Investigation on the

Automatic Geo-Referencing of Archaeological UAV Photographs by Correlation with Pre-Existing Ortho-Photos

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Archaeological Image Archive: Purpose & Problem

- Archaeological image archive at UHA, University of Vienna
  - 110,000 images of archaeological features
  - Started decades ago with professional large format aerial cameras, vertical analogue images
  - Nowadays semi-professional cameras, oblique digital images
  - More and more UAV data sets
- Purpose of archive: archaeological features shall be
  1. Documented & archived
  2. Mapped: spatial ensemble & context; conveniently done in derived ortho-photos
  3. Overlaid with other spatial data
- Geo-referencing: quality demands increase from 1. to 3.
  - Time-consuming when done manually
  - Off-the-shelf automatic tools unavailable

  → many data sets remain with only a coarse geo-referencing (flight records)

Typical imagery

- Archaeological features may be small & faint
- Located in rural areas
  - Few man-made objects in the scene with resp. sharp edges
  - Dominated by meadows, cropland, forests
  - Possibly flat terrain
- Vertical / oblique images
- Low flying altitude, normal lens

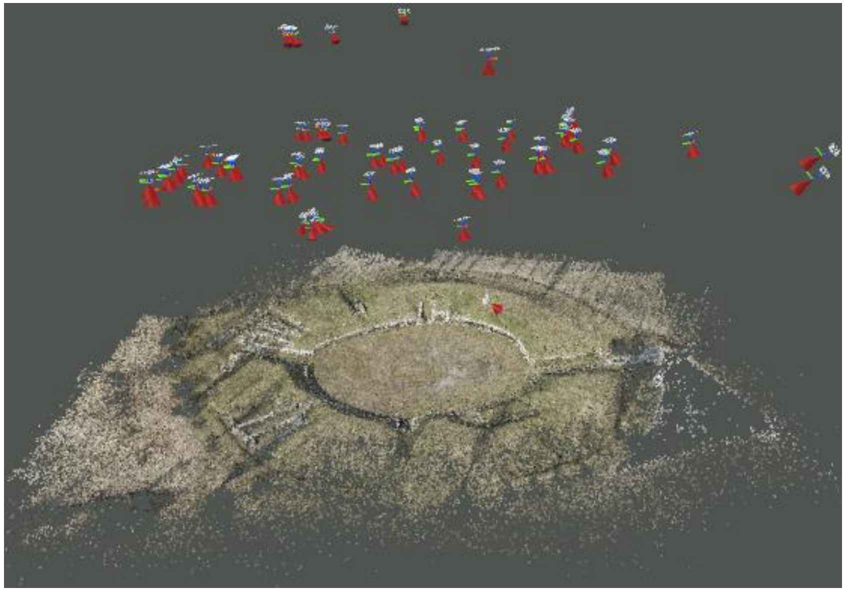
  → Large features not fully pictured on single images
- Data capture at arbitrary time of day, season, and possibly bright sunlight

  → Strong & large cast shadows
- Additional sensors may be available or not: GNSS receiver, IMU, barometre

UAV images

Prior work: relative orientation

- Relative orientation can be fully automatically computed
- Image feature point descriptor matching & incremental reconstruction
- For challenging data sets: reduce the outlier ratio by
  - Semi-local graph matching in image space
  - Compare texture along line segments of putative pairs of matches
- Also delivers sparse object reconstruction and interior camera orientation (SfM)



Sparse reconstruction by OrientAL

UAV image geo-referencing

- Direct geo-referencing
  - Additional sensors needed
  - Easily automated
  - Accuracies better than a few metres – may not be enough
  - No ground control
- Indirect geo-referencing
  - Based on surface texture
    - use existing ortho-photo map or
    - image feature data base (e.g. roof edges) as reference data
  - Based on surface shape
    - use building / surface model as reference data
  - Generally higher accuracy and reliability achievable
  - (coarse) initial values needed
  - Difficult to fully automate
- Integrated geo-referencing
  - Use additional sensor data for initial values and as additional observations / constraints

Requirements on geo-referencing method and implications

- Work without additional sensor data, but benefit from them if available
  → Indirect / Integrated geo-referencing
- Independent of buildings in the field of view, but take advantage of features found in rural areas
- Cope with flat terrain i.e. independent of terrain height variation
  → use surface texture, not shape
- Master vertical and oblique imagery
- Clearly indicate failure, while being successful often enough to be helpful
- Depend only on widely available external spatial data products as reference data
  →Use external ortho-photo maps and DSMs (countrywide available)

