From Sparse Matching Based on Evolutionary Search to Dense Matching Based on Intrinsic curves: Preliminary Results

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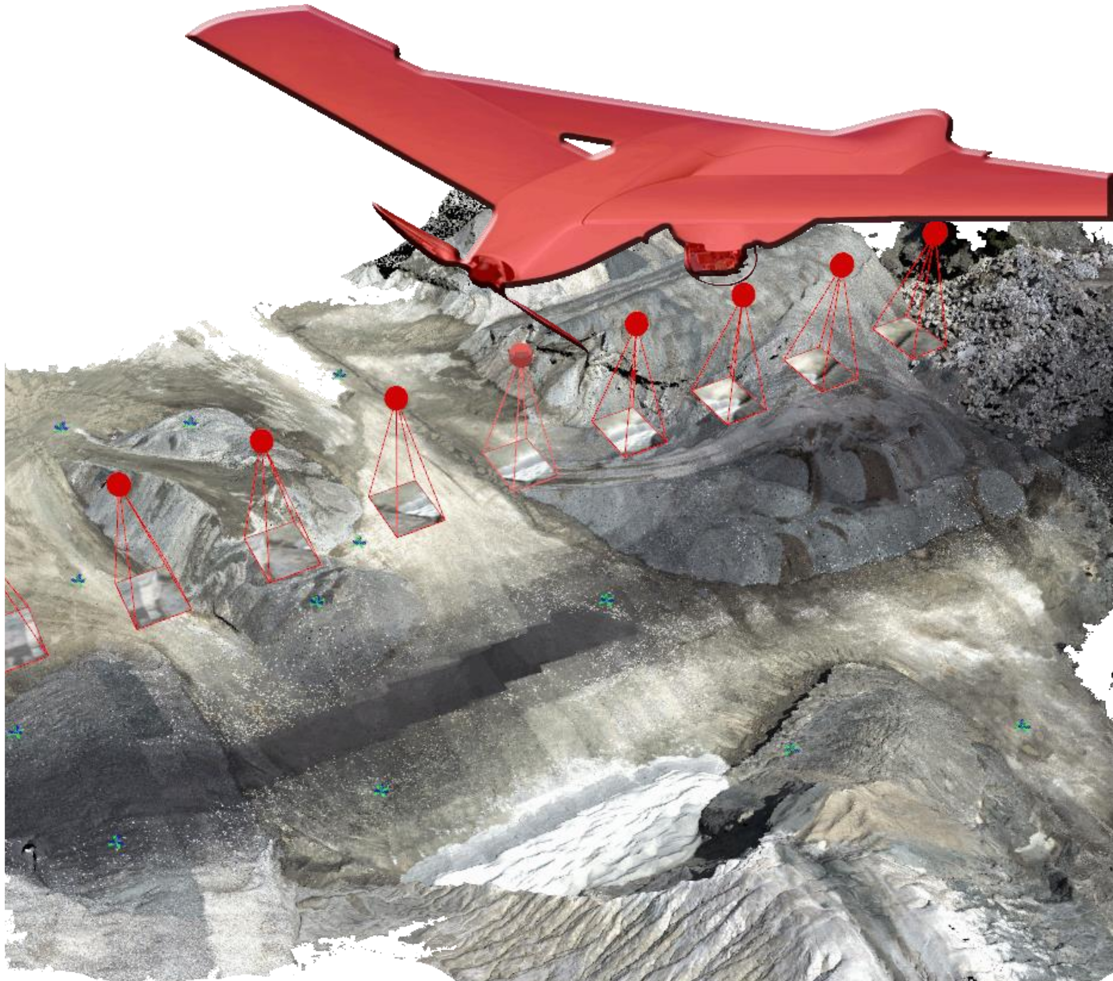


Outline

1. Objectives
2. Methodology
3. System Development
4. SfM Computation

Project Objectives

- Develop a UAV-based high resolution imaging and mapping system
- Apply photogrammetric and computer vision techniques to generate precise 3D point clouds
- Applications:
  - 3D modelling the environment of a gravel open-pit mine

Methodology

1. **System Development**
   - I. **Pre-flight**
     - i. **Integration**
     - ii. **Calibration**
     - iii. **Planning**
   - II. **Data Acquisition**

2. **Structure from Motion Computation**
   - I. **Sparse Matching and Motion Estimation**
   - II. **GCP Detection and Block Bundle Adjustment**
   - III. **Dense Matching and 3D Point Cloud Generation**

System Development

❑ Equipment

- Platform
- Navigation sensor
- Imaging sensors
- Computer
- Terrestrial surveying instruments

System Development

❑ System Integration

Camera controller

Time Synchronization

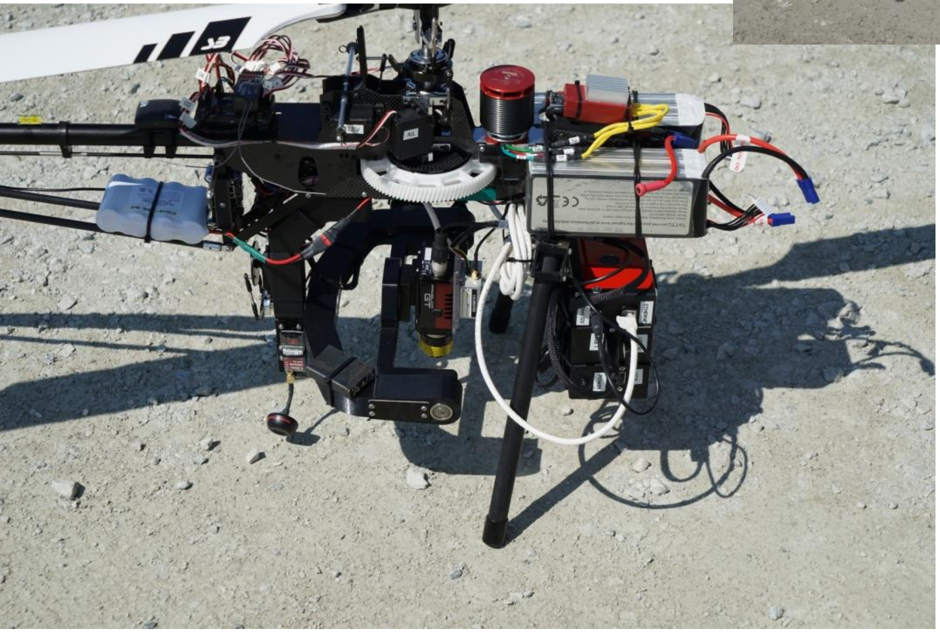
INS controller

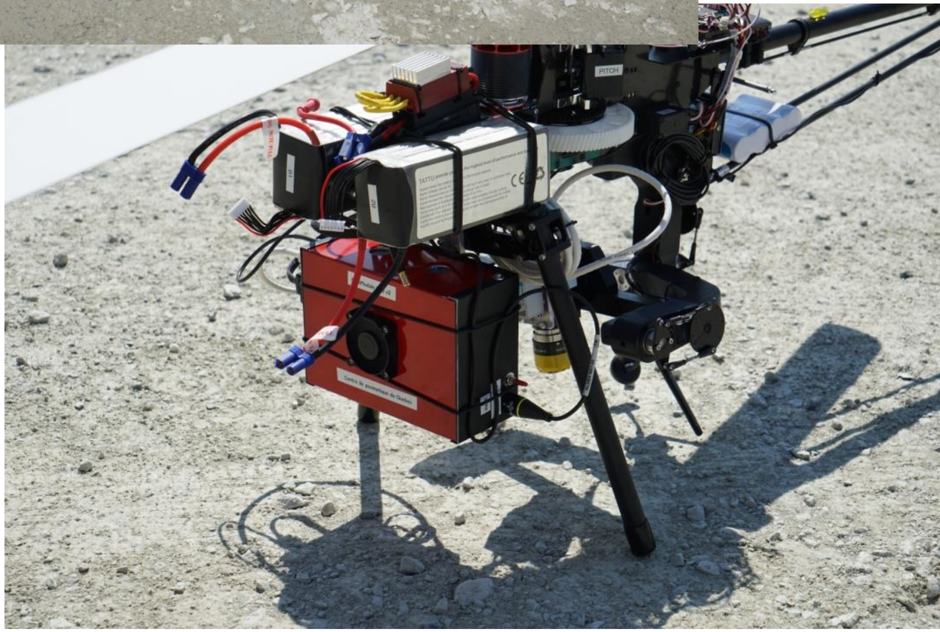
Two threads joined

Time tags ……………..
Geo tags ………………
Images ………………..
INS data ……………..

