A NEW APPROACH FOR AN INCREMENTAL ORIENTATION OF MICRO-UAV IMAGE SEQUENCES

Martin Reich*, Jakob Unger,
Franz Rottensteiner, Christian Heipke

Motivation

Motivation

- incremental orientation
  - real time compatible
  - (adaptive) exploration of new (unknown) environment
    - cartography
    - modelling
- a new approach
  - image orientation is an ill-posed problem
  - improvement by using convexly optimised initial values

Contents

- Hardware
- Methodology
- Experimental results
- Conclusion

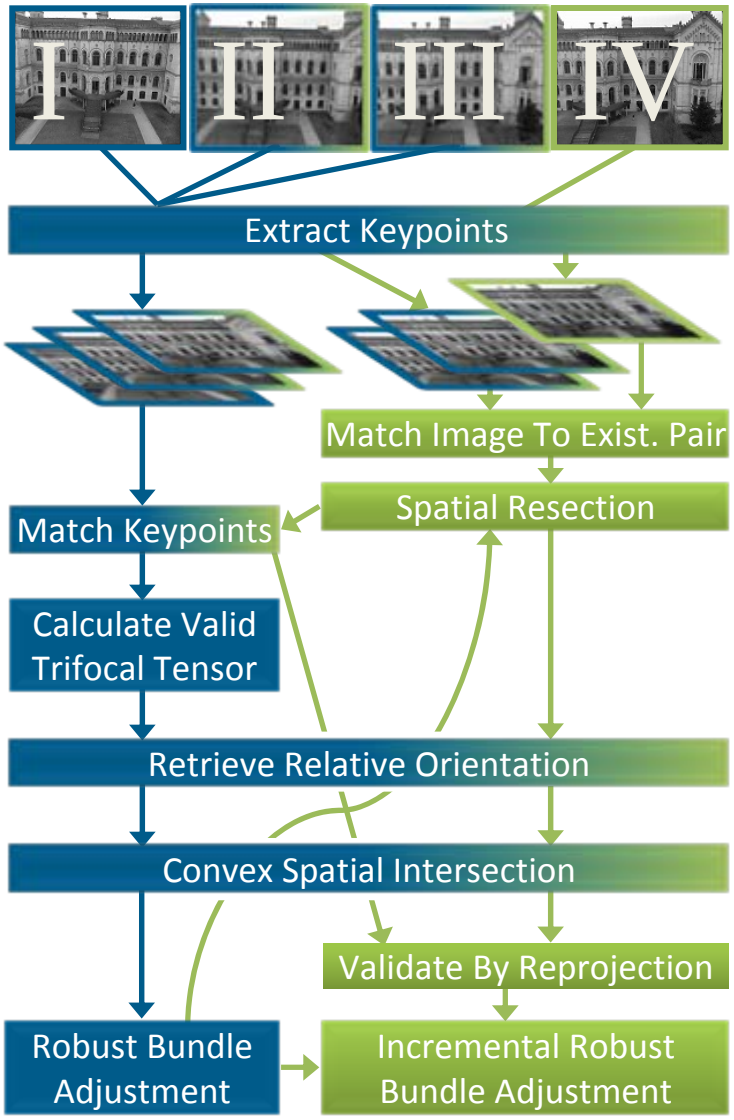
Hardware

- Microdrones md4-200 VTOL Quadrocopter
  - max. payload: 200g
  - max. flight duration: 30min
  - cruising speed ~5m/s
  - GPS, SBAS, IMU, Magnetometer, Barometer

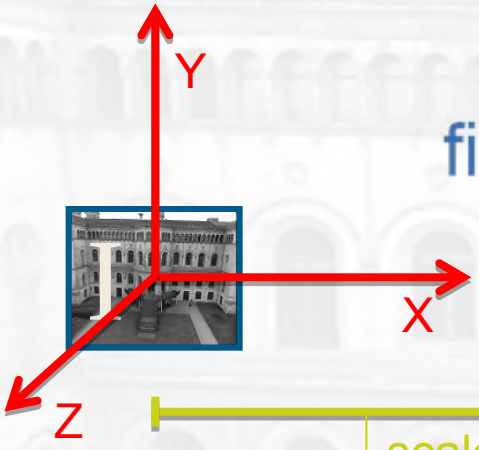
- Canon Powershot S110
  - weight: 200g
  - resolution: 720 x 576 px
  - transmission: e. g. WiFi SD-card

