A Comparative Analysis of Different Software Packages for 3D Modelling of Complex Geometries

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3D documentation of CH sites

- Importance of 3D documentation of cultural and natural heritage sites is well-understood at an international level
- Some cultural and natural sites correspond to complex geometries
- Such a site is the UNESCO world heritage site of Meteora

One of the largest and most precipitously built complexes of Eastern Orthodox monasteries.

characterized by **inaccessible giant rocks** with morphological peculiarities and challenging topographical features

- "METEORA" project (Information System for Multi-level Documentation of Religious Sites and Historic Complexes)

Purpose of our work

- Investigation of the performance of well-established commercial and open-source software packages for the automated 3D reconstruction of complex cultural and natural sites

Commercial software

Agisoft Metashape | RealityCapture

Open-source software

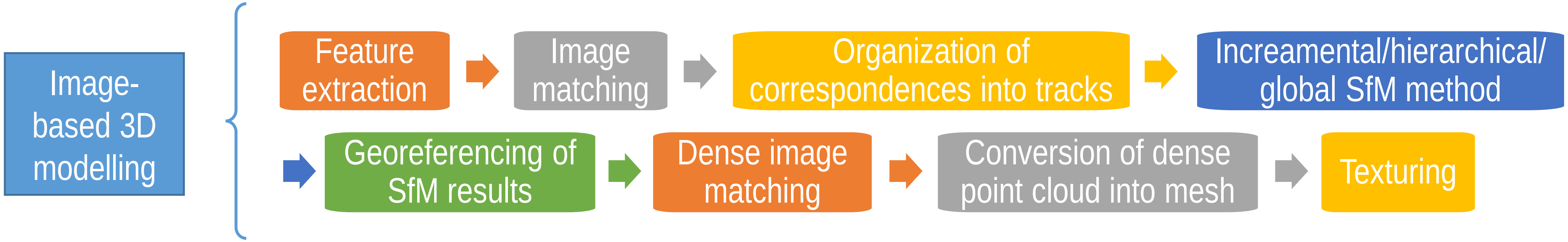
MicMac | Meshroom

- Study area:
  part of the rock of St. Modestos, known as "Modi", located in the Meteora site.
  - ruins of the old monastery of St. Modestos exist
  - about 200 m of height; the ascent to this rock is of increased difficulty

  Its topographic features are representative of complex cultural and natural sites

Image-based 3D modelling

- Structure from motion – SfM: the process of estimating the camera poses corresponding to a 2D image sequence and reconstructing the sparse scene geometry
- Multi-view stereo – MVS: the general term given to a group of methods using stereo correspondences as their main cue in more than two images
- The combination of SfM and MVS provides automated workflows for generating dense 3D point clouds and surface models



Test dataset

- 238 UAV images depicting part of the giant rock of Modi, located in the archaeological site of Meteora, in central Greece
  - captured by a DJI camera, using a DJI Phantom 4 Pro UAV
  - 5,472×3,648 pixels
  - focal length of 8.8 mm
  - pixel size of 2.41 μm
  - GPS/INS data

- The ground coordinates of 6 GCPs were computed via Agisoft Metashape using a georeferenced model of the Meteora site

Agisoft Metashape experiment

- SfM in local coordinate system: "Align Photos" (GPS/INS use; full-resolution images; feature point limit: 30,000; tie point limit: 15,000; 11DoF distortion model)
- Measurement of GCPs: "Markers" (6 GCPs measured: 129 image measurements in total)
- Absolute orientation and bundle adjustment: "Optimize cameras" (autocalibration)
- Dense image matching: "Build Dense Cloud" (downscaled by 16; aggressive depth filtering)
- Cropping of dense point cloud: "Free-form selection"
- Meshing: "Build Mesh" (arbitrary surface; high face count; interpolation enabled)
- Cropping of 3D mesh: "Free-form selection"
- Texturing: "Build Texture" (mode: generic, mosaic; size: 15,000)

RealityCapture experiment

- SfM in local coordinate system: “Align” (GPS/INS use; alignment mode: high; max features per image: 60,000; preselector features: 10,000; 8DoF distortion model)
- Measurement of GCPs: the GCPs measured in Metashape were used
- Absolute orientation and bundle adjustment: “Align” (before and after GCPs input)
- Dense image matching and meshing: “Reconstruction” (detail level: normal; no image downscaling; max vertices count per part: 5,000,000; no decimation; no editing of dense point cloud)
- Cropping and editing of 3D mesh: “Selection toolbox”, “Simplification tool”, “Check topology tool”
- Texturing: “Texture” (visibility-based; size: 8,192; max count: 40)