System Development

- UAV system





System Development

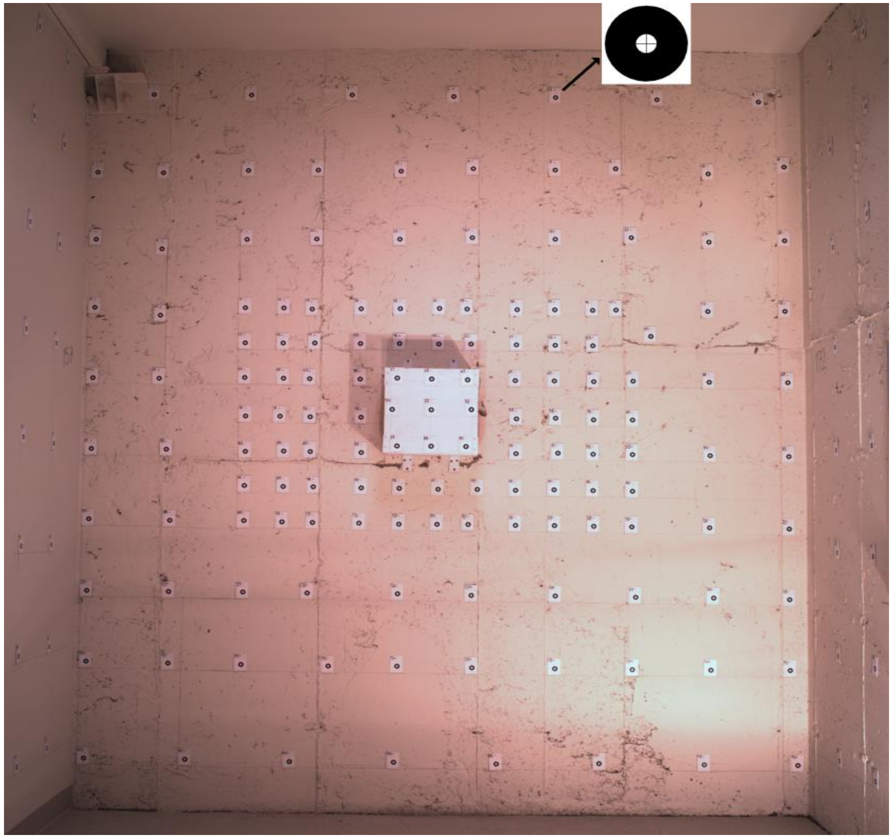
Camera calibration

Principal point offsets

Radial and tangential lens distortions

Sensor distortions, scale and shear

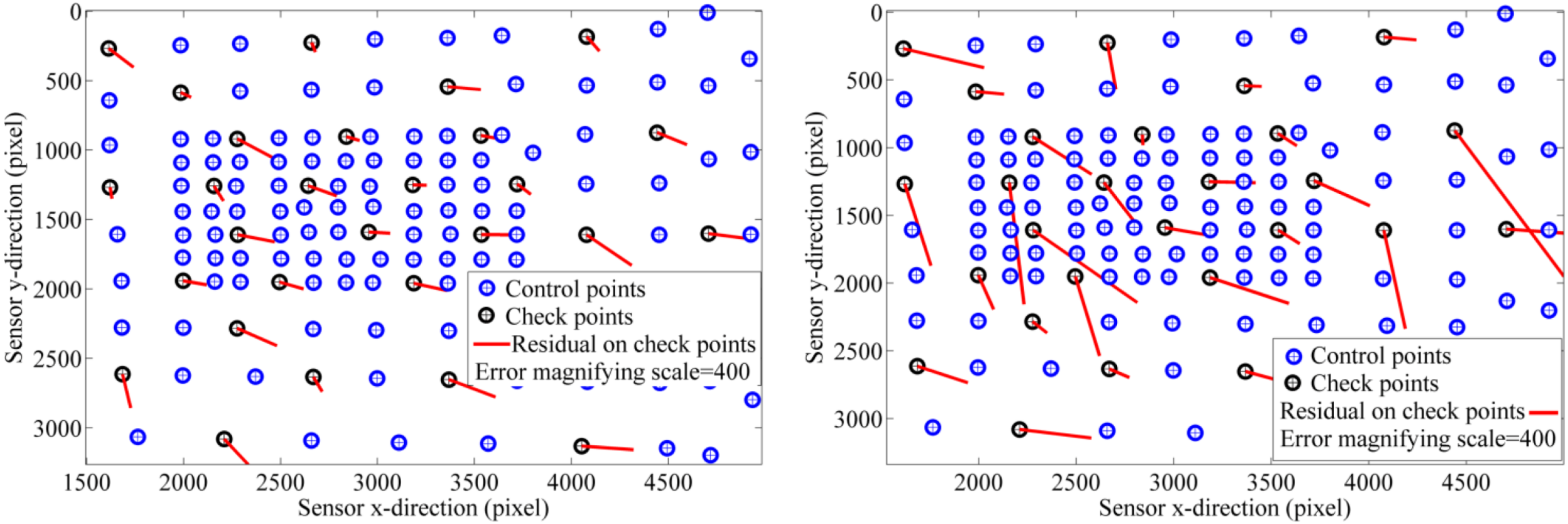
Focal length



- Testing the stability of the measurements by repeating the calibration and performing statistical tests

System Development

❑ Camera calibration

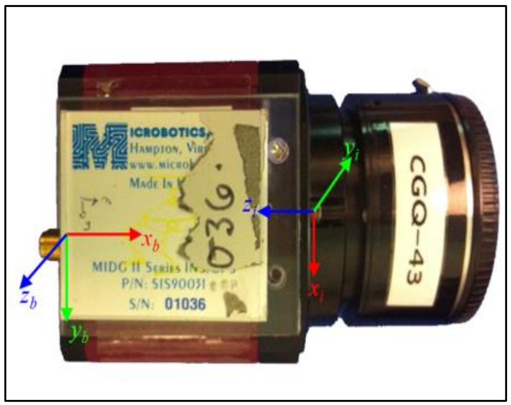


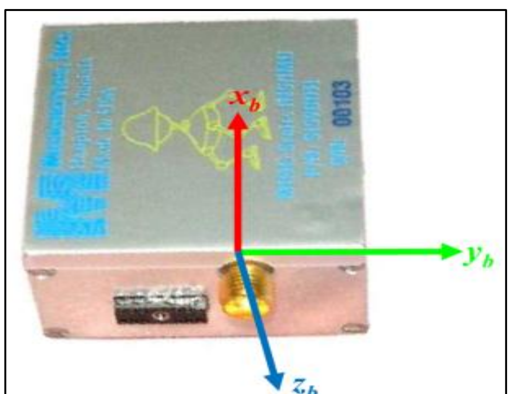
(a) (b)

System Development

❑ Platform calibration

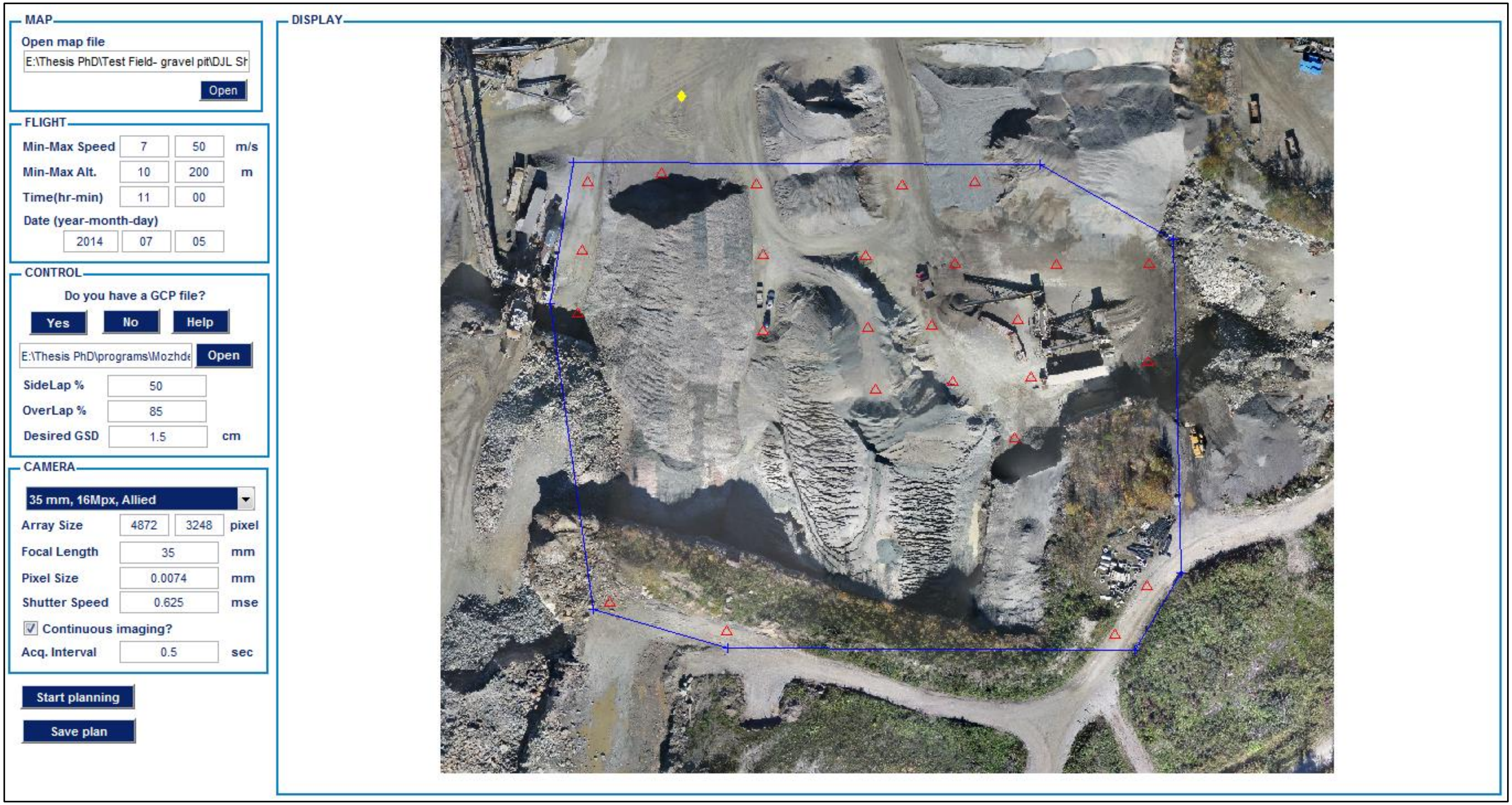
➢ **Bore sight angles between imaging coordinate system and INS sensor-fixed system**





System Development

❑ Flight Planning



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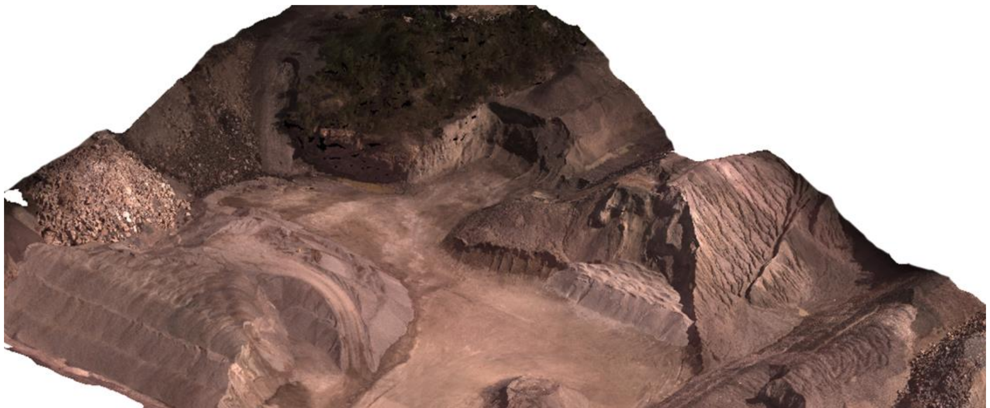
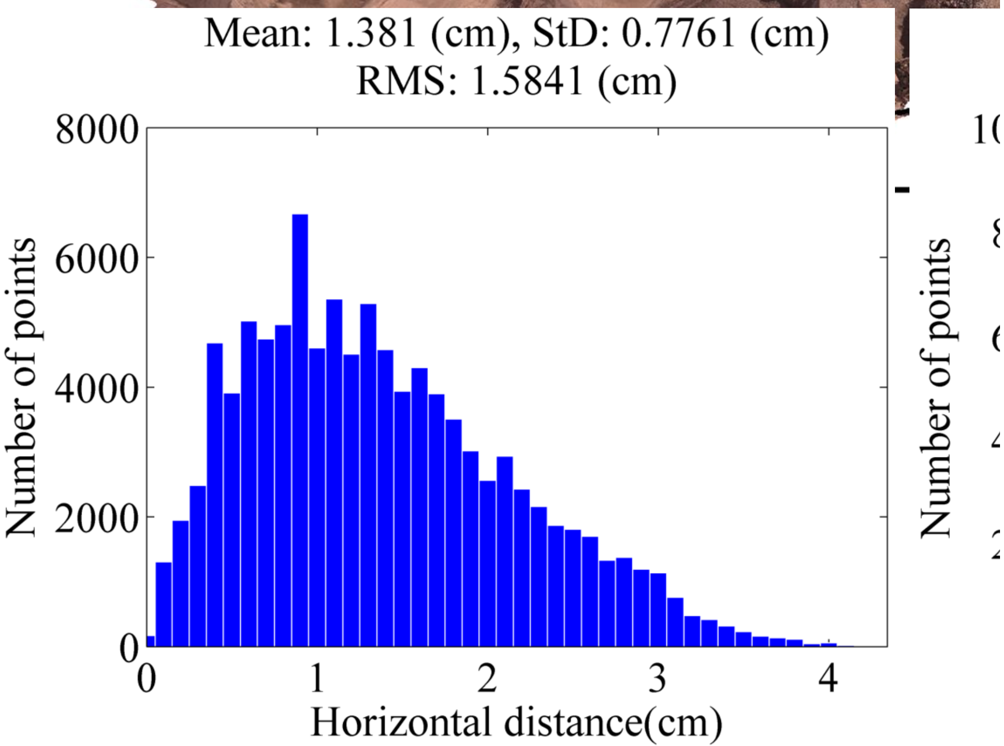
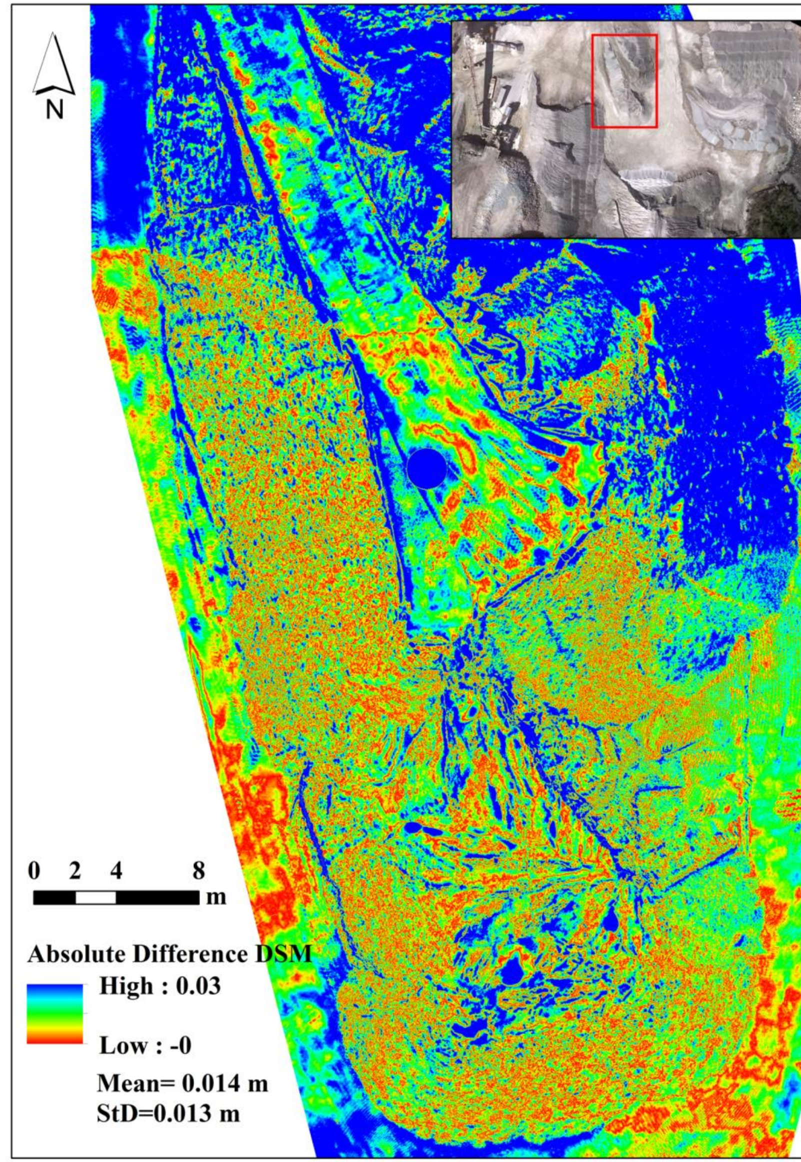
System Development

