Open Source Geospatial Tools to Enable Large Scale 3D Scene Modeling

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Motivation for 3D Urban Scene Modeling

Visibility analysis
Energy demand estimation
Emergency response
Shadow estimation
Utility management
Solar potential estimation
3D cadastre
Infrastructure planning
Indoor navigation
Noise propagation

Objectives

- Leverage prior JHU/APL work with lidar
- Develop software to enable metric analysis of global-scale 3D urban scene modeling research based on satellite imagery
- Release as open source with nonrestrictive license
- Promote challenges and release of public datasets to establish benchmarks
- Help establish minimum baselines for expected algorithm performance
- Encourage public advances in the state of the art

Credit: http://www.printmakersnetwork.org/carmela-venti/
Ckarma Graphics, Waterford, Connecticut

Concept Development  Research & Development  Program of Record

Digital Globe Images

Ground Truth Lidar

MVS Solution for Metric Analysis

<table>
<thead>
<tr>
<th>Rank</th>
<th>Team</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Carlo de Franchis, Gabrielle Facciolo, and Enric Meinhard-Llopis – NCSR, France</td>
</tr>
<tr>
<td>2</td>
<td>Przemyslaw Debiak – Poland</td>
</tr>
<tr>
<td>3</td>
<td>Sebastian Drouyer – Mines ParisTech, France</td>
</tr>
<tr>
<td>4</td>
<td>Rongjun Qin – Ohio State University, USA</td>
</tr>
<tr>
<td>5</td>
<td>Konstantinos Batsos – Stevens, NJ, USA</td>
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Available solutions from contest winners:

- **1st place**: https://github.com/MISS3D/s2p
- **2nd place**: https://github.com/FakePsycho/mvs
- **3rd place**: https://github.com/sdrdis/iarpa
- **4th place**: http://u.osu.edu/qin.324/rsp/


Public benchmark data and code: www.jhuapl.edu/satellite-benchmark.html
Can you write an algorithm to classify facility, building, and land use from satellite imagery?

Email questions to FunctionalMap@IARPA.gov, or join the conversation on Twitter at #IARPAfMoW.

Key Reasons to Participate:

- $100,000 TOTAL PRIZE PURSE!
- One of the largest publicly available satellite-image datasets to date, with more than one million points of interest
- Cash incentives to open source solutions
- Winners will be invited to Washington, D.C., to showcase solutions to government leaders
JHU/APL Open Source to Enable 3D Scene Modeling

- Metric analysis tools for 3D point clouds and 3D building models
  - Focus is data collected from airborne and space-borne sensors
- 3D point cloud registration (C++)
- 3D point cloud scene classification (C++)
- Spectral image calibration (C#)

Public software and data: [www.jhuapl.edu/pubgeo.html](http://www.jhuapl.edu/pubgeo.html)
General Purpose 3D Point Cloud Registration

Iterative Closest Point (ICP)

Feature Descriptor Correspondence

Credit: http://pointclouds.org/

Credit: https://www.researchgate.net/publication/258021939

Credit: https://taylorwang.wordpress.com/

Credit: https://www.researchgate.net/publication/258021939
ALIGN3D  
JHU/APL Open Source 3D Point Cloud Registration

- Focus on airborne and space-borne 3D sensor data
  - Airborne lidar
  - Multi-view stereo
  - Synthetic Aperture Radar (SAR) point clouds (not shown)
  - Terrestrial lidar – only for alignment with airborne lidar (also not shown)

- Approach can be simple, fast, and more robust than general 3D methods
  - Grid each point cloud as Digital Surface Model (DSM)
    - Define ground sample distance (GSD)
  - Search entire space of translations explicitly with uniform sample of points
    - Define maximum translation (MAXT)
    - Note: Rotation can be similar but not included here because not required
  - Select integer offset that minimizes Root Mean Square (RMS) Z error
  - Interpolate to achieve sub-pixel accuracy

Example usage: 
align3d reference.las target.las gsd=1.0 maxt=10.0
Simple Registration Examples with ALIGN3D

1m Lidar
Jacksonville, FL

Lidar with XYZ Offset
(5.5m, 5.5m, 7m)