Methodology

- Work-flow



First image triplet



first image triplet defines local system

scale

trifocal tensor

$$p^{I,i}\left(p^{II,j}\epsilon_{jpr}\right)\left(p^{III,k}\epsilon_{kqs}\right)T_i^{pq}=0_{rs}.$$

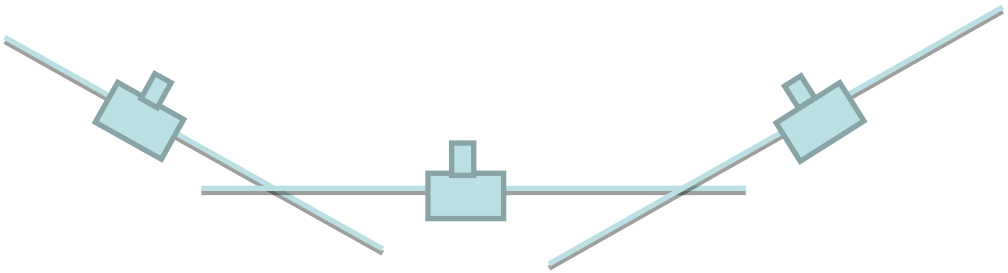
→ relative orientation → convex spatial intersection

Convex spatial intersection

- spatial intersection not always has a unique solution
- objective: minimise reprojection error

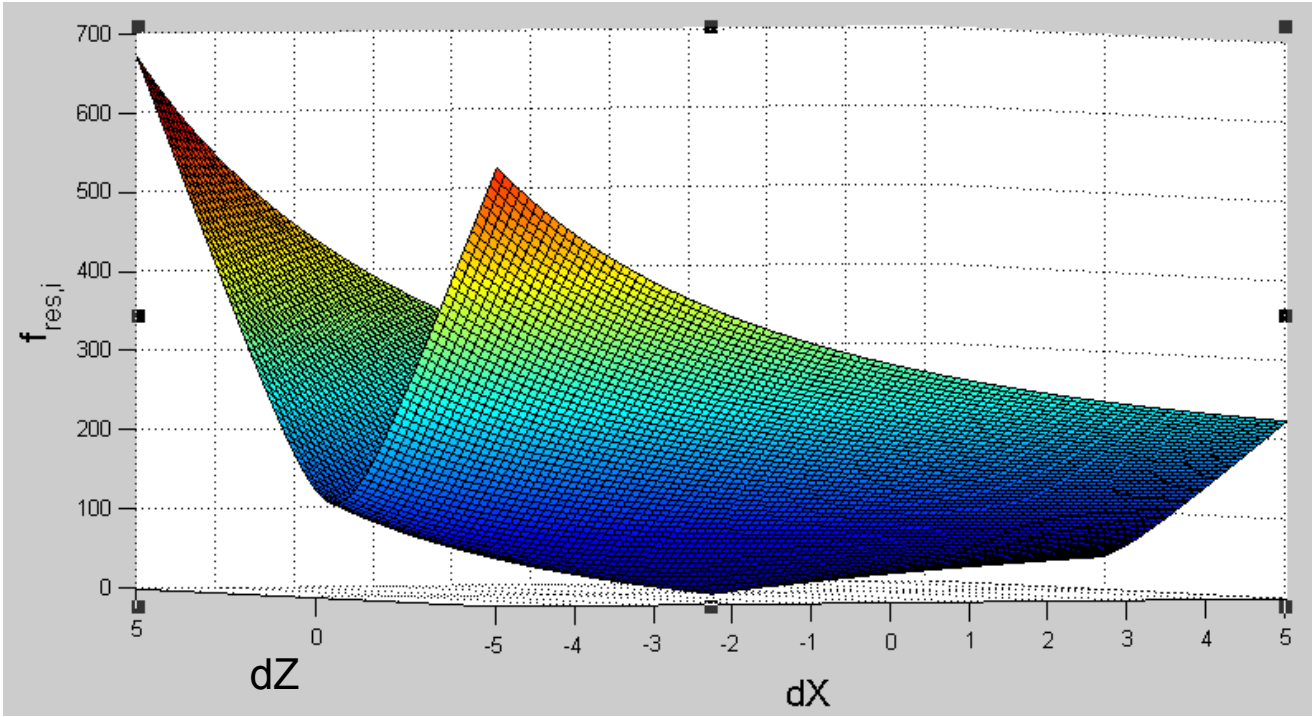
$$f_{res,i}(\mathbf{X}) = \|\mathbf{x}_{proj,i} - \mathbf{x}_i\|_m$$