❑ Quick assessment of data quality

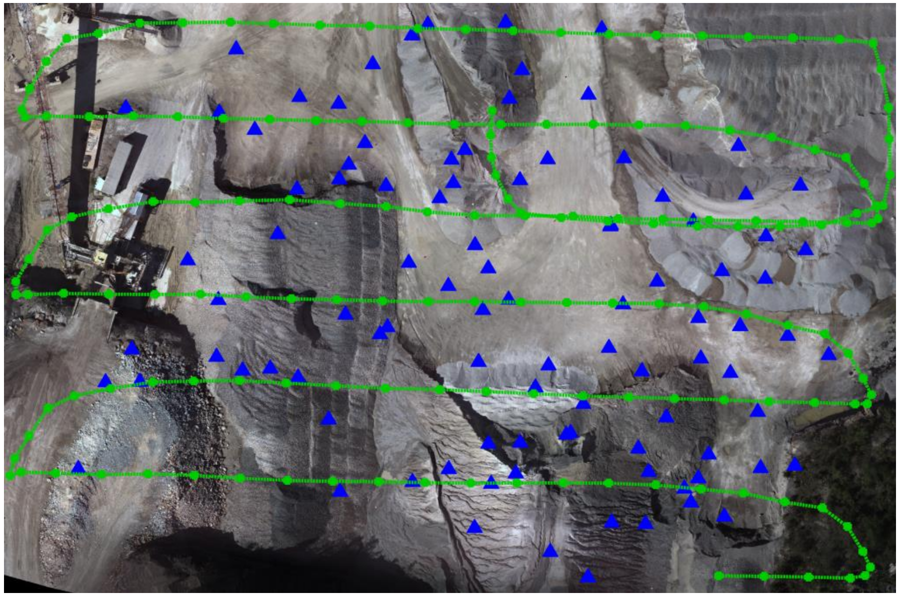






System Development

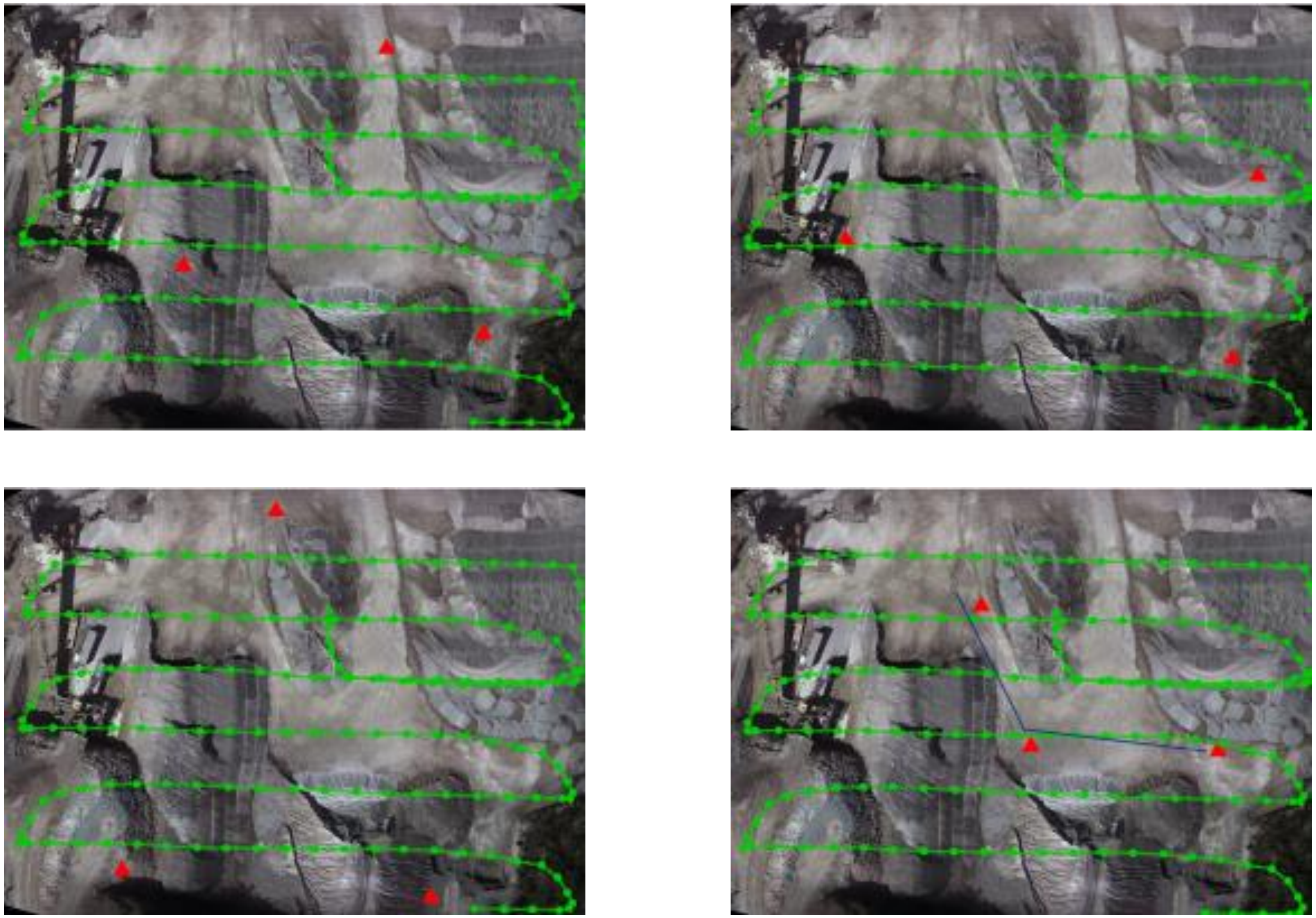
❑ Quick assessment of data quality



Horizontal error (cm)			Vertical error (cm)		
Trimble R8	**SXBlue**	**Garmin GLO**	**Trimble R8**	**SXBlue**	**Garmin GLO**
RMS	**RMS**	**RMS**	**RMS**	**RMS**	**RMS**
0.4	61.9	180.7	1.7	15.5	413.0

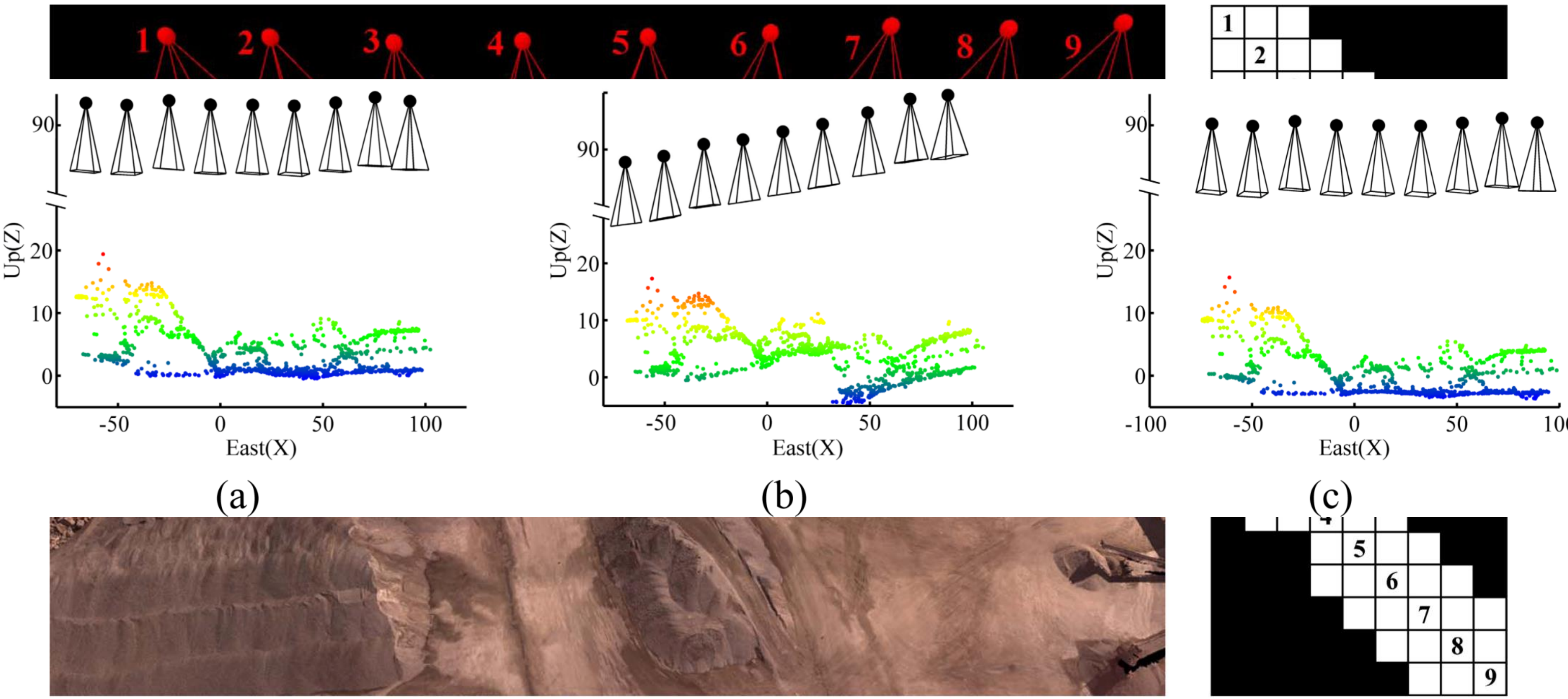
System Development

❑ Quick assessment- Minimum GCP numbers



System Development

❑ Quick assessment- Overlap importance in absence of redundant GCPs



(a) (c)