Ground Filtered / Void Filled
Demonstrates Scene Change

These examples:
- 1.5 million points each
- 40MB LAS file
- 2 sec on a laptop

Estimated XYZ (Error)
X = 5.512m (0.123m)
Y = 5.527m (0.027m)
Z = 7.001m (0.001m)

Spherical Error < 13cm
Performs well as expected

Estimated XYZ (Error)
X = 6.072m (0.572m)
Y = 5.580m (0.080m)
Z = 6.985m (0.015m)

Spherical Error < 58cm
Performs well for edge cases

Note: Ground filter is imperfect
3D Point Cloud Classification

- **Examples shown**
  - Public data from IARPA MVS contest
  - Classification using Global Mapper
- **Many acceptable solutions are available for lidar, not open source**
  - Multiple lidar returns assist with classifying vegetation
- **Classifying MVS point clouds is more challenging**
  - Adding multispectral imagery can make this easier

**Satellite Imagery**

**Lidar**

**Lidar with Classified Points**

**Multi-View Stereo (MVS)**

**MVS with Classified Points**

<table>
<thead>
<tr>
<th>Ground</th>
<th>Vegetation</th>
<th>Building</th>
<th>Unlabeled</th>
</tr>
</thead>
</table>

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Shareable High Resolution 3D (SHR3D)
JHU/APL Open Source 3D Point Cloud Classification

SHR3D produces:
- GeoTIFF Digital Surface Model (DSM)
- GeoTIFF Digital Terrain Model (DTM)
- GeoTIFF classification labels

This example:
- 14 million points
- 400MB LAS file
- 11 sec on a laptop
SHR3D Approach In a Nutshell

- Apply 2D segmentation algorithm to label objects above ground
  - Label object boundaries
    - DH = Horizontal precision or spacing for computing gradients
    - DZ = Vertical precision for defining gradient magnitude threshold
  - Group adjacent boundary labels into individual objects
  - Fill the individual object bounds
  - Anything not labeled object is classified as ground

- Classify non-ground points
  - Classify as vegetation if multiple returns in a bin
  - Classify buildings using simple geometric constraints
    - AGL = minimum height above ground level
    - AREA = minimum object area
  - Classify remaining points as unlabeled

Example usage:
shr3d points.las dh=0.5 dz=0.5 agl=2.0 area=50
Evaluating SHR3D with US Cities Lidar & Shape Files

Building Labels for Jacksonville, FL Lidar

Results
Recall 0.92
Precision 0.82
F-score 0.87
IOU 0.77

JHU/APL SHR3D
Ground Truth
Evaluation

TP = True Positive
FP = False Positive
FN = False Negative

Most of FP is this elevated road
**SHR3D Example with MVS Point Cloud**

This example:
- 2 million points
- 56MB LAS file
- 1 sec on a laptop

Results are reasonable here with only geometric segmentation and labeling; including additional constraints from multispectral imagery should improve performance
Automated Labeling Results

Manual Editing to Produce Ground Truth

Automated open source JHU/APL software performs about as well with lidar as other available methods that are not open source.
Spectral Calibration to Enable Material Labeling

- Developed software to apply spectral calibration to Digital Globe images
- Source: [https://www.digitalglobe.com/resources/technical-information](https://www.digitalglobe.com/resources/technical-information)
- Two orders of magnitude faster than best known commercial tool
- Provided as a convenience for public use

[Uncalibrated and Calibrated images with spectral samples graph]
Material Labeling Example

RGB Image
San Fernando, Argentina

Material Label Ground Truth
Automated Classification + Manual Editing

<table>
<thead>
<tr>
<th>Unclassified</th>
<th>Asphalt</th>
<th>Ceramic</th>
<th>Concrete/Gravel</th>
<th>Tree</th>
<th>Short vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal</td>
<td>Polymer</td>
<td>Soil/Sand</td>
<td>Solar panel</td>
<td>Water</td>
</tr>
</tbody>
</table>
What Next?

- Improve tools to better enable JHU/APL test and evaluation efforts for emerging urban 3D modeling capabilities
- Maintain public software and data at [www.jhuapl.edu/pubgeo.html](http://www.jhuapl.edu/pubgeo.html)
  - Data and test scripts for examples shown are available on the web site
- Solicit public feedback for how tools could be more useful