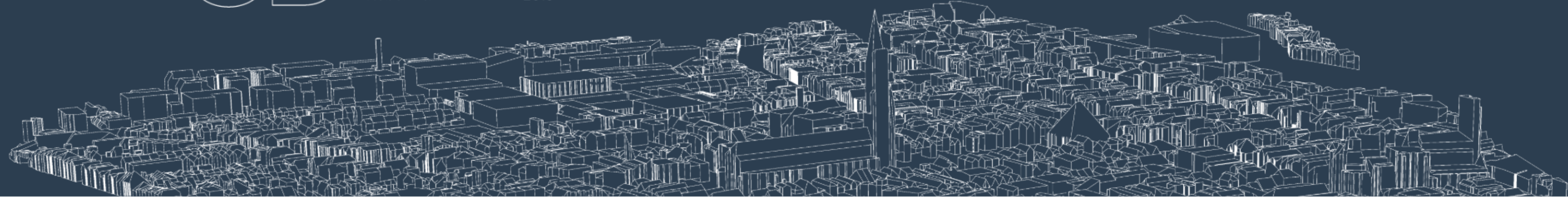
3D GEOINFO CONFERENCE
October 1 & 2 DELFT2018



A photogrammetry-based Structure from Motion algorithm using robust iterative bundle adjustment techniques

Styliani Verykokou

Rural & Surveying Eng., PhD Candidate

Dr. Charalabos Ioannidis

Professor of Photogrammetry

National Technical University of Athens | School of Rural and Surveying Engineering | Department of Topography | Laboratory of Photogrammetry

Purpose of our work

A novel incremental photogrammetry-based structure from motion (SfM) algorithm

Contributions

- ✓ reduction of the required manual work for georeferencing of the SfM results *(GCP measurements in one image)*
- ✓ elimination of all the erroneous matches in challenging image datasets *(robust iterative bundle adjustment methods)*
- ✓ photogrammetry-based workflow

Prerequisites

- ✓ Image dataset without the need for GPS/INS information; *the images of the starting pair have to depict a scene with a planar surface*
- ✓ Measurement of four coplanar GCPs in one image
- ✓ Camera interior orientation

Algorithm workflow

Determination of overlapping images

↓

Image matching and feature tracking

↓

Exterior orientation estimation of the starting image pair (*img1*-*img2*)