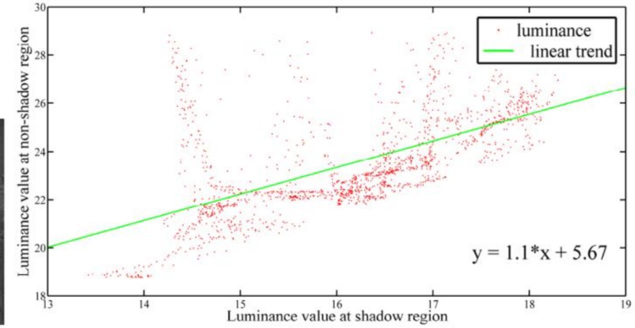
Structure from Motion Computation

Photogrammetric processing

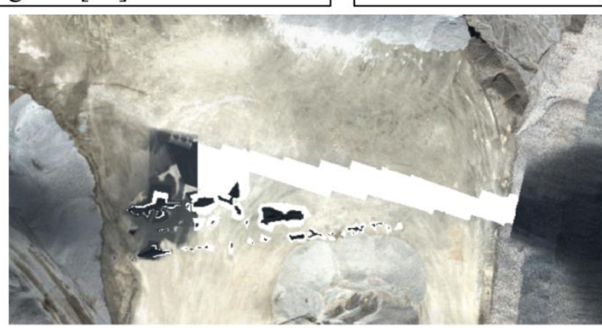
- Image pre-processing
- Camera network determination
- Stereo sparse matching and motion estimation
- Automatic detection of GCPs
- Block bundle adjustment
- Rectify the stereo pairs and perform the dense matching
- Triangulation and 3D point cloud generation

Structure from Motion Computation

❑ Image pre-processing



Converting image from RGB to YCbCr and successive binary thresholding of the luminance image to detect candidate shadow regions [34] → Extending the region boundary with morphological operations and measuring average luminance values of shadow and non–shadow regions from a moving window → Determining the linear transformation between shadow luminance values and non–shadow luminance values → Recovering the candidate shadow region using the linear transformation



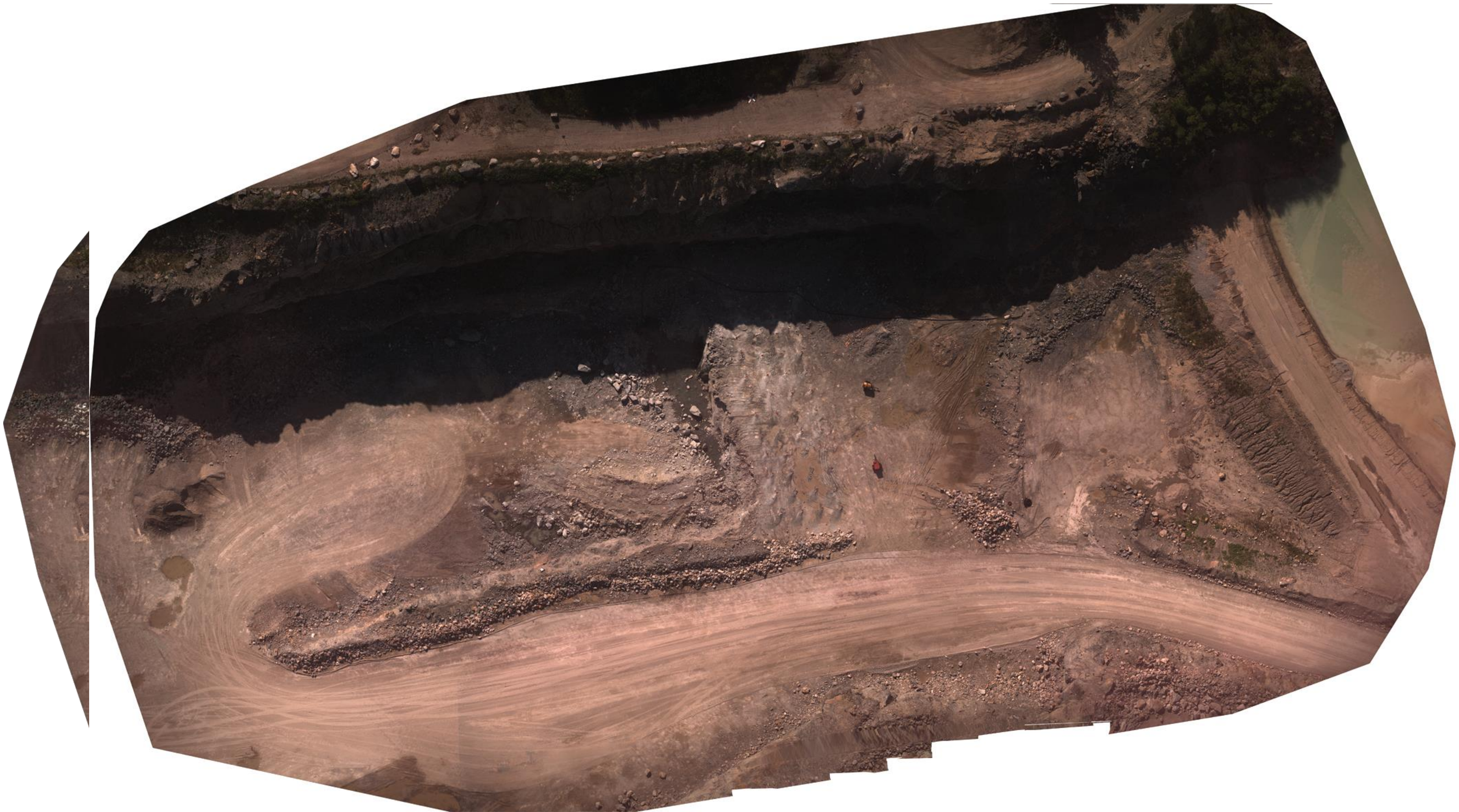
(e)

(f)

