveys can be freely obtained from public institutions responsible for geodesic and cartographic documentation, such as the Polish Geoportal site (Geoportal Krajowy 2023). Unfortunately, the raw point clouds acquired by high-altitude aerial surveys are largely incomplete due to restrictions in sensor resolution and scanning angles, as well as object occlusions, which can negatively affect the performance of remote sensing applications, especially in case of urban areas. Because of this, existing solutions for generating 3D models representing large-scale urban areas (Yang and Lee 2017; Peters *et al.* 2022; Župan *et al.* 2023) use lidar data primarily for reconstructing regular-shaped roofs and are not suited for rebuilding ornaments found on building facades. If the missing parts of data provided by high-altitude lidar surveys could be recovered, it would grant the possibility of increasing the level of detail of automatically generated 3D city models without the need to acquire additional data. Therefore, recovering the complete point clouds of urban environments from partial data is highly desirable.

Point cloud completion is the process of estimating and recovering missing geometric information in order to create a more faithful representation of the scene or object (Wen *et al.* 2020; Zhang and Czarnuch 2023). Automated point cloud completion methods not only offer benefits such as improving data quality and reducing manual labor required for data acquisition but also have many application scenarios including improving accuracy in object detection (Zhang *et al.* 2021), reducing errors in registration (Yuan *et al.* 2018), and improving quality of 3D surface reconstruction (Kulawiak and Lubniewski 2020). Over the years, many different approaches to 3D shape completion have been proposed. Traditional attempts (Nguyen *et al.* 2016; Dai *et al.* 2017; Han *et al.* 2017; Varley *et al.* 2017; Wang *et al.* 2017; Yang *et al.* 2017; Stutz and Geiger 2018) relied on voxelization and 3D convolutions; however, these methods suffer from heavy memory consumption that grows as the spatial resolution increases. An alternative approach was proposed with the introduction of PointNet (Qi, Su, *et al.* 2017), which is a deep neural network that uses a multilayer perceptron architecture for learning point-wise features directly from point clouds. By design, PointNet does not capture local structures induced by the metric space points live in, limiting its ability to recognize fine-grained patterns; nevertheless, it served as an inspiration to many similar machine learning solutions (Qi, Yi, *et al.* 2017; Qi *et al.* 2018; Engelmann *et al.* 2017; Guerrero *et al.* 2018; Zhou and Tuzel 2018; Groueix *et al.* 2018; Mandikal and Radhakrishnan 2019; Sarmad *et al.* 2019; Zhang *et al.* 2021; Shi *et al.* 2022), which offered the possibility to directly manipulate raw point cloud data by following an encoder–decoder design. These include adversarial networks (Tchapmi *et al.* 2019; Huang *et al.* 2020; Wang *et al.* 2020; Zhang *et al.* 2020; Wen *et al.* 2021; Xia *et al.* 2021; Xie *et al.* 2021) that perform multi-step point cloud generation in attempt to recover a final point cloud with fine-grained details, as well as graph-based methods (Wang *et al.* 2019; Wu and Miao 2021; Wu *et al.* 2021; Zhu *et al.* 2021) that are known to more accurately consider regional geometric details. Although these methods provided better feature extractors and decoders, they do not consider the distribution of existing points. Because of this, more recent solutions, such as PoinTr (Yu *et al.* 2021, 2023), reformulate point cloud completion as a set-to-set translation problem by adopting a transformer encoder–decoder architecture for point cloud completion. A similar strategy is proposed by SeedFormer (Zhou *et al.* 2022) while also introducing Patch Seeds that can be propagated to the following upsample layers, focusing on the decoding process of recovering fine details from incomplete partial point clouds. The latest research is represented by ProxyFormer (Li *et al.* 2023), which shares similar ideas with PoinTr and SeedFormer but modifies the query of transformer to make it more suitable for the prediction of the missing part, while also reducing the number of parameters in order to avoid excessive computation.

This being said, while the performance of the most recent point cloud completion methods (Yu *et al.* 2021, 2023; Zhou *et al.* 2022; Li *et al.* 2023) has been reported for objects of various shapes, it is not clear how well these methods would perform when applied to high-altitude lidar point clouds of buildings. Should these methods perform well enough, it would create the possibility of generating satisfactory shape classification and surface reconstruction results from sparse lidar point clouds from freely available sources. In the above context, this paper aims to test the capabilities of recent point completion networks

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