MicMac experiments – 2 tests

- Search for pairs: “OriConvert” (GPS/INS use)
- Feature extraction & matching: “Tapioca” (test 1: full-res images; test 2: images downscaled by 16)
- Interior and relative orientation: “Tapas” (8DoF distortion model)
- Sparse point cloud generation: “AperiCloud”
- Measurement of GCPs: the GCPs measured in Metashape were used
- Absolute orientation: “GCPBascule”
- Bundle adjustment: “Campari” (no autocalibration)
- Sparse point cloud generation in reference coordinate system: “AperiCloud”
- Dense image matching: “C3DC” (the 3D coordinates of 1 point per 4 pixels were computed)
- Cropping of dense point cloud: MeshLab (no editing tools of MicMac)
- Meshing: “TiPunch” (Poisson reconstrution; max reconstruction depth = 8)
- Cropping of 3D mesh: MeshLab (no editing tools of MicMac)
- Texturing: “Tequila” (criteria: Stretch; mode: Basic; size: 15,000)

Meshroom experiment

- Search for pairs: “Image Matching”
- Feature extraction: “Feature Extraction” (downscaled by 16)
- Image matching: “Feature Matching”
- SfM in local coordinate system: “Structure-from-Motion”
- Dense image matching: “PrepareDenseScene”; “DepthMap”; “DepthMapFilter”
- Cropping of dense point cloud: MeshLab (no editing tools of Meshroom)
- Meshing: “Meshing”
- Cropping of 3D mesh: MeshLab (no editing tools of Meshroom)
- Texturing: “Texturing”

Computational time

	Metashape	Reality-Capture	MicMac test 1	MicMac test 2	Meshroom
SfM	0h 16min	0h 6min	41h 0min	15h 14min	0h 8min
DIM	2h 36min	1h 8min	18h 21min	2h 15min	38h 0min
Meshing-texturing	0h 27min	3h 24min	0h 9min	0h 9min	2h 18min
Total time	3h 19min	4h 38min	59h 30min	17h 38min	40h 26min

Quickest option

All experiments were performed using a 64-bit Intel Core i7-8700 CPU 3.2 GHz computer with 24 GB of RAM and MS Windows 10 Pro operating system

Results

Metric	Metashape	RealityCapture	MicMac test 1	MicMac test 2	Meshroom
Avg tie points per image	n/a	10,000	181,295	11,030	n/a
Max tie points per image	11,200	10,000	283,023	13,991	n/a
Min tie points per image	n/a	10,000	49,845	3,584	n/a
Avg residual of tie points	0.58 pix	0.38 pix	0.40 pix	0.83 pix	1.10 pix
Max residual of tie points	43.45 pix	0.99 pix	0.46 pix	1.03 pix	4.00 pix
Avg GCPs residual	0.57 m	n/a	0.52 m	0.53 m	n/a
Max GCPs residual	0.69 m	n/a	0.74 m	0.71 m	n/a
Avg GCPs residual in X, Y, Z (m)	0.21,0.25,0.43	0.22,0.25,0.38	0.24,0.25,0.34	0.23,0.24,0.37	n/a
Max GCPs residual in X, Y, Z (m)	0.40,0.36,0.60	0.42,0.45,0.55	0.46,0.56,0.56	0.42,0.53,0.60	n/a
RMS error of GCPs in X, Y, Z (m)	0.23,0.30, 0.45	n/a	0.27,0.30,0.38	0.25,0.29,0.41	n/a
Sparse cloud points	0.65M	4.7M	35.6M	2.7M	0.018M
Dense cloud points	24.2M	81.9M	24.4M	24.8M	24.0M
Dense cloud points (cropped)	21.2M	25.1M	21.9M	21.9M	12.8M
Vertices of final 3D mesh	1.4M	25.1M	0.07M	0.07M	8.2M
Faces of final 3D mesh	2.9M	50.0M	0.15M	0.11M	13.4M

