FIG WORKING WEEK 2019

22–26 April, Hanoi, Vietnam

"Geospatial Information for a Smarter Life and Environmental Resilience"

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A Global Photogrammetry-Based Structure from Motion Framework: Application in Oblique Aerial Images

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Purpose of our work

- Establishment of an efficient **Structure from Motion (SfM)** framework based on photogrammetric algorithms
- Application in challenging datasets of **oblique aerial images** under a **non-ideal scenario** characterized by the availability of a small number of GCPs of bad distribution and image measurements at the minimum possible number of images

Computation of camera exterior orientation parameters

Structure-from-Motion

SfM is a **Computer Vision technique**: Images taken of an object or scene from multiple different angles are used to create a **point cloud in 3D space**

Accurate models can be built by **matching unique features** in each image and determining from which **position and direction the images were taken**

Matching is the process of finding a corresponding feature from one set in another using a descriptor

A **descriptor** is a vector of numbers that describes the surrounding environment around a feature point in an image

Methodology – 1. Determination of the overlapping images in an unorganised collection of images

- **GPS/INS-based** determination of overlapping images *OR*
- **Image-based** determination of overlapping images (SURF features and image matching)

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- **Graph creation** (undirected weighted graph)

Methodology – 2. Image matching and feature tracking

- **SURF** feature extractor
- **Ratio test** during image matching
- Geometric verification of matches: **RANSAC – fundamental matric computation** & **RANSAC – homography estimation** (approximate relationship, big threshold)
- **Feature tracking**: after the image matching stage of each pair
  - **Only tracks of at least 3 correspondences** are kept
  - Result: a matrix that stores the image coordinates of the feature points and a matrix that stores information about whether a point is visible in each image (number of rows = number of images; number of columns = number of tracks)

Methodology – 3. Aerial triangulation

Approximate exterior orientation parameters from **GPS/INS** sensors

1. **Computation of approximate ground coordinates for the 3D tracks**
   - **Photogrammetric space intersection** for each pair of corresponding feature points between each pair of overlapping images
2. **Rejection of remaining outliers**
   - Estimation of the distance between the ground coordinates of each track, which have been computed using different combinations of overlapping images
   - The track is discarded if this distance is above a maximum accepted threshold for at least one combination of image pairs
3. **Bundle block adjustment**

Developed software and test dataset

- Programming language: **C++**
- Libraries: **OpenCV, Eigen, GDI+, GeographicLib, Boost**

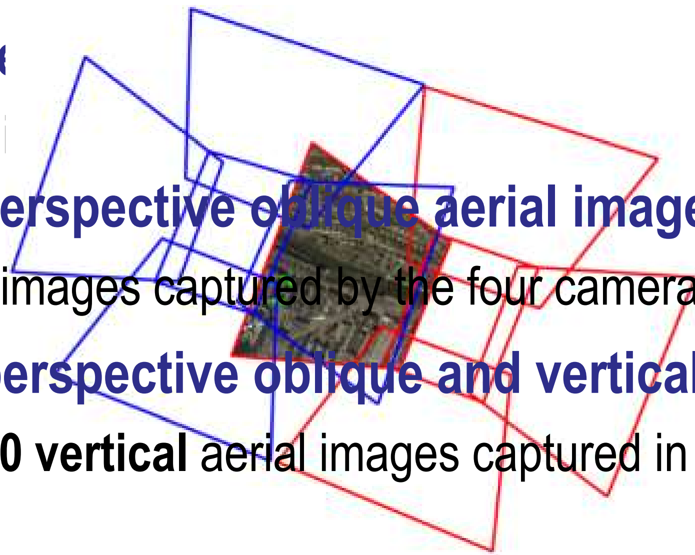
50 calibrated multi-perspective oblique and vertical aerial images

- *"Benchmark on High Density Image Matching for DSM Computation" ISPRS/EuroSDR*
- **Maltese-cross configuration**, (4 oblique tilted at 35°, 1 nadir camera)
- **Leica RCD30 Oblique Penta** camera system with a 60-Mpixel sensor; flying height of about 520 m
- GSD between 6 and 13 cm; approximate image overlap in nadir view: 70%

Test dataset

Aerial triangulation scenarios

- **Scenario 1: Obliqu… …spective**
  - **10 oblique** aerial … …era
- **Scenario 2: Multi-perspective oblique aerial images**
  - **40 oblique** aerial images captured by the four cameras
- **Scenario 3: Multi-perspective oblique and vertical aerial images**
  - **40 oblique and 10 vertical** aerial images captured in Maltese cross configuration



Measurement of four coplanar GCPs in one of the four starting oblique aerial images

Automatic estimation of their image coordinates in its successive oblique aerial image taken by the same camera