Proposed method

- Extract homologous points in UAV images and the ortho-photo map: the most critical step
- Interpolate surface heights for points in the ortho-photo
  → 3D control points in object space
- Determine homologous points in overlapping UAV images using coarse object model (in model space) and known relative orientation of images, forward intersect
  → 3D control points in model space
- Compute robust spatial similarity transformation from model to object space (RANSAC)
- Augment the bundle block from relative orientation with resp. observations
- Robust, hybrid bundle block adjustment, possibly with observations from additional sensors

Pre-existing ortho-photo maps

- Non-true ortho-photo (with perspective displacements)
- Captured at a different time of day, in another season of a different year

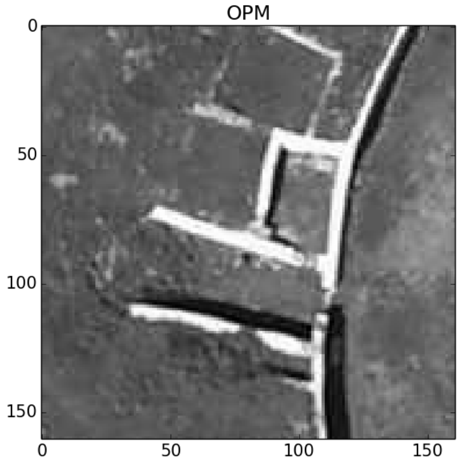
  → Strong cast shadows in a different direction

  → Vegetation generally in a different phenological state and of different size

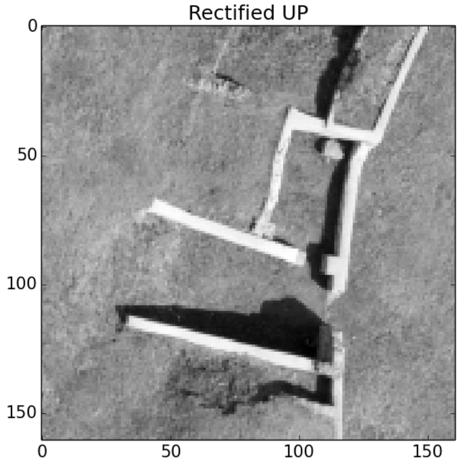
  → cropland in another phase of cultivation, with different plough marks

  → Possibly, building measures have been taken in the meantime

Ortho photo map detail: August 2008



UAV image: March 2011, 09:30h



The quest for homologous points 1/2

- Matching image abstractions fails:
  - Point features (as in relative orientation)
  - Edges
  - Regions

- Probable reasons:
  - Cast shadow boundaries result in strongest edges
    - Automated shadow suppression / removal is difficult here
  - Non-distinctive texture of vegetation
  - Temporally stable features are large vs. limited field of view

- → Operate directly on imagery: area-based matching
- Approximate values?
  → Brute-force search

