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
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)
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 $\sigma_{\text{MAD}}$
  - Use continuous and continuously differentiable function for weighting
- $r_{\text{weighted}} = 57\%$
- 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)