3D Models

Textured 3D models

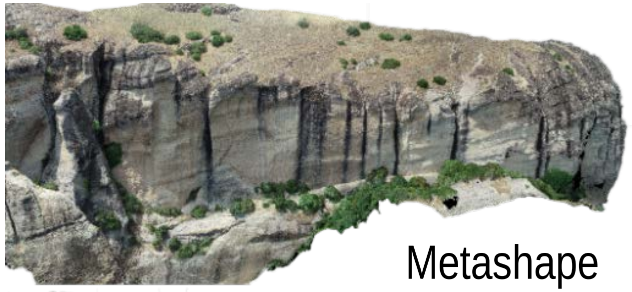
Metashape

RealityCapture

MicMac – test 2

Meshroom

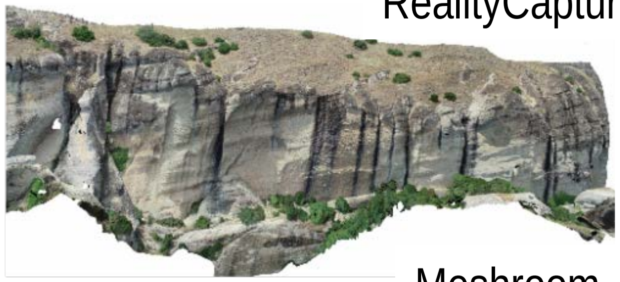
Zoom-in views



Metashape

MicMac – test 2

RealityCapture



Meshroom

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Dense point cloud comparisons

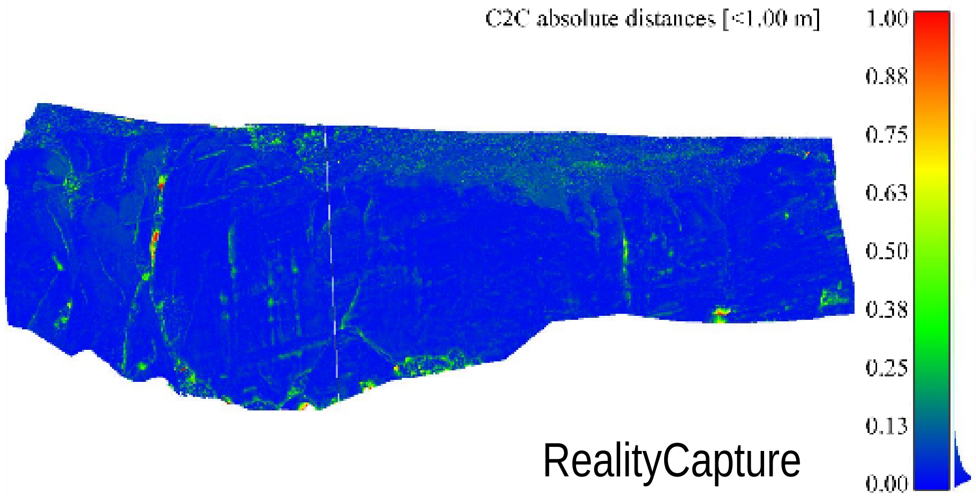
- CloudCompare software; Metashape dense cloud → reference
- The RealityCapture and MicMac point clouds were georeferenced
- The Meshroom cloud was in an arbitrary system → it was aligned to the reference one via measurement of common points, followed by the ICP algorithm

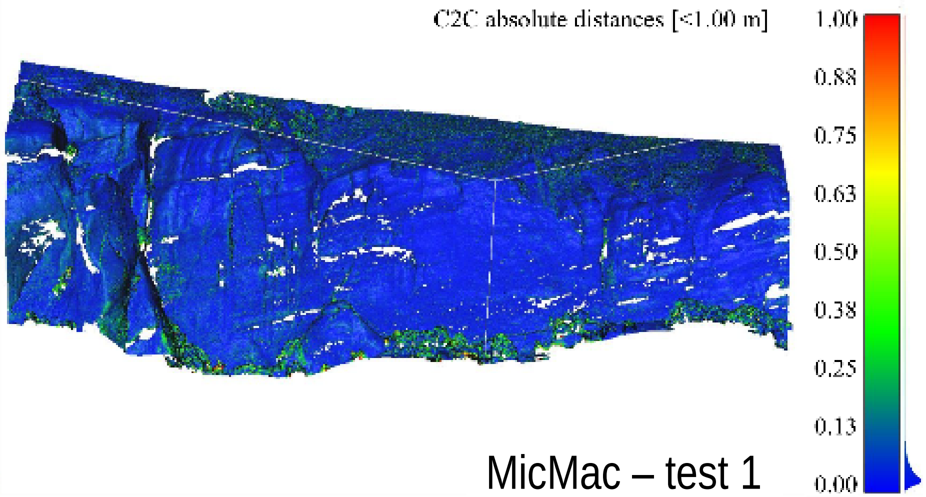
Distances between the reference (Metashape) dense cloud and the compared ones