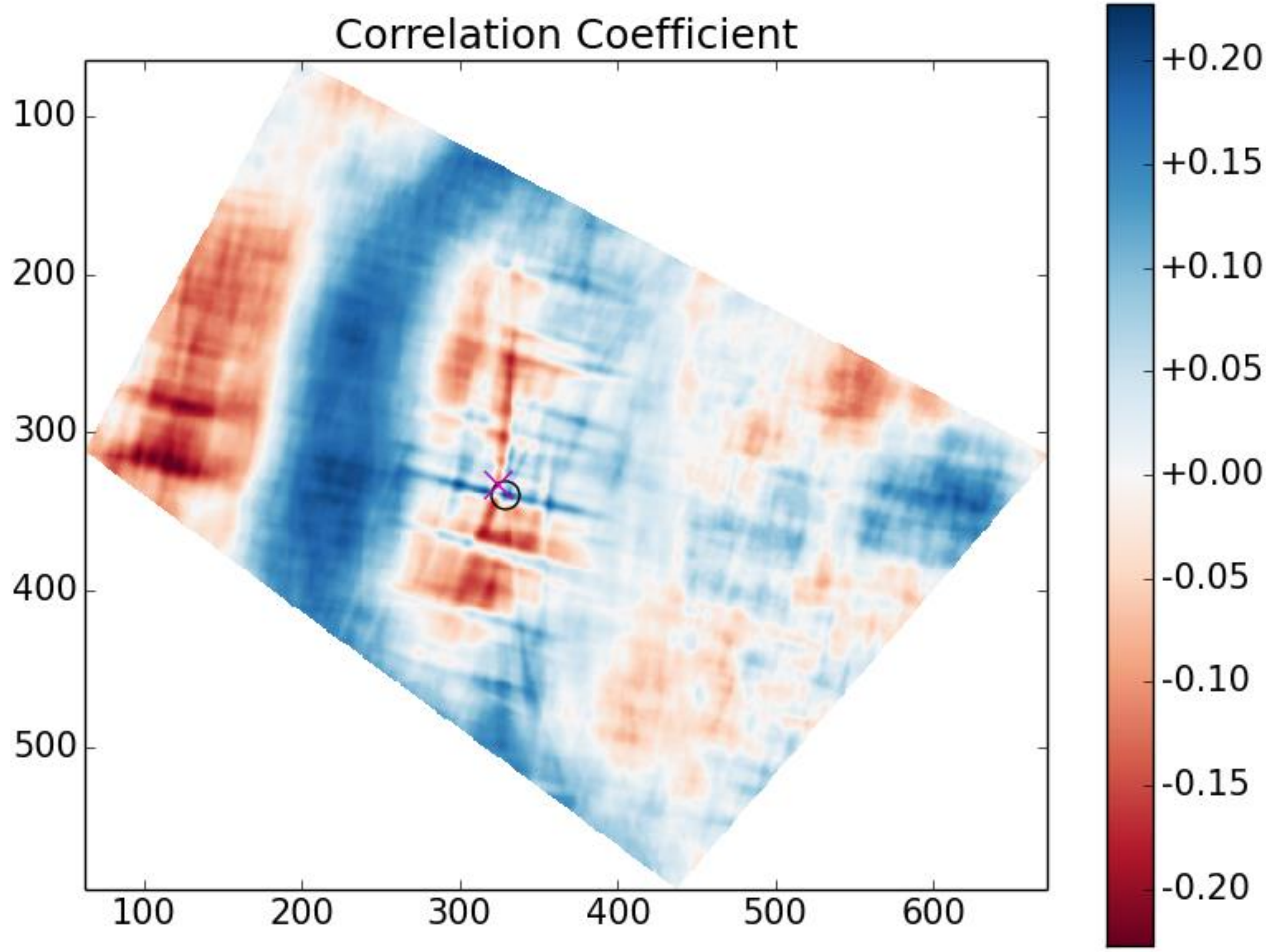
The quest for homologous points 2/2

- Search space is 7 – dimensional!
- Limit the search space considering a priori knowledge:
  - Additional sensor data, if available
  - Adjusting plane through sparse point cloud in model space
    → projectively rectify UAV images w.r.t. the horizontal plane of object space
  - Flying height, focal length -> relative image scale
  - Approx. planar position (flight records)
- Vary
  - Planar displacement
  - Relative image scale
  - Azimuth
- Extract maximum (positive) correlation
- Refine with least-squares matching
- Typical (minimal) extents of temporally stable objects
  → define template size in object space
- Quality check on LSM results