Structure from Motion Computation

❑ Image pre-processing

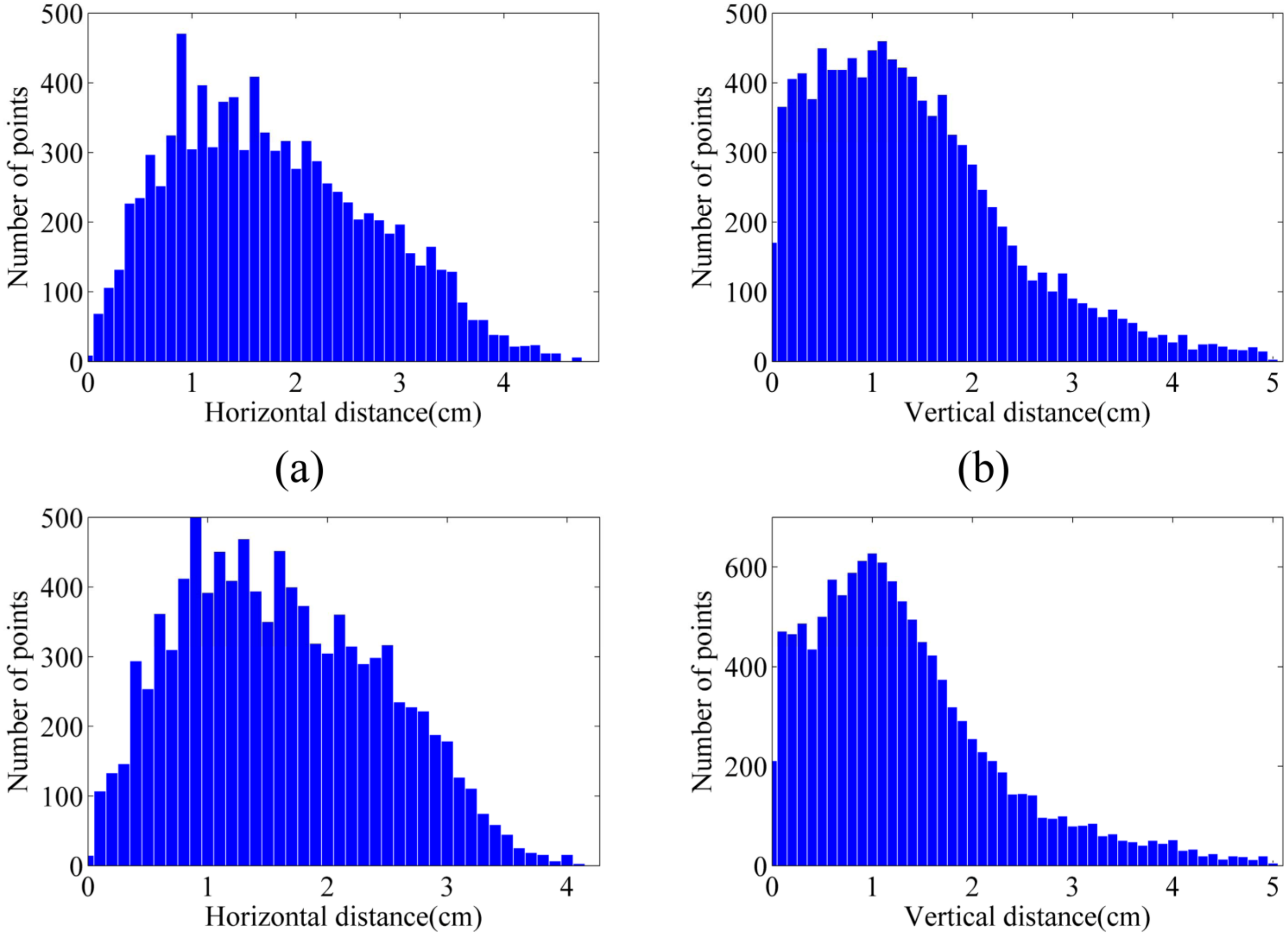
- **Shadow removal**



Structure from Motion Computation

❑ Image pre-processing

➢ **Shadow removal**



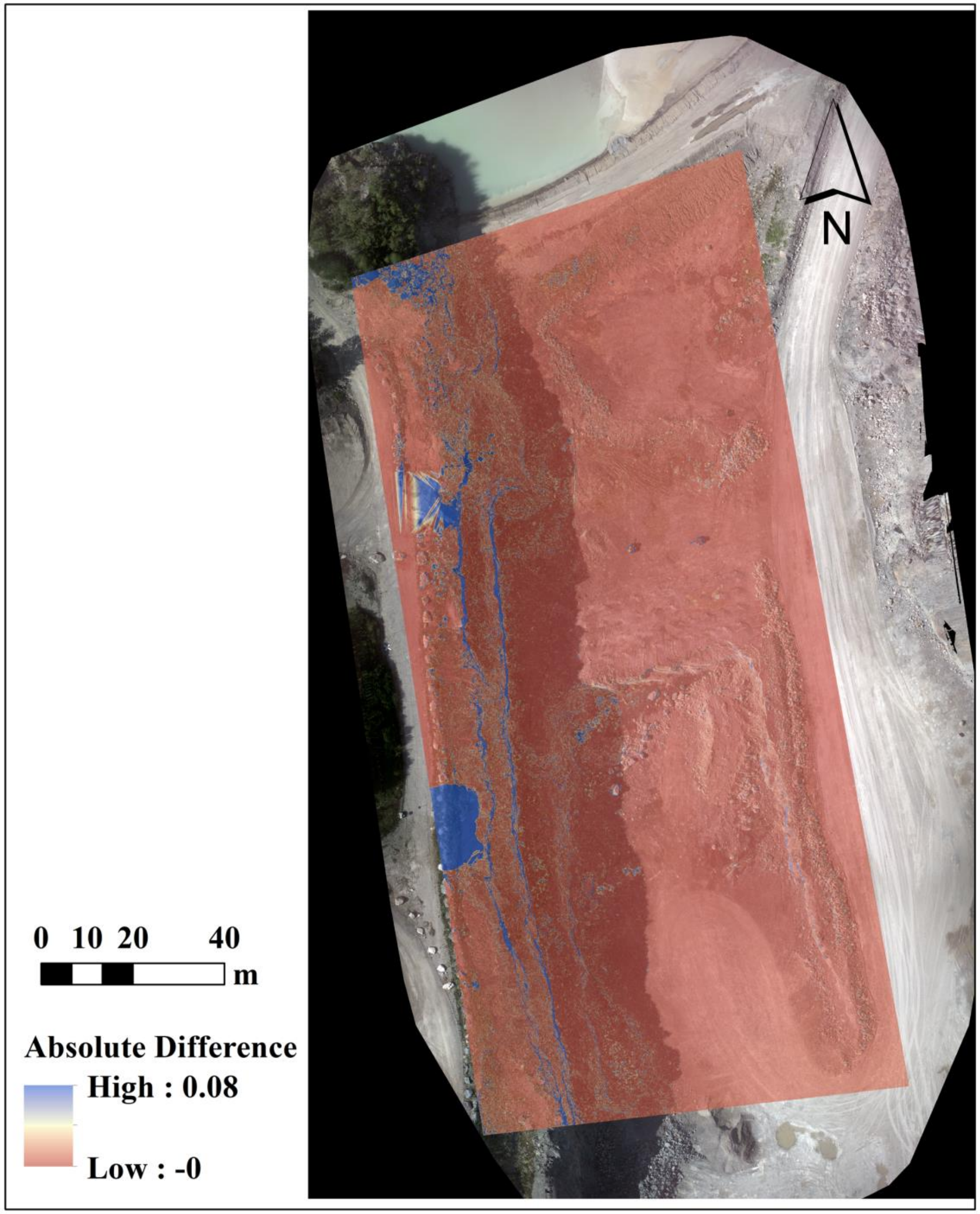
(a) (b)

(c) (d)

Structure from Motion Computation

❑ Image pre-processing

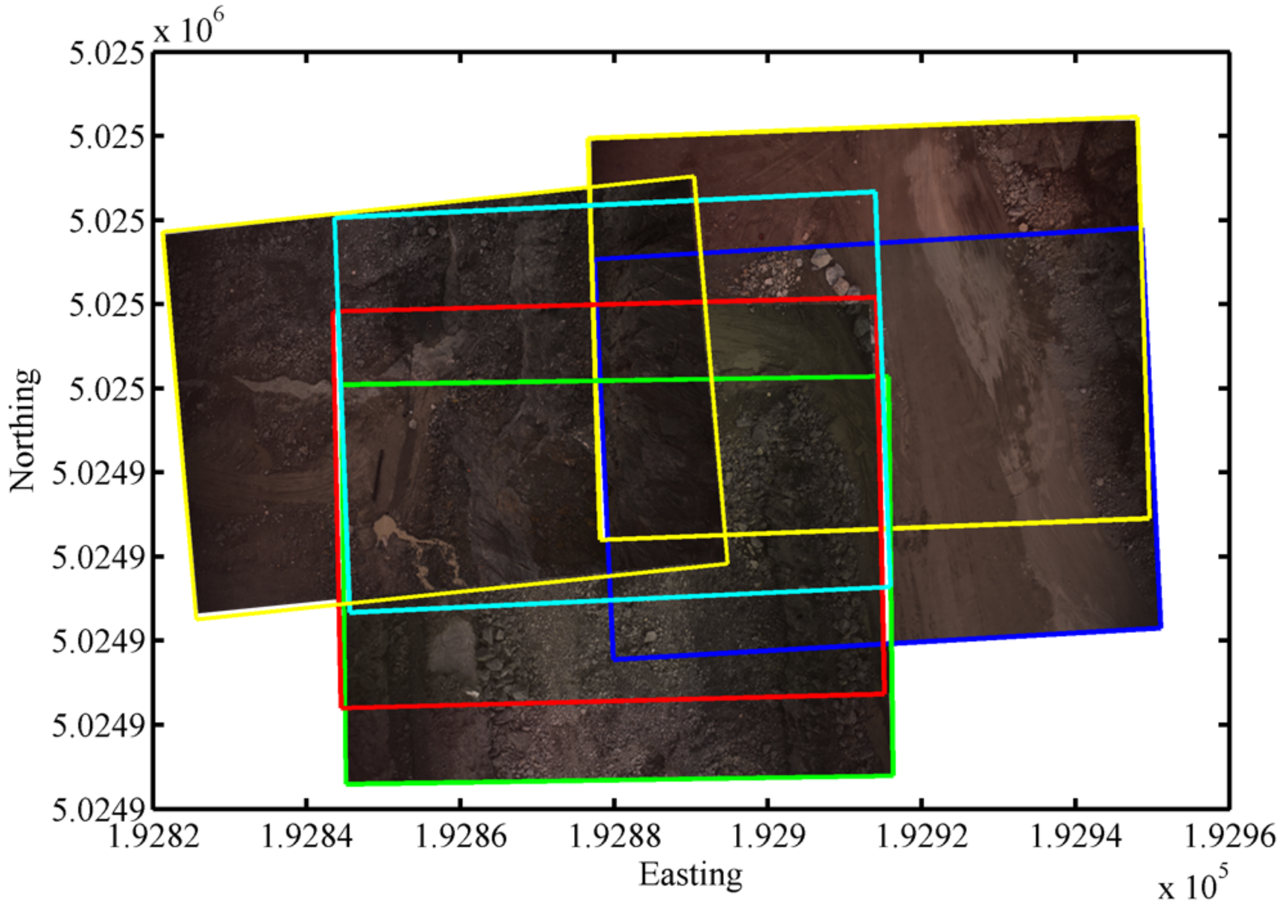
- ➢ **Shadow removal**



Structure from Motion Computation

❑ Camera network (connectivity model) determination

➢ **Using the approximate FoV of cameras**



Structure from Motion Computation

Stereo sparse matching and motion estimation

Input

Putative correspondences

Output

Estimated epipolar geometry (fundamental matrix) and the entire set of inlier matches

a) **Genetic Algorithm**

- Input: The label-set of matches, based on their position

- Output: Optimal motion model estimated from the inlier-set of minimum cardinality (More than the essential minimum) as the elite solution of GA that minimizes the objective function (based on the ordered residuals and not the support size

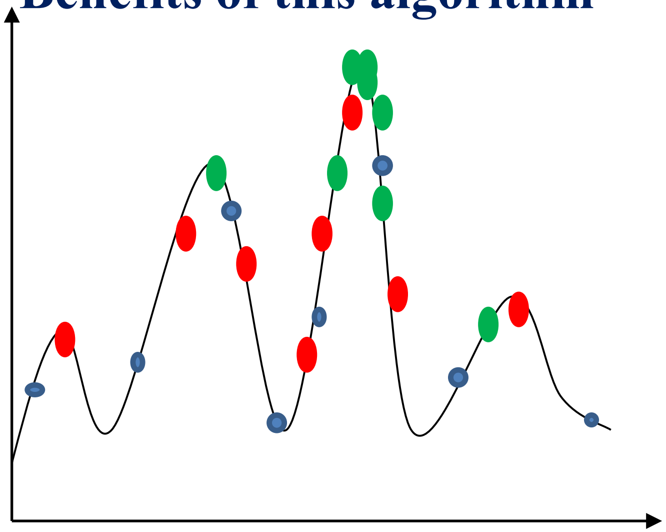
b) Estimate the uncertainty of the motion model

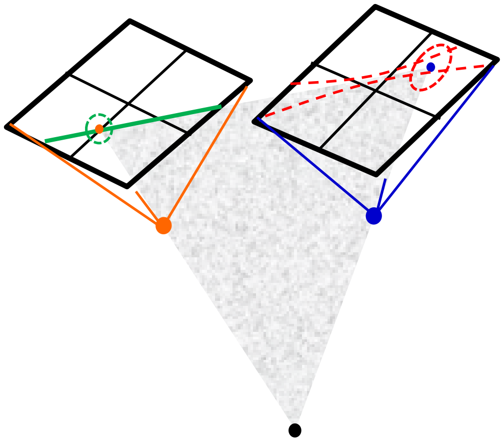
d) Use this information to threshold the residuals on other matches to determine the entire set of inliers