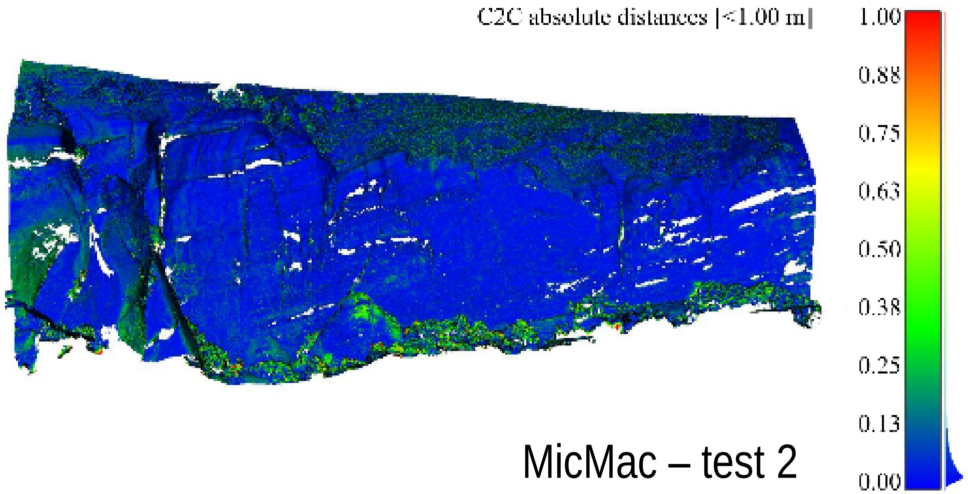
Metric	RealityCapture	MicMac - test 1	MicMac - test 2	Meshroom
Mean (cm)	6.9	5.8	7.4	6.7
Std. dev. (cm)	9.4	6.4	7.5	8.5

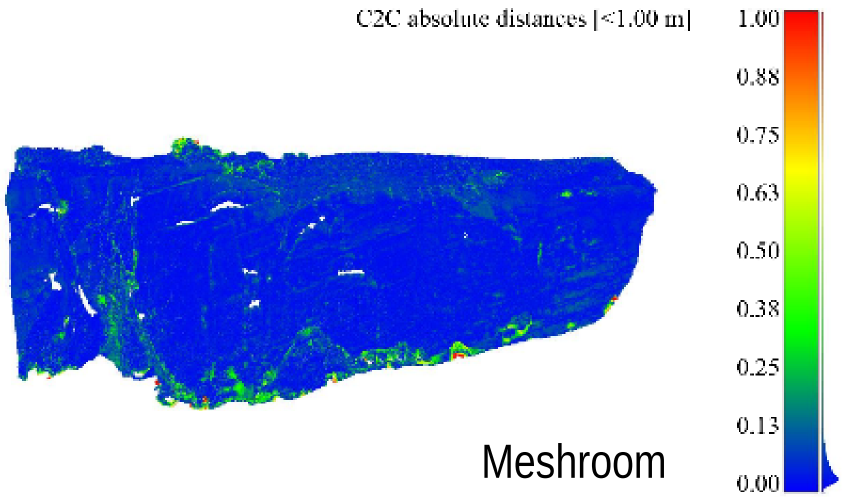
- Approximately comparable results
- A computationally intensive full-resolution matching via MicMac is not generally needed

Absolute differences between reference and compared clouds









Conclusions (1/2)

- Regarding bundle adjustment results, all solutions produced comparable outputs in terms of accuracy
- The mean distance of the derived dense point clouds was almost negligible
- A major disadvantage of Meshroom was the fact that it does not provide the possibility for measuring GCPs
- MicMac produced satisfactory results in terms of dense point cloud; however, its final textured mesh model was not satisfactory
- In terms of computational time, the commercial software packages were the most efficient solutions, with Metashape being the fastest one
- MicMac is not very user-friendly; it is intended to be used by experts in photogrammetry

Conclusions (2/2)

- In cases of geometric documentation of complex sites in a ground system defined by GCPs:
  - Metashape and RealityCapture are suitable for generating a textured 3D surface model
  - MicMac is suitable for generating a 3D dense point cloud, which may be inserted in another software for the meshing and texturing process
- Meshroom may only be used for generating a 3D model in an arbitrary coordinate system.
- Metashape and RealityCapture are commercial software, so if the budget of an organization or project does not permit a purchase of their licenses, both free solutions yield acceptable results in terms of accuracy and dense point clouds

Thank you for your attention!

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