↓

Robust incremental SfM

***img1*: image with the coplanar GCP measurements**
img2*: image with the maximum number of correspondences with *img1

Image matching

❑ SURF features

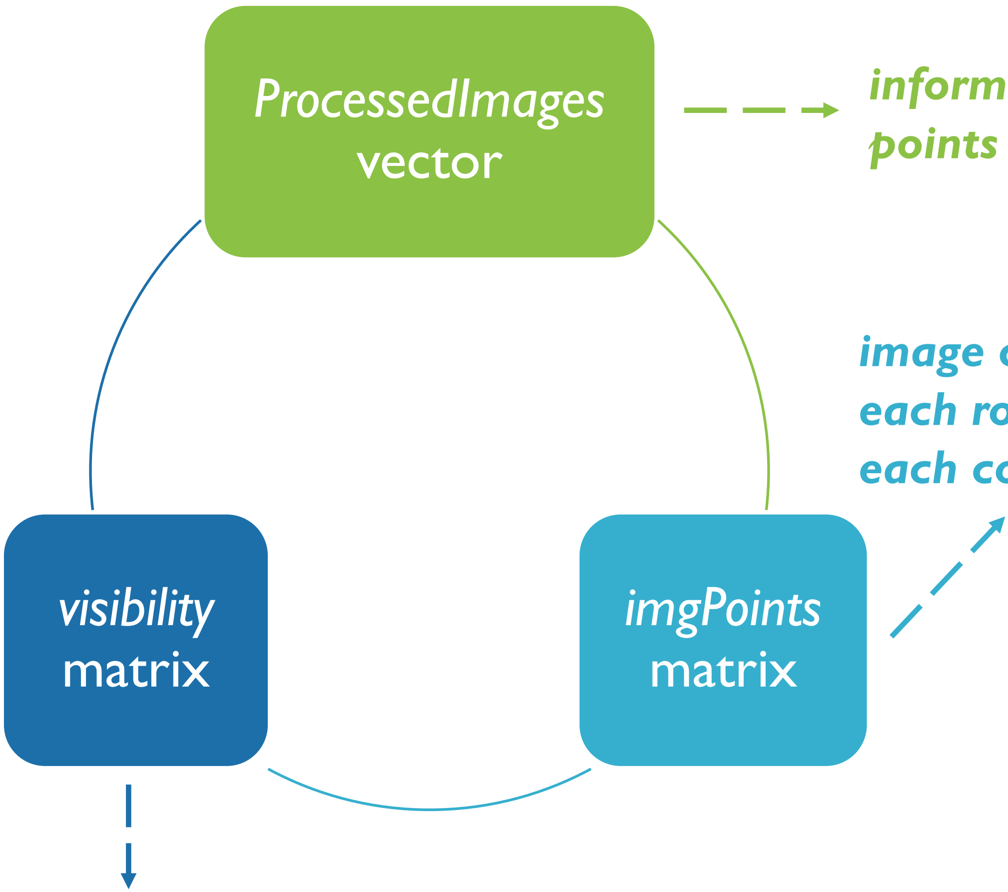
Image matching applied for

1. **Determination of overlapping images** (low resolution)
2. **Image matching of overlapping images** (higher resolution than 1)
3. **Image matching of the first pair of images** (original resolution)

Checks for removing outliers:

- Cross-check test
- Thresholding of the distance between the descriptors
- RANSAC through fundamental algorithm computation
- RANSAC through homography estimation (point-to-point constraint) with a sufficiently large pixels threshold *(only in 2&3)*

Organization of the matches into tracks



information about whether feature points have been stored for each image

image coordinates of feature points;
each row stores information for one image;
each column stores information for one track

information about whether a point is visible in each image;
same dimensions as the imgPoints matrix

Exterior orientation estimation of the starting image pair

1. Image matching between *img1* and *img2* (original size)
2. Computation of the fundamental matrix
3. Estimation of the epipolar lines in *img2* for the GCPs measured in *img1*
4. Rough estimation of the homologous points of the GCPs in *img2* through template matching
5. Iterative procedure for the estimation of the homography induced by the plane of GCPs in *img1* and *img2* using the detected tie points and the constraints imposed by the template matching results
6. Homography-based estimation of the GCPs in *img2*
7. Detection of matching tie points in *img1* and *img2* on the plane of GCPs
8. Homography estimation from the plane of GCPs in *img1* to the ground CRS
9. Estimation of ground coordinates for the detected coplanar tie points using their image coordinates in img1 and the homography computed in step 8
10. Exterior orientation estimation of *img1* and *img2*

Photogrammetry-based incremental SfM

Input: Exterior orientation parameters of the starting image pair

Iterative process implemented until all images have been oriented

1. Triangulation of the tie points of *img_i* and *img_j* via space intersection
2. Rejection of the already triangulated wrong points
3. Exterior orientation estimation of *img_j* through space resection
4. Determination of the next pair of *img_i* and *img_j*
5. Iterative process implemented until there is not any outlier
   i. Bundle adjustment with a predefined maximum number of iterations
   ii. Rejection of any outlier track
6. Bundle adjustment without constraint on the number of iterations

Fixed & *Global* bundle adjustment

***Fixed* bundle adjustment**: it keeps fixed the exterior orientation of the images that have passed through a bundle adjustment process and computes best values for the exterior orientation parameters of the one image that has not passed through a bundle adjustment process

applied in each iteration of the SfM process except for the first one

***Global* bundle adjustment**: it computes best values for the exterior orientation parameters of all the images for which initial exterior orientation parameters have been computed

applied

- in the first iteration of the SfM process
- after *fixed* bundle adjustment, if 5 images have not passed through a *global* bundle adjustment
- in the last iteration of the SfM process, after *fixed* bundle adjustment

Experiments

In-house developed software *(C++, OpenCV, Eigen)*

Tested using **3 datasets of UAV oblique aerial images** incorporating **15**, **25** and **33 images** (Sony Nex-7 camera, 6000×4000 pixels, GSD 1-3 cm, focal length of 16 mm)
"ISPRS benchmark for multi-platform photogrammetry"

For comparison reasons:

Reference exterior orientation parameters are obtained via commercial SfM software using a block of 645 UAV and terrestrial images along with the released GCPs of the benchmark

Results

Average absolute differences between the computed and the reference exterior orientation parameters via the developed software and commercial SfM software assuming fixed interior orientation

	Developed solution (GCPs in 1 image)	Commercial SfM software (GCPs in 2 images)
	15 images	
$(|\Delta Xo|+|\Delta Yo|+|\Delta Zo|) / 3$ (m)	0.21	0.36
$(|\Delta \omega|+|\Delta \phi|+|\Delta \kappa|) / 3$ (deg.)	0.24	0.56
	25 images	
$(|\Delta Xo|+|\Delta Yo|+|\Delta Zo|) / 3$ (m)	0.29	0.47
$(|\Delta \omega|+|\Delta \phi|+|\Delta \kappa|) / 3$ (deg.)	0.21	0.42
	33 images	
$(|\Delta Xo|+|\Delta Yo|+|\Delta Zo|) / 3$ (m)	0.37	0.41
$(|\Delta \omega|+|\Delta \phi|+|\Delta \kappa|) / 3$ (deg.)	0.32	0.36

- ✓ **higher accuracy of the proposed solution compared to commercial SfM software**
  - ✓ **the accuracy is higher in smaller datasets of imagery because of the ground control existence in only one image**

Discussion

- ✓ fully **automatic** algorithm
- ✓ requirement for measurements in a **single image**

} easily adoptable by operators without expertise or even basic knowledge on photogrammetry

INDICATIVE USE CASES

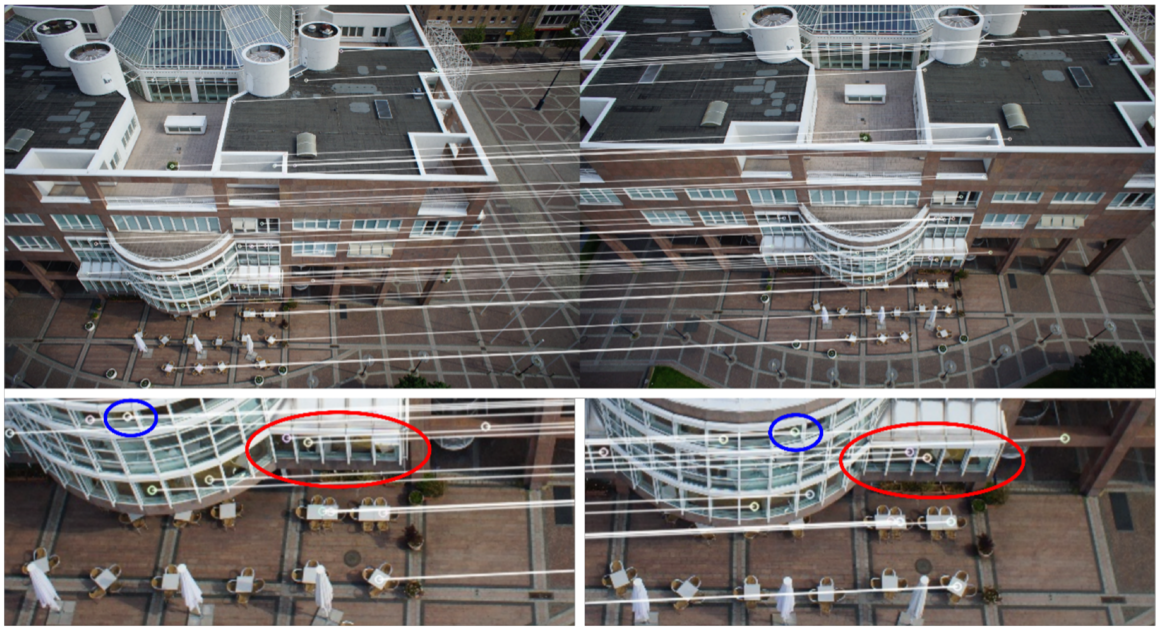
- ✓ applications for which a small number of coplanar GCPs distributed in a small area compared with the area of the total image dataset is available
- ✓ applications for which the measurement of GCPs in the area of interest is not possible
- ✓ applications for which the person in charge of the orientation process is a non-photogrammetrist