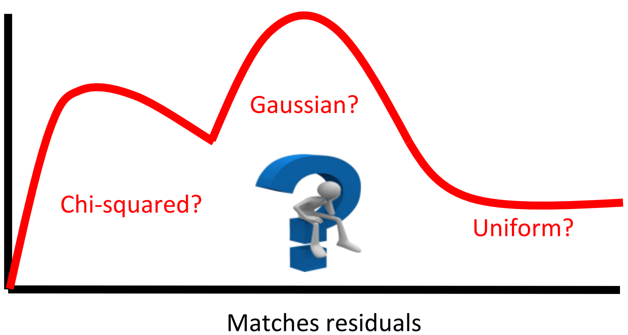
Structure from Motion Computation

❑ Stereo sparse matching and motion estimation

➢ Benefits of this algorithm



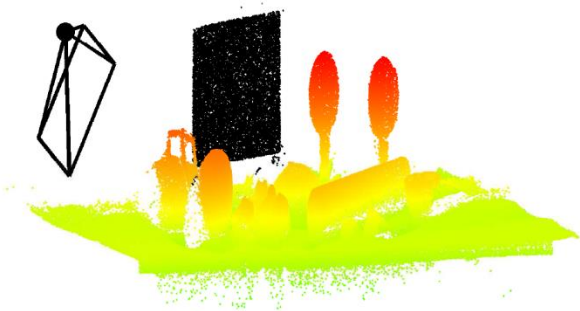


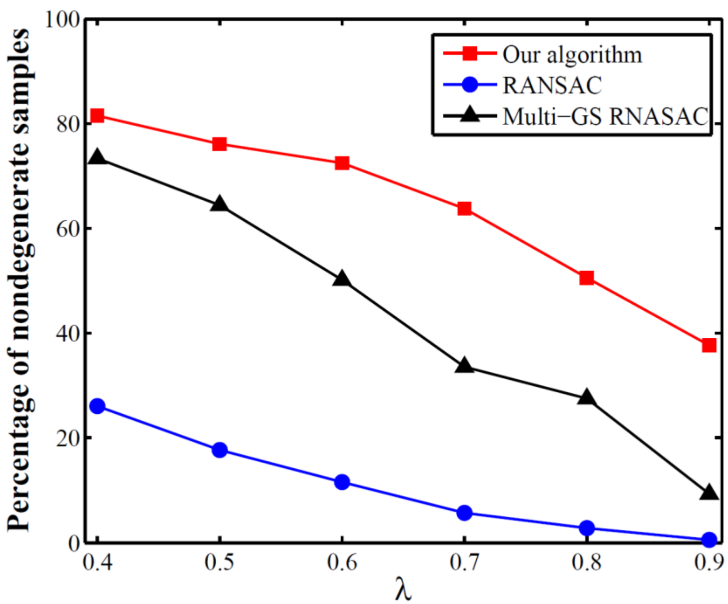


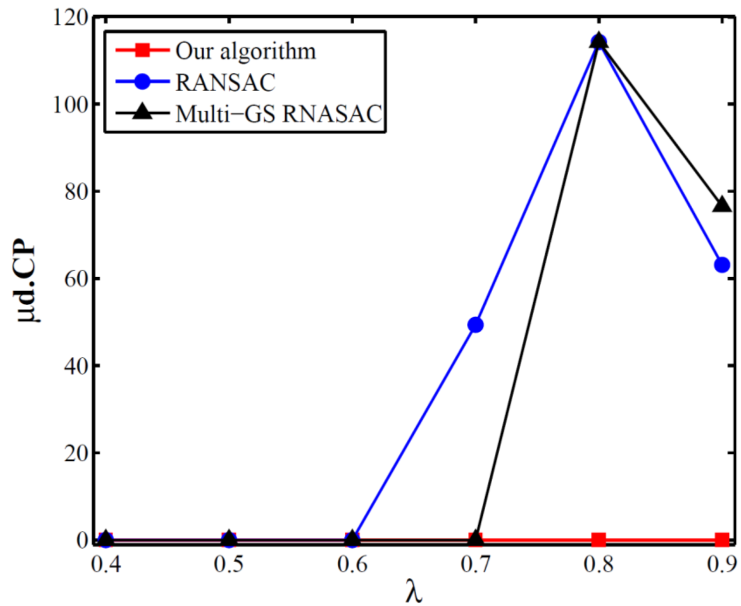
Structure from Motion Computation

❑ Stereo sparse matching and motion estimation

➢ **Increasing points on the dominant plane, limited sampling budget of 1000 samples, outlier ratio of 40%**



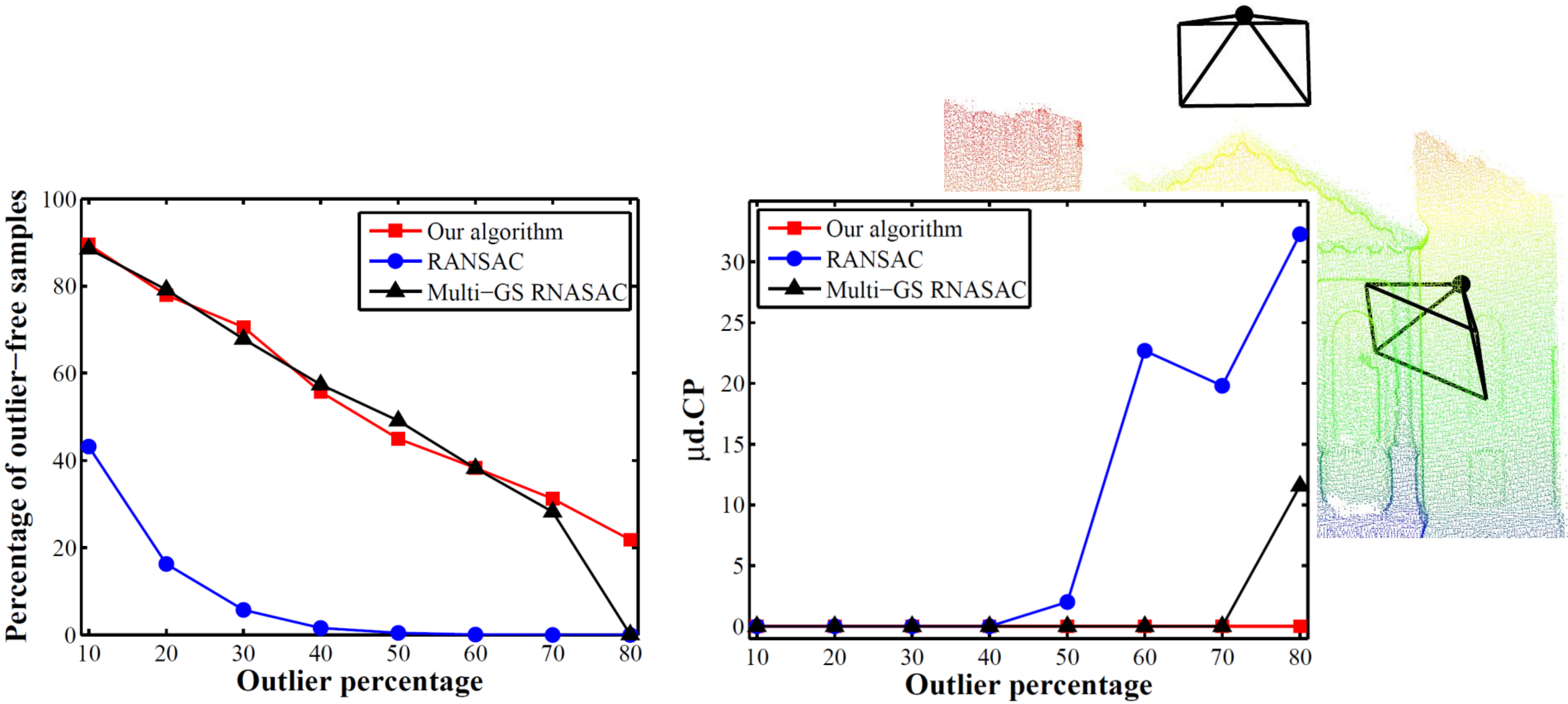




Structure from Motion Computation

❑ Stereo sparse matching and motion estimation

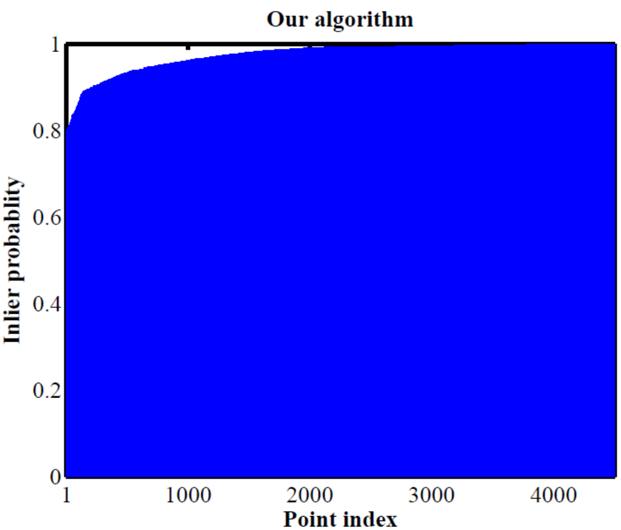
➢ **Increasing outlier ratio, limited sampling budget of 1000 and 5000 samples for less than 50% and more than 50% outliers**