Metrics Computed

Estimation of the linear and the angular difference between the computed exterior orientation parameters and the reference ones (*provided by the benchmark*), through the following metrics:

- $D_{projCenters}$: indicates the distance between the computed projection center for an image and the reference one
- $D_{quaternions}$: indicates the distance between the unit quaternion that corresponds to the computed Euler angles (ω, φ, κ) for an image and the unit quaternion that corresponds to the reference Euler angles for the same image

Computation of the **average** (Avg), **maximum** (Max) and **minimum** (Min) values of these metrics among all images for each aerial triangulation scenario along with their **standard deviation** (Stdev)

Results derived by the in-house developed software

	Metric	Avg	Max	Min	Stdev
Scenario 1	$D_{projCenters}$ (m)	0.529	1.058	0.118	0.286
	$D_{quaternions}$	$2.667 \cdot 10^{-4}$	$4.412 \cdot 10^{-4}$	$1.075 \cdot 10^{-4}$	$1.228 \cdot 10^{-4}$
Scenario 2	$D_{projCenters}$ (m)	0.747	1.949	0.246	0.407
	$D_{quaternions}$	$6.782 \cdot 10^{-4}$	$16.175 \cdot 10^{-4}$	$0.000 \cdot 10^{-4}$	$2.884 \cdot 10^{-4}$
Scenario 3	$D_{projCenters}$ (m)	0.605	1.719	0.045	0.355
	$D_{quaternions}$	$6.579 \cdot 10^{-4}$	$18.628 \cdot 10^{-4}$	$0.000 \cdot 10^{-4}$	$3.486 \cdot 10^{-4}$

Results derived through the developed method

- **Highest accuracy** in the exterior orientation parameters for the dataset of **10 single-perspective oblique** images (scenario 1)
- **The largest differences from the reference data** are observed for the dataset of **40 multi-perspective oblique** aerial images (scenario 2),

  as there is very poor overlap between the four oblique aerial images acquired by the multi-view camera system at a single time instance.
- The dataset of **50 multi-perspective oblique and vertical** aerial images (scenario 3) corresponds to **smaller differences from the reference data than the oblique-only multi-perspective dataset** (scenario 2), as the five images that are acquired by the multi-camera system provide a sufficiently stronger geometry to tie the side oblique aerial images of the strip together.

Results derived by Agisoft PhotoScan

For comparison reasons, the exterior orientation parameters of the images of the three aerial triangulation scenarios were computed through Agisoft PhotoScan software

Agisoft PhotoScan Results

	Metric	Avg	Max	Min	Stdev
Scenario 1	$D_{projCenters}$ (m)	0.661	0.957	0.295	0.174
	$D_{quaternions}$	$6.009 \cdot 10^{-4}$	$7.930 \cdot 10^{-4}$	$1.936 \cdot 10^{-4}$	$1.551 \cdot 10^{-4}$
Scenario 2	$D_{projCenters}$ (m)	0.786	1.519	0.257	0.223
	$D_{quaternions}$	$6.849 \cdot 10^{-4}$	$16.332 \cdot 10^{-4}$	$0.000 \cdot 10^{-4}$	$3.428 \cdot 10^{-4}$
Scenario 3	$D_{projCenters}$ (m)	0.774	1.399	0.263	0.222
	$D_{quaternions}$	$6.641 \cdot 10^{-4}$	$14.744 \cdot 10^{-4}$	$0.000 \cdot 10^{-4}$	$3.150 \cdot 10^{-4}$

Comparison between the developed software results and Agisoft PhotoScan results

- The **average value of** $D_{projCenters}$ is smaller for the case of the proposed approach than the one corresponding to Agisoft PhotoScan for all aerial triangulation scenarios
  - This **improvement** reaches the percentage of **20%, 5% and 22%** for scenario 1, 2 and 3, respectively
- The **average value of** $D_{quaternions}$ is also improved for all aerial triangulation scenarios for the case of the proposed approach, compared to Agisoft PhotoScan results
  - this **improvement** reaches the percentages of **56% 1%** and **1%** for scenario 1, 2 and 3, respectively.
- **Bigger systematic error** is derived by the **Agisoft PhotoScan** software

Conclusions

The proposed procedure has established an **efficient SfM framework based on photogrammetric algorithms** and demonstrates the results that can be achieved in **challenging datasets of oblique aerial imagery** in non-ideal aerial triangulation scenarios characterized by lack of well-distributed GCPs and minimum manual image measurements.

- Impact of **different feature extraction algorithms** on the aerial triangulation results of oblique aerial imagery
- Impact of a **weighting strategy** for image measurements during the bundle block adjustment of oblique views
- **Iterative bundle adjustment procedures** for rejecting any remaining **outlier** tracks

Thank you for your attention!

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