] *e.g., emergency response situations*

Discussion

ROBUST ITERATIVE BUNDLE ADJUSTMENT METHODS

✓ Necessary for datasets depicting scenes with repetitive structures



Wrongly identified feature points that (i) happen to lie on the epipolar line of the homologous feature point under consideration and (ii) are close to the correct homologous point, are not rejected during the feature tracking process

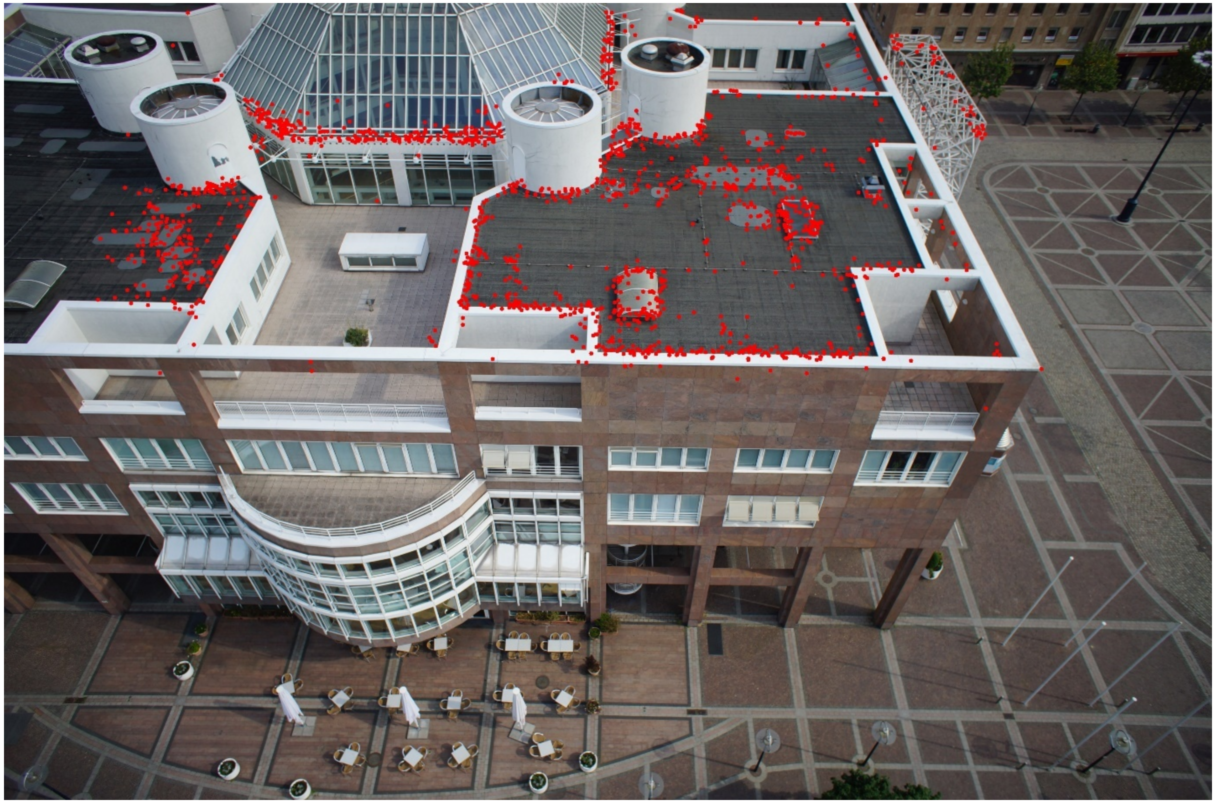
They are rejected via the proposed robust iterative bundle adjustment methods

Discussion

COPLANAR POINT DETECTION

The proposed methodology for detecting coplanar points, as implemented in the starting pair of images, may be applied:

- ✓ for the detection of coplanar points in entire datasets of imagery
- ✓ for the estimation of approximate exterior orientation parameters for entire datasets of imagery for input in a global bundle adjustment process



Thank you for your attention!

Prof. Dr. Charalabos Ioannidis

Lab. of Photogrammetry, NTUA

E-mail: cioannid@survey.ntua.gr

3D GEOINFO CONFERENCE
October 1 & 2 DELFT2018