subject to a convex set defined by halfspaces of involved image planes



Convex spatial intersection

- reprojection error in image *i* is a quasiconvex function

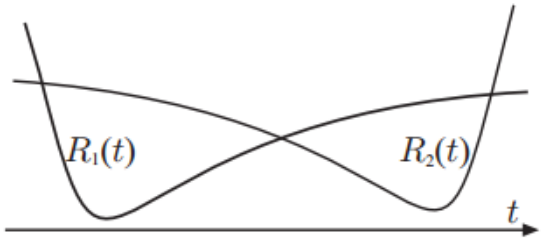


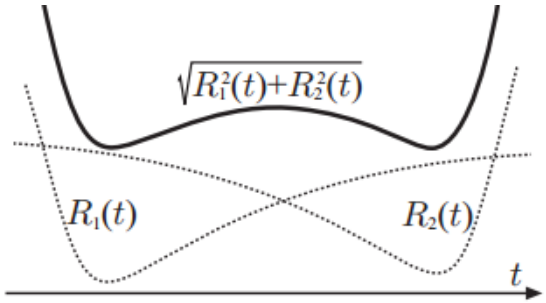
- minimising reprojection error in images *i = 1, …, N*

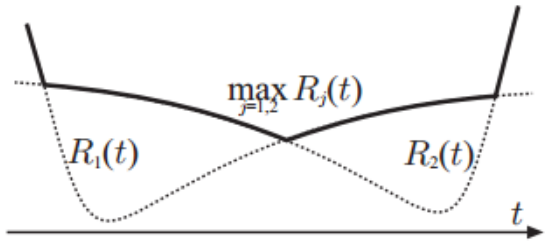
  → how quasiconvexity behaves?

Convex spatial intersection

- how quasiconvexity behaves?







[Schneider, 2011]

Convex spatial intersection

- using L_∞ norm → quasiconvexity is preserved

$$\text{minimise} \qquad \max_{i=1}^{3} f_{res,i}(\mathbf{X})$$

$$f_{res,i}(\mathbf{X}) = \left\| \begin{pmatrix} -c\frac{\mathbf{r}_{i,1}^T(\mathbf{X}-\mathbf{X}_0)}{\mathbf{r}_{i,3}^T(\mathbf{X}-\mathbf{X}_0)} + x_0 - x_i \\ -c\frac{\mathbf{r}_{i,2}^T(\mathbf{X}-\mathbf{X}_0)}{\mathbf{r}_{i,3}^T(\mathbf{X}-\mathbf{X}_0)} + y_0 - y_i \end{pmatrix} \right\|_m$$

$$= \left\| \begin{pmatrix} \frac{\left(-c\cdot\mathbf{r}_{i,1}^T+(x_0-x_i)\mathbf{r}_{i,3}^T\right)\mathbf{X}-\left(-c\cdot\mathbf{r}_{i,1}^T+(x_0-x_i)\mathbf{r}_{i,3}^T\right)\mathbf{X}_0}{\mathbf{r}_{i,3}^T\mathbf{X}-\mathbf{r}_{i,3}^T\mathbf{X}_0} \\ \frac{\left(-c\cdot\mathbf{r}_{i,2}^T+(y_0-y_i)\mathbf{r}_{i,3}^T\right)\mathbf{X}-\left(-c\cdot\mathbf{r}_{i,2}^T+(y_0-y_i)\mathbf{r}_{i,3}^T\right)\mathbf{X}_0}{\mathbf{r}_{i,3}^T\mathbf{X}-\mathbf{r}_{i,3}^T\mathbf{X}_0} \end{pmatrix} \right\|_m$$

$$f_{res,i}(\mathbf{X}) = \frac{\|\mathbf{A}_i\mathbf{X}+\mathbf{b}_i\|_m}{\mathbf{c}_i^T\mathbf{X}+d_i}$$