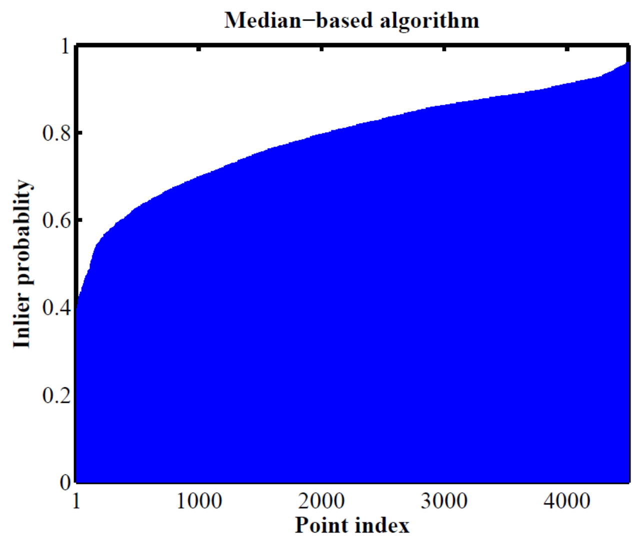


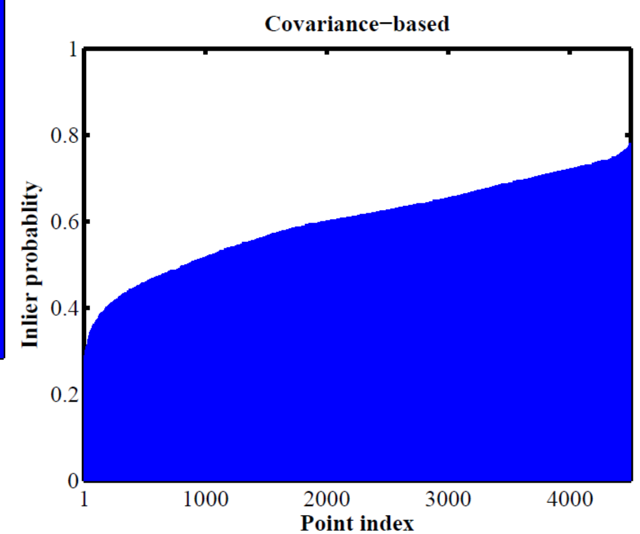
Structure from Motion Computation

Stereo sparse matching and motion estimation

- **No outliers, drawing the same samples, inlier classification**

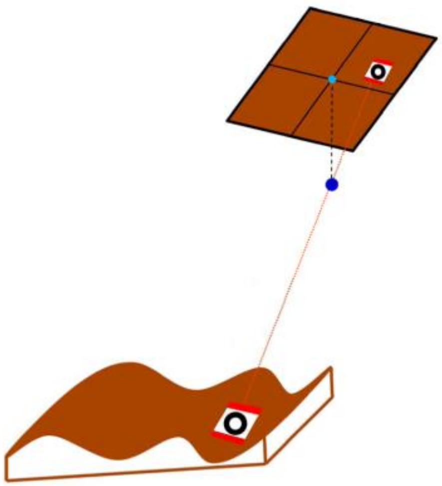


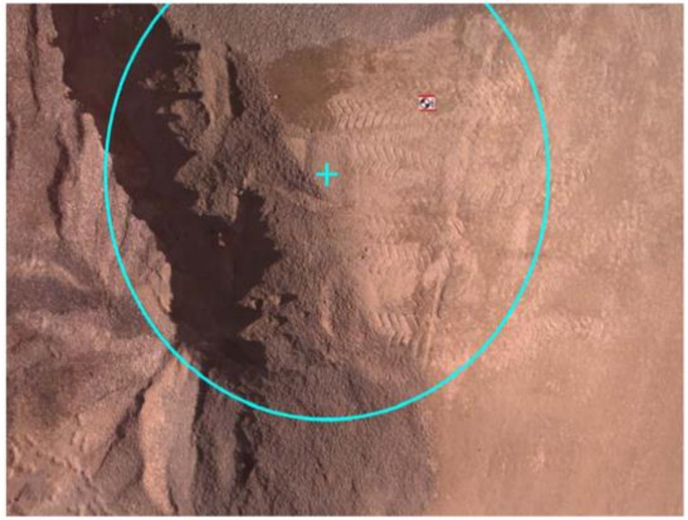


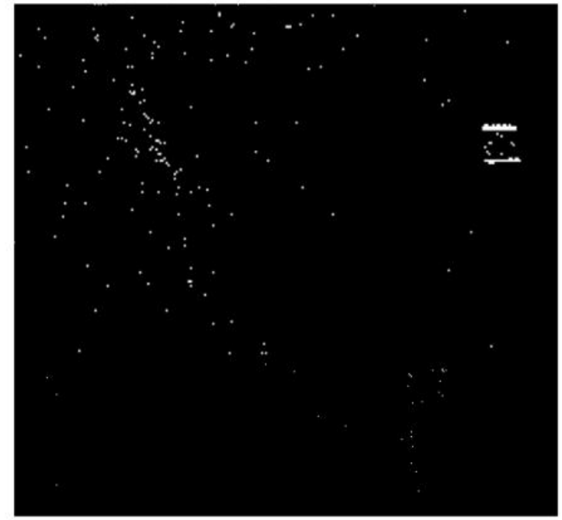


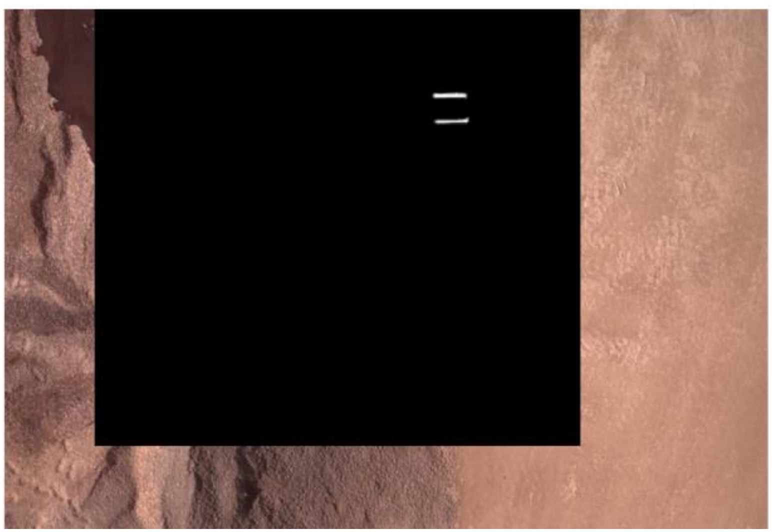
Structure from Motion Computation

❑ GCP detection and Block Bundle Adjustment



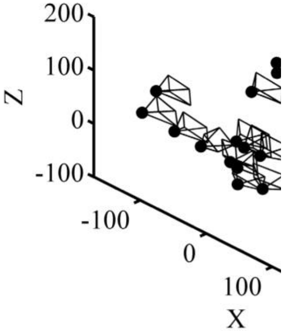


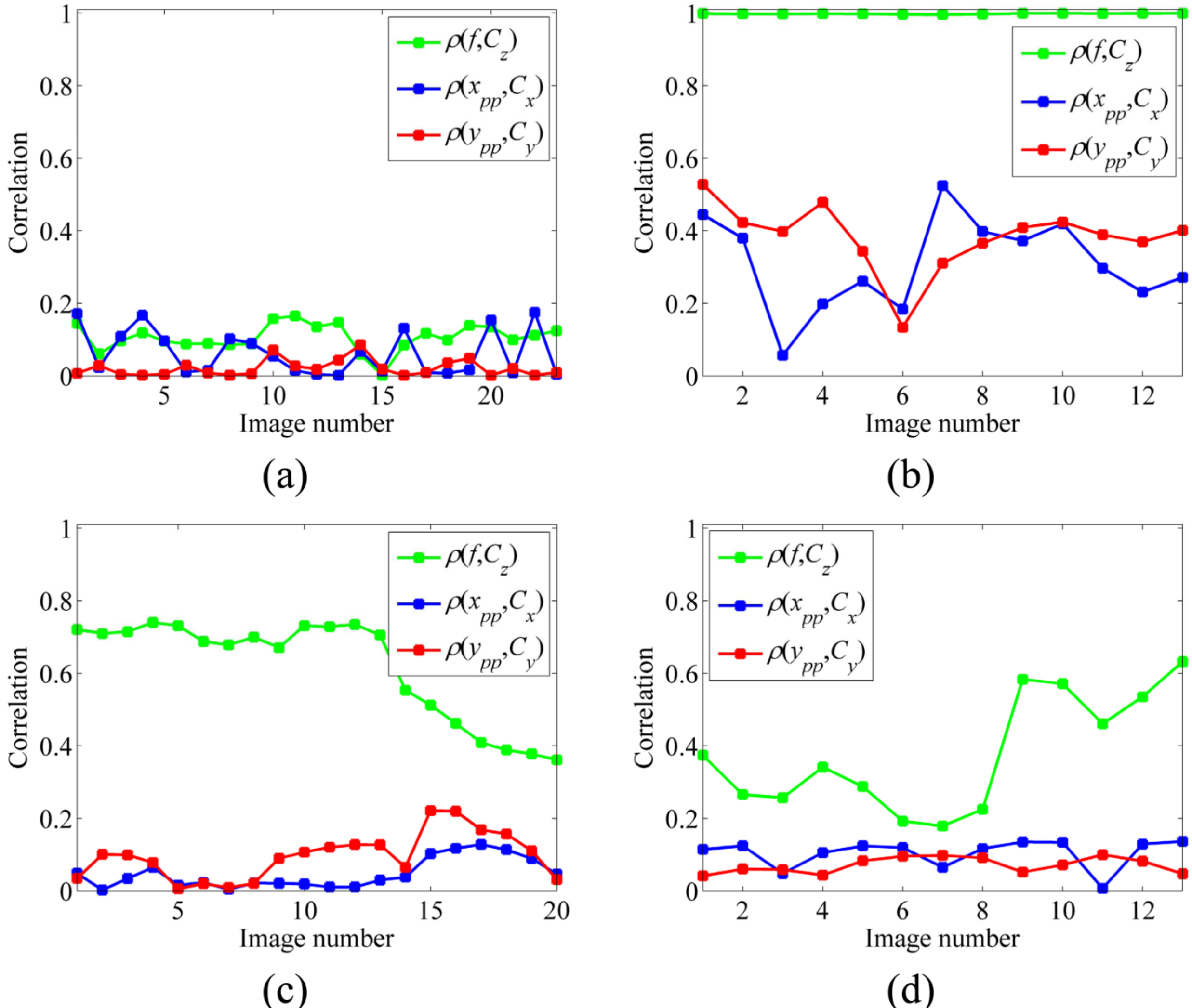


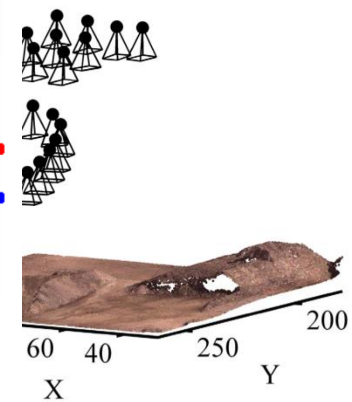


Structure from Motion Computation

❑ GCP detection and Block Bundle Adjustment







(c)

$W + A\delta$ ...

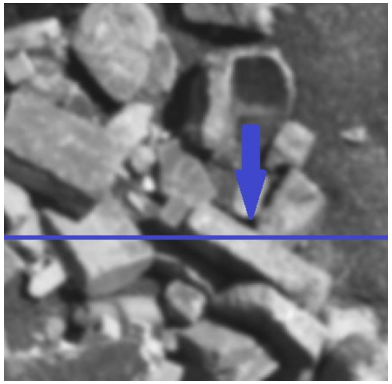
$\Sigma_K = (P_X$ ... $D D^T)^{-1} D$

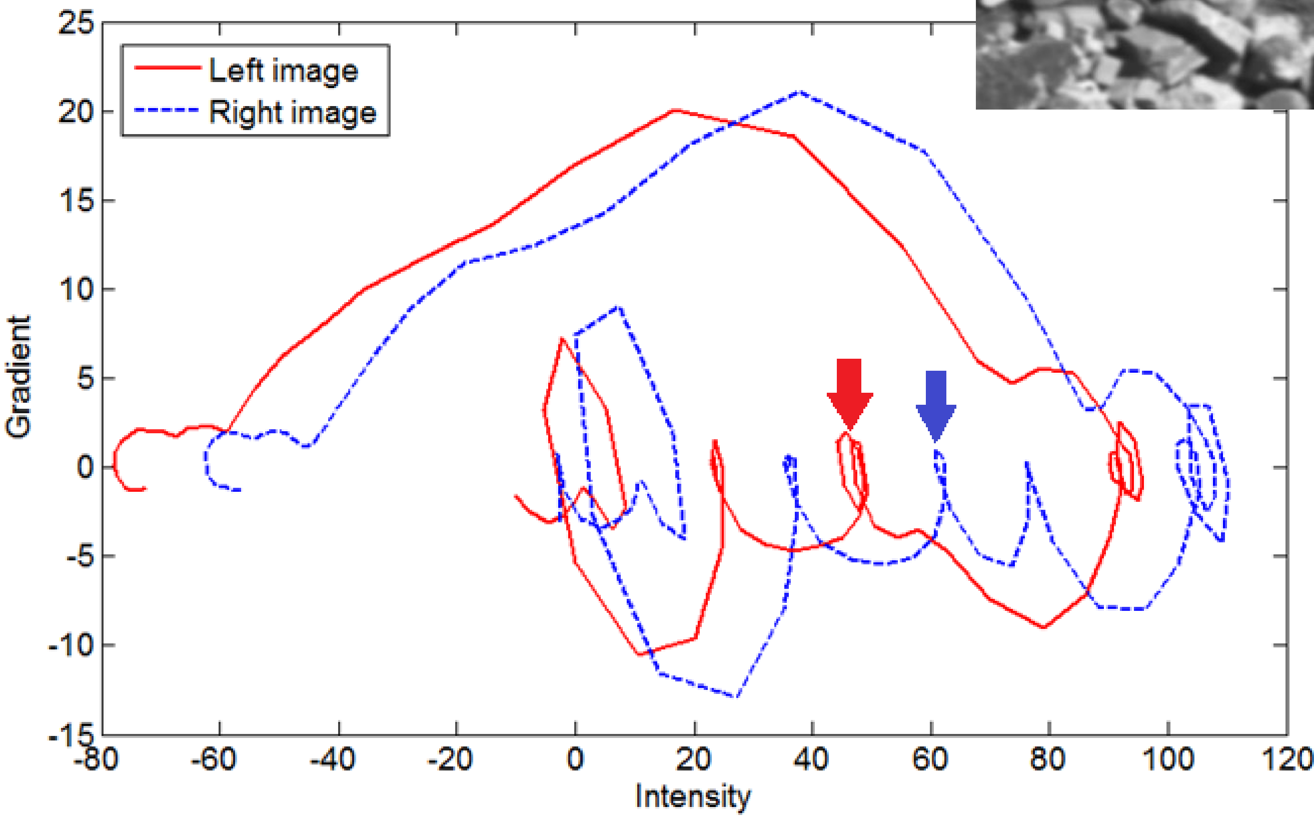
Structure from Motion Computation

❑ Dense Matching and 3D Point Cloud Generation

➢ **Based on the concept of intrinsic curves**

➢ **Multidimensional representation of a signal, e.g.** $C^l = I'(I)$





Structure from Motion Computation

Dense Matching and 3D Point Cloud Generation

- **Intrinsic curves are invariant to affine mapping**

- **If the transformation between the left and right scan-lines was only an affine geometric one, then the two intrinsic curves would coincide at matching points!**