Projective rectification

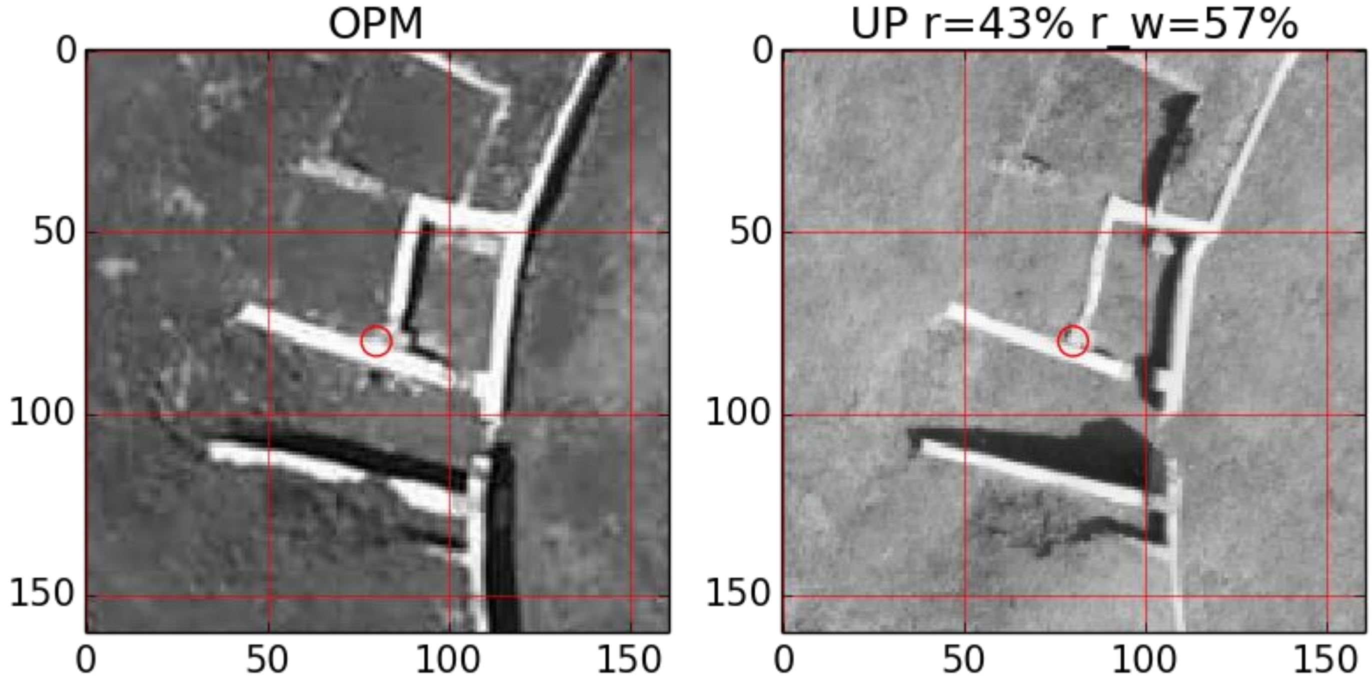
Brute force search

- At full ortho-photo resolution (12.5cm)
- For one set of relative image scale & azimuth
- All planar displacements with full overlap
- Max. correlation coefficient: only +23%
- Error: 1m



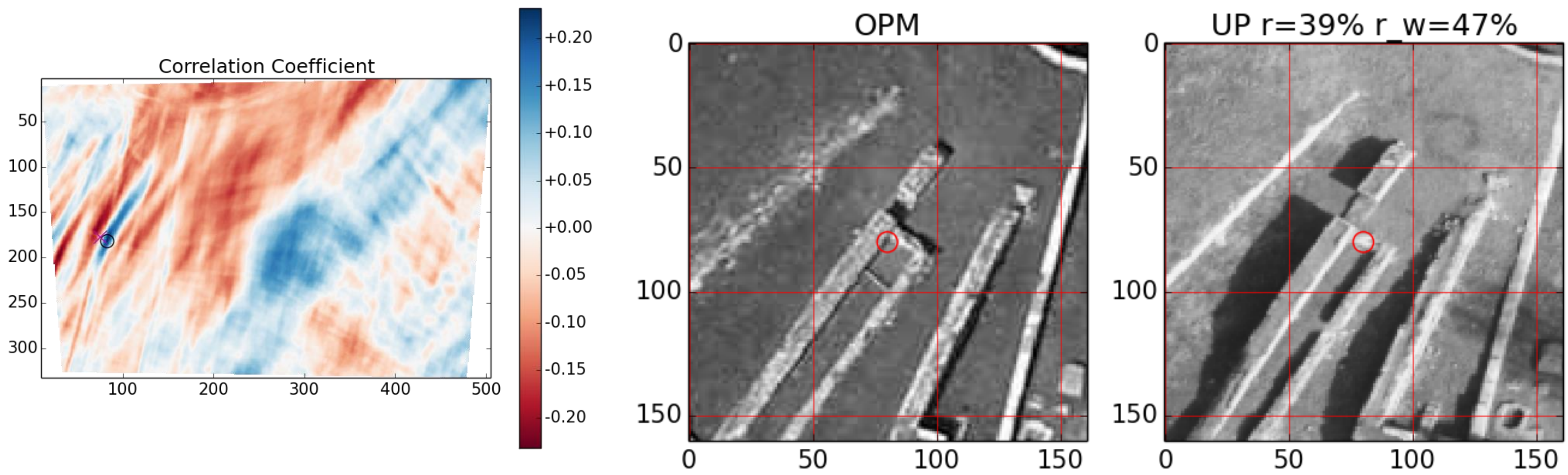
Least-squares matching

- r=43%
- Weighting function to reduce influence of cast shadows:
  - Down-weight negative differences from the median, scaled by σ_{MAD}
  - Use continuous and continuously differentiable function for weighting
- $r_{weighted}$=57%
- Error: 35cm



Another example

- r_{bf}=23%
- r=39%
- $r_{weighted}$=47%
- Error: 47cm



Conclusions

- Method matches data from different years and seasons, captured at different times of day
- Depends only on reference data that is available nationwide in many countries
- Works without additional sensors, but benefits from them, if available
- Copes with low flying altitudes with resp. small image foot-prints
- Copes with flat terrain
- Works with both vertical and oblique images
- Every correct match reduces the brute force search space dramatically – for flat terrain, only 2 are sufficient
- Brute force search can be skipped as soon as geo-referencing is accurate enough
  → Continue with LSM only to increase reliability and accuracy

Outlook

- Intelligent selection of template windows
- Reduce the number of false positives by an enhanced assessment of the quality of LSM results
- Evaluate more data sets of different characteristics
- Reduce processing time (e.g. by parallel processing)