Convex spatial intersection

- using L_∞ norm → quasiconvexity is preserved

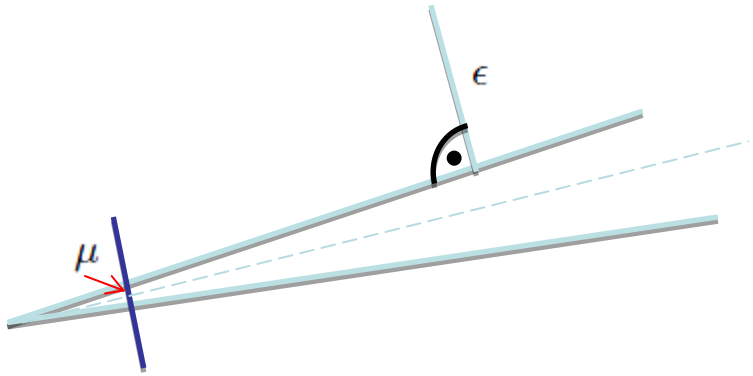
$$\text{minimise} \qquad \max_{i=1}^{3} f_{res,i}(\mathbf{X})$$

$$f_{res,i}(\mathbf{X}) = \frac{\|\mathbf{A}_i\mathbf{X} + \mathbf{b}_i\|_m}{\mathbf{c}_i^T\mathbf{X} + d_i}$$

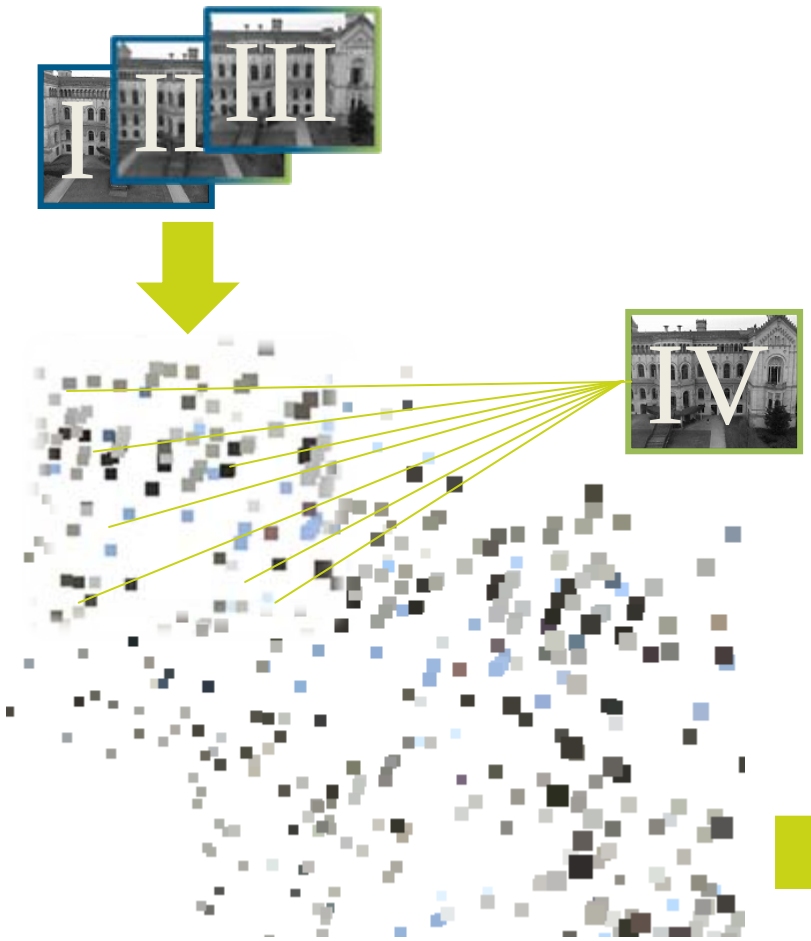
$$\text{minimise} \qquad \epsilon$$

$$\text{subject to} \qquad \|\mathbf{A}_i\mathbf{X} + \mathbf{b}_i\|_\infty \; - \mu(\mathbf{c}_i^T\mathbf{X} + d_i) \leq \epsilon,$$

$$i = 1...3.$$



Further triplets



incremental
bundle adjustment

Incremental bundle adjustment

$$\begin{pmatrix} \mathbf{l}_1 + \mathbf{v}_1 \\ \mathbf{l}_2 + \mathbf{v}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{A}_{11} & 0 \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{pmatrix} \begin{pmatrix} \mathbf{p}_1 \\ \mathbf{p}_2 \end{pmatrix}$$

- two different types of parameters
  1. parameters related to already estimated unknowns $\mathbf{p}_1$
  2. parameters related to unknowns that are estimated for the first time $\mathbf{p}_2$

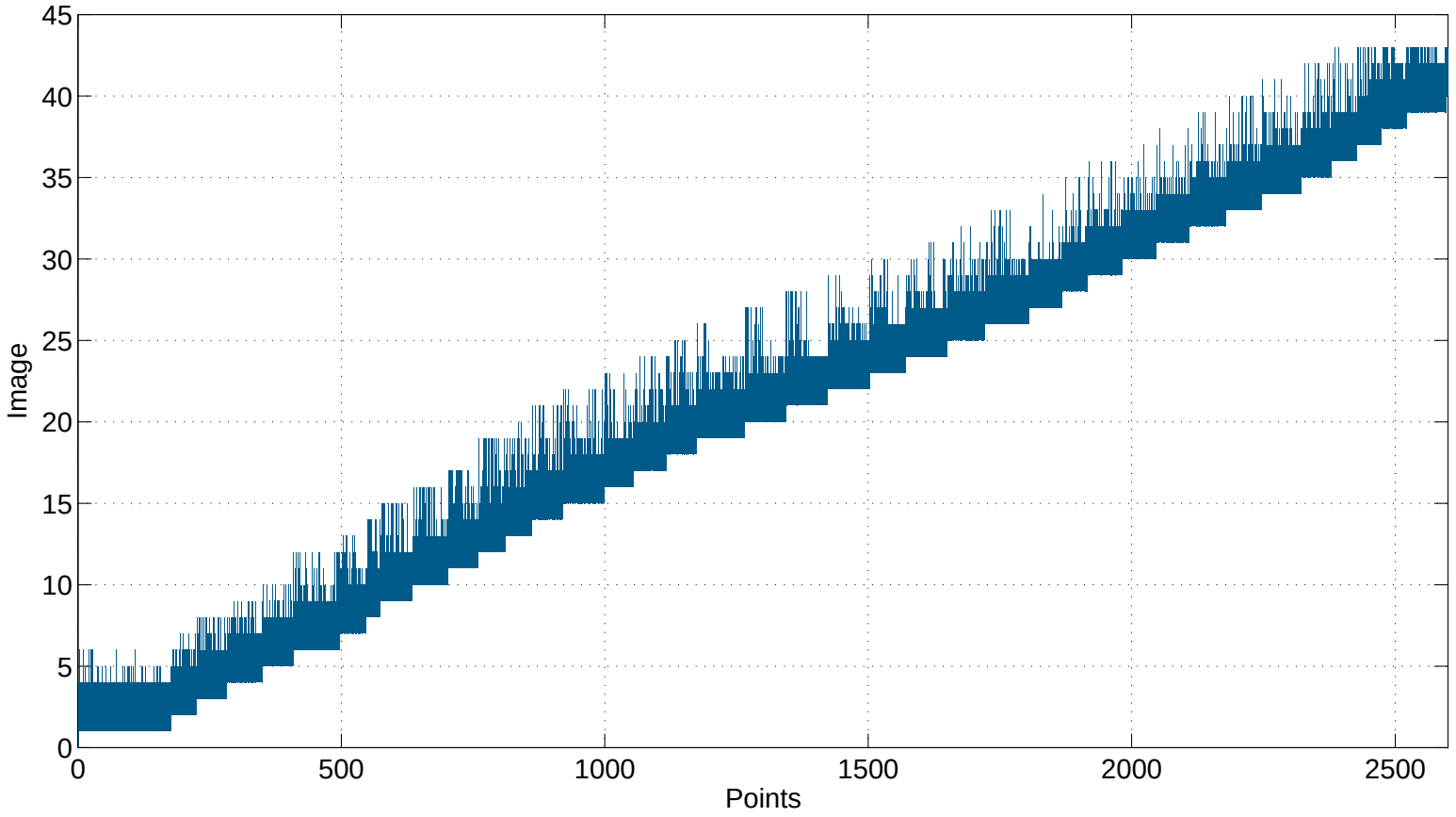
$$\begin{pmatrix} \hat{\mathbf{p}}_{1,+} \\ \hat{\mathbf{p}}_2 \end{pmatrix} = \mathbf{N}_+^{-1} \begin{pmatrix} \mathbf{A}_{11}^T \mathbf{P}_{11} \mathbf{l}_1 + \mathbf{A}_{21}^T \mathbf{P}_{22} \mathbf{l}_2 \\ \mathbf{A}_{22}^T \mathbf{P}_{22} \mathbf{l}_2 \end{pmatrix}$$

Settings

- camera calibrated before flight
- setting: Welfenschloss Hannover
- images collected in a fixed time interval
  - three separate flights each consisting of about 250 images
- number of observations limited based on distribution in the image
- old images are eliminated based on number of re-measured points

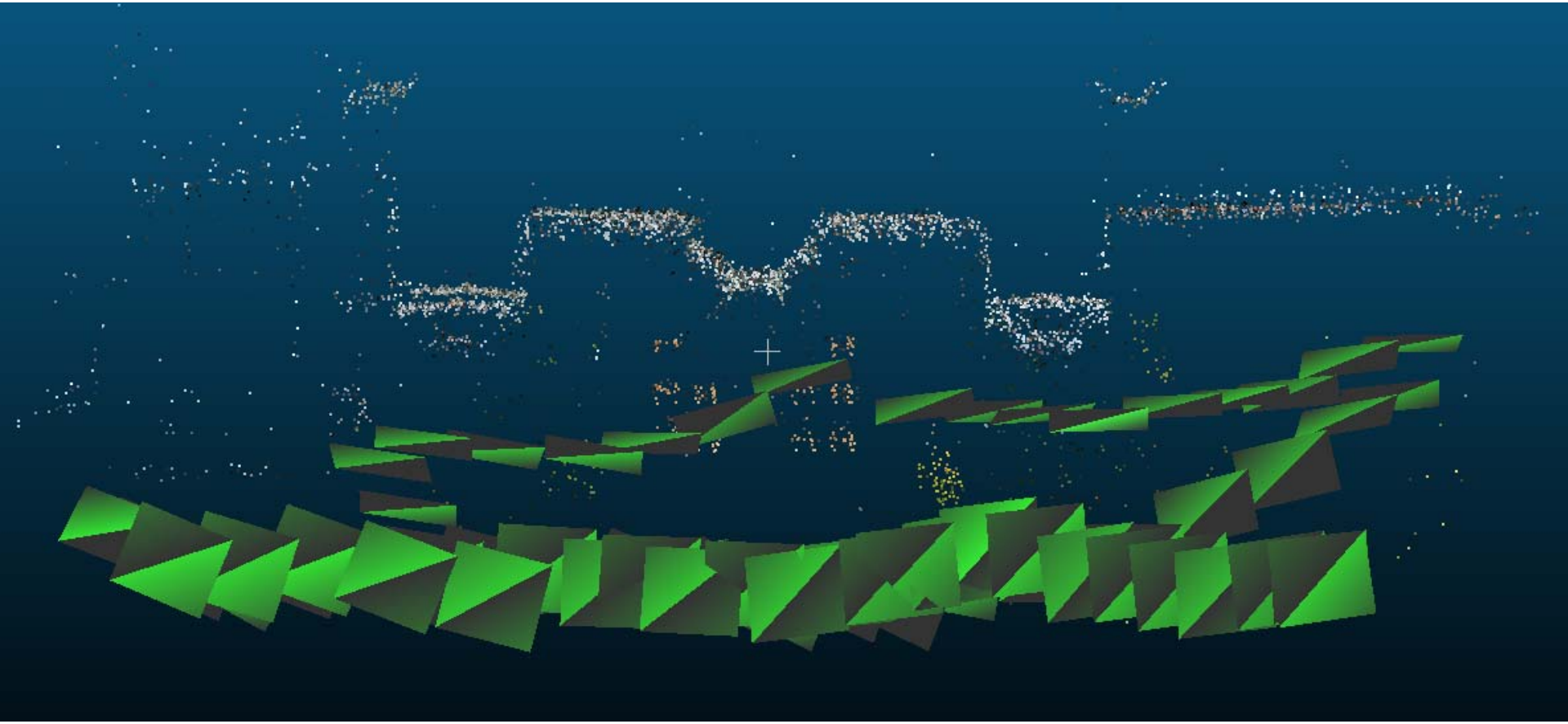
Results

- point/image distribution



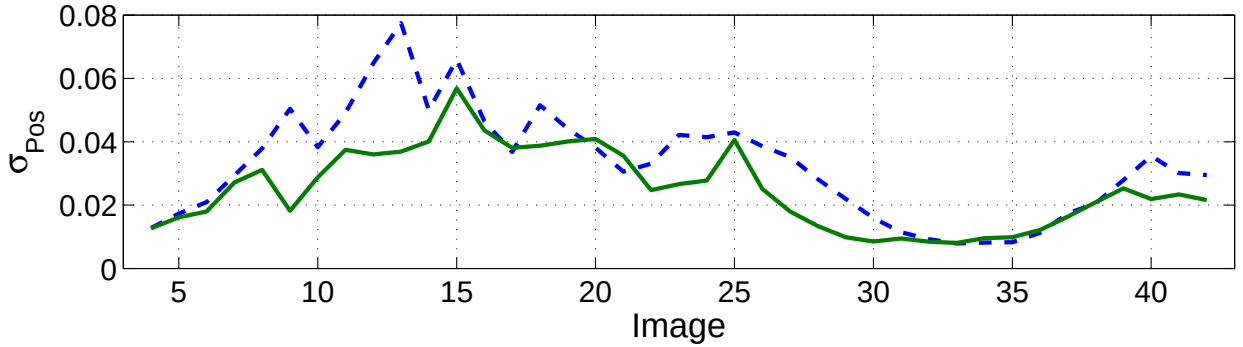
Results

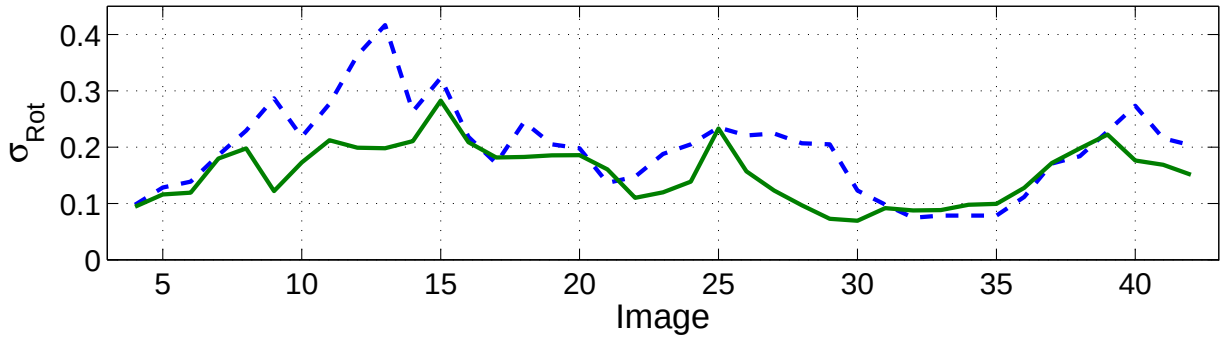
- sparse point cloud and image orientation

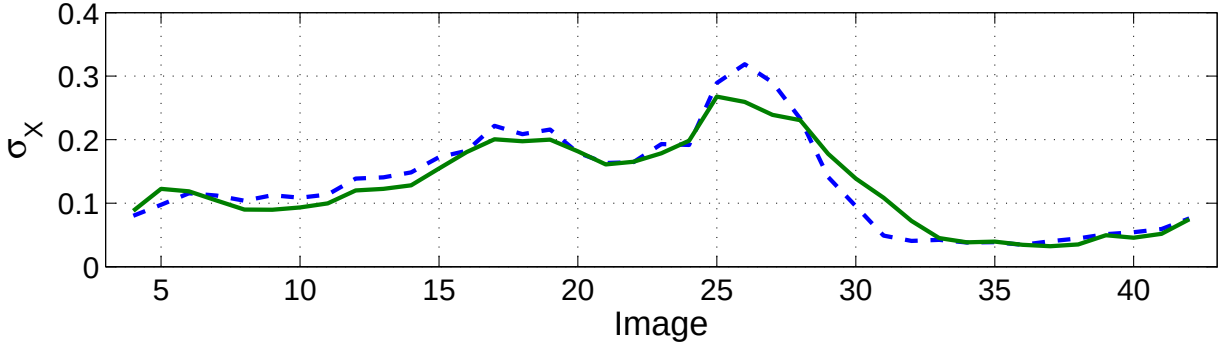


Results

- precision of the bundle adjustment

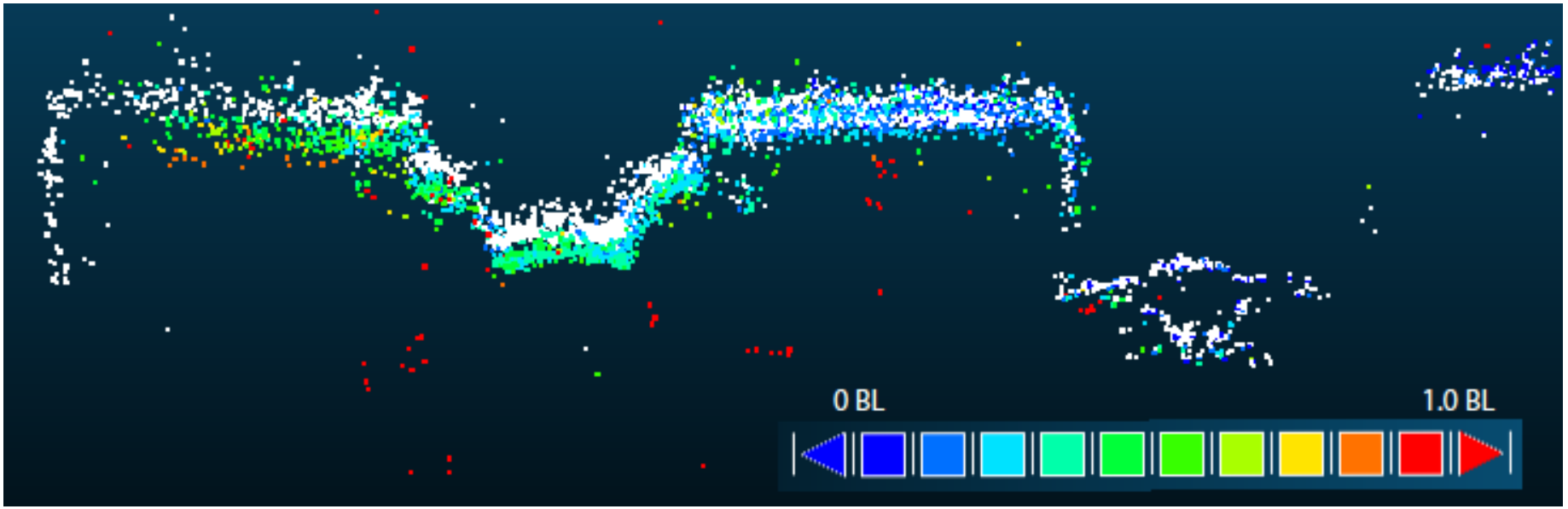






Results

- point cloud comparison



Conclusion

- incremental adjustment allows
  - estimation of new parameters
  - improvement of estimated parameters
- computation time highly depends on the number of newly found object points
  - limitation of number of observations necessary
  - nearly constant due to incremental bundle adjustment (~10s/image → non-optimised → covariance estimation)

Conclusion

- convex optimisation shows promising results
  - improved initial values
  - distribution of object points in space
- future challenges
  - unstable solution/drift → loop closure in on-line mode
  - absolute orientation of the model → integrate telemetry data
  - solid reference model → terrestrially measured/defined in a global coordinate system

Thank