$$x_i^r \leftrightarrow x_i^l \qquad d_i = x_i^l - x_i^r$$

The right intrinsic curve can be predicted from the left intrinsic curve in a local neighbourhood of i

$$C_i^r = r'(r_i) \qquad r_i = a_i.l(x_i^l + d_i) + b_i \qquad \tan\theta_i^l = \frac{\Delta l_i'}{\Delta l_i} \qquad \text{where: } \Delta l_i = l_{i+1} - l_i$$

$$C_i^l = l'(l_i) \qquad r_i' = a_i.l'(x_i^l + d_i) \qquad \Delta l_i' = l_{i+1}' - l_i'$$

$$\tan\theta_i^r = \frac{\Delta r_i'}{\Delta r_i} = \frac{a_{i+1}.l'(x_{i+1}^l + d_{i+1}) - a_i.l'(x_i^l + d_i)}{a_{i+1}.l(x_{i+1}^l + d_{i+1}) + b_{i+1} - (a_i.l(x_i^l + d_i) + b_i)} \cong \frac{a_i.\Delta l_i'}{a_i.\Delta l_i}$$

Structure from Motion Computation

❑ Dense Matching and 3D Point Cloud Generation

- **Hypothesis generation: search disparity values**

$$\left|\tan\theta_j^r - \tan\theta_i^l\right| \le T \xrightarrow{\text{hypothesis}} (x_i^l \leftrightarrow x_j^r)$$

- **Potential matching pairs form a graph, connected if obey the ordering condition**

- **Weights of the edges= Matching quality**

- **The same cost function as SGM**

- **The objective is to go through the scan-lines from the first matching pair to the last matching pair while maximizing the overall quality of matching = finding the longest path**

- **The matching pairs on this path are considered as the final, correct matches.**

Structure from Motion Computation

Dense Matching and 3D Point Cloud Generation

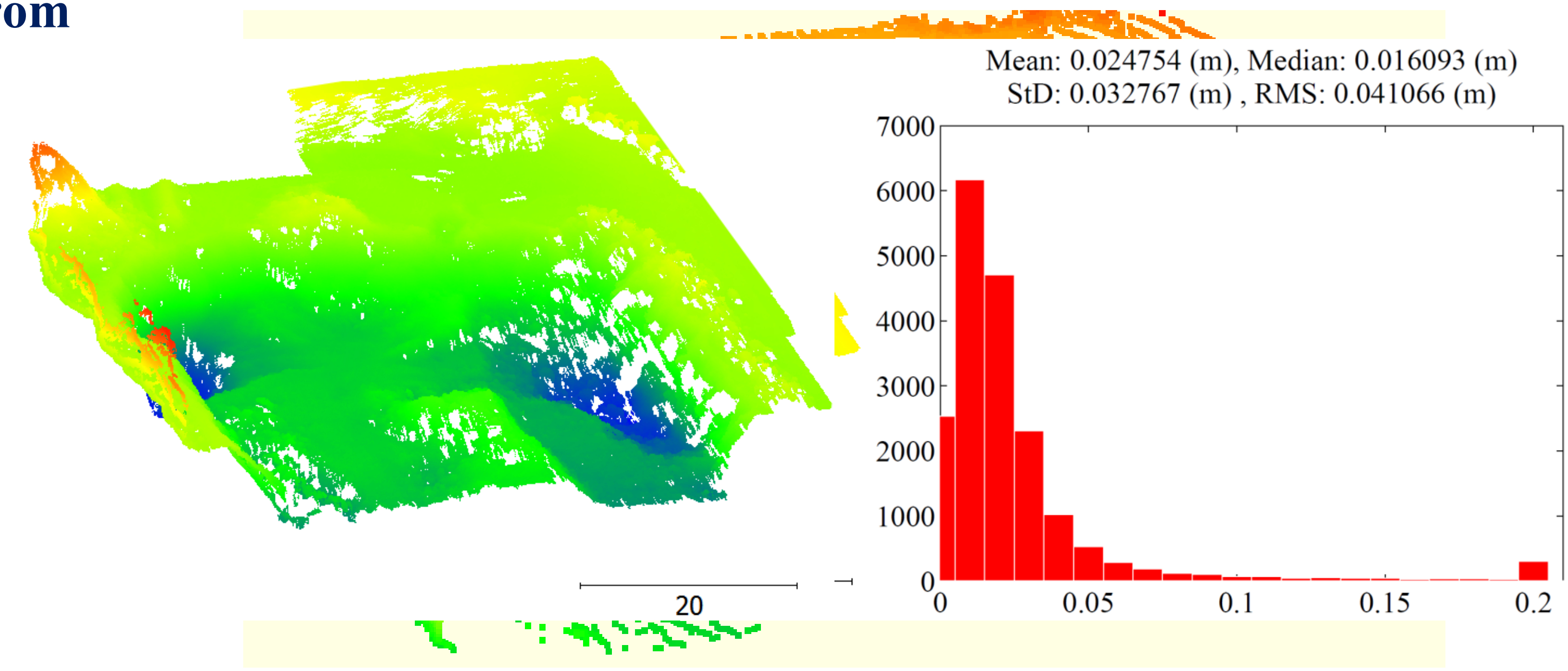
- Matching candidates are hypothesized based on the similarity in intrinsic curve space
- No assumptions / pre-calculations are required to put a limiting search range on disparity values
- Preventing occlusion, using the curvature specs of the curves*
- Adding regularization term in the space of curves, based on the fact the radial lines passing the matched points close to each other on the curve space intersect*
- Currently, graph-based path optimization is used where the graph is constructed considering ordering condition*
- Currently, no post-processing done on the PC*

Structure from Motion Computation

❑ Dense Matching and 3D Point Cloud Generation

➢ **Comparing results of dense point clouds against the laser point cloud**

from



Conclusions

I. Potentials of UAV-photogrammetry to produce high resolution (less than 2 cm GSD) 3D point cloud with high accuracy (better than 2 cm)

II. Potentials of sparse matching based on evolutionary search to improve performance in terms of robustness against noise, outliers, degeneracy

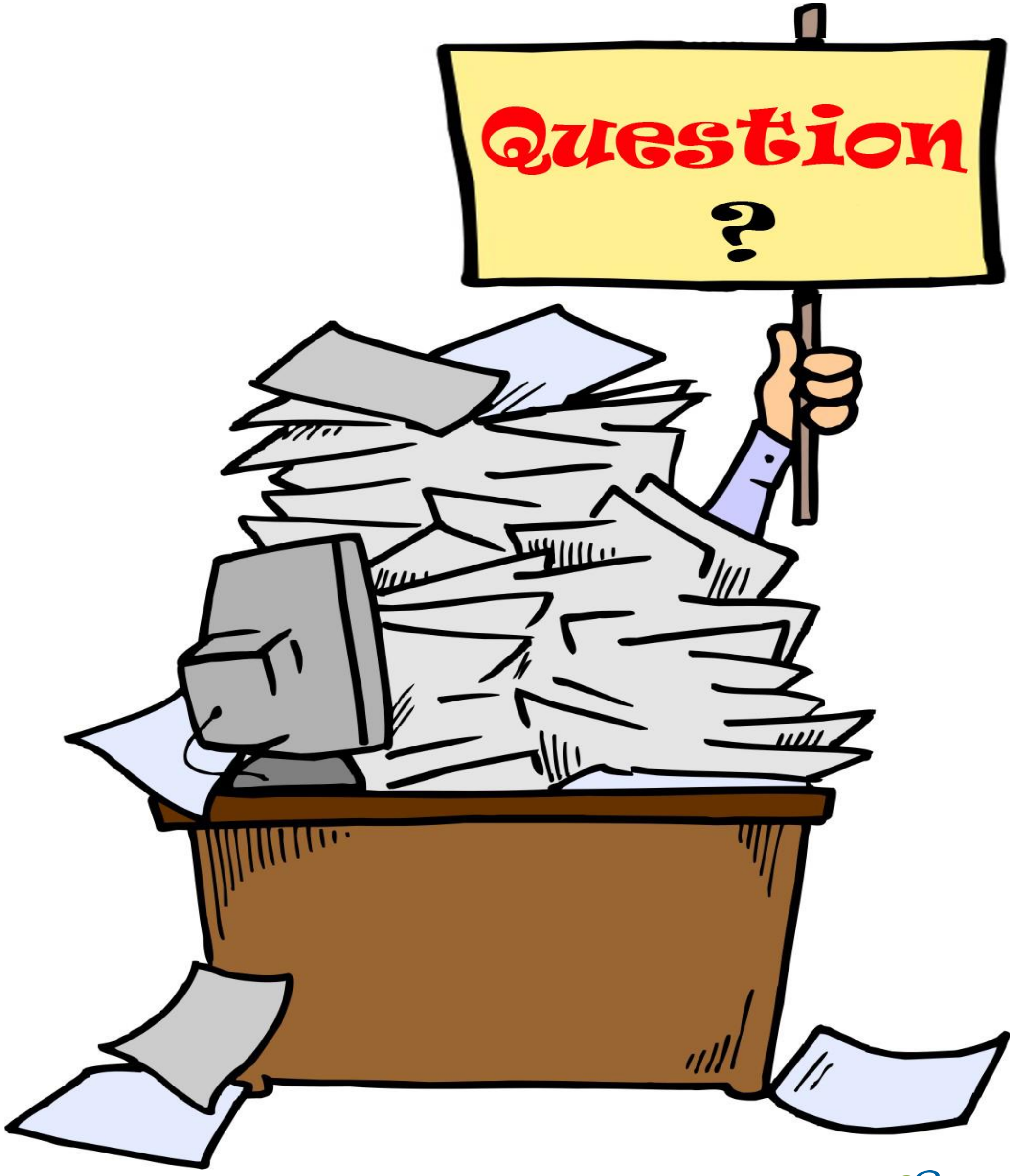
III. Potentials of dense matching based on intrinsic curves to reduce computational efforts and handling occlusions

IV. Benchmark tests:

  I. IO

  II. DIM

Thank you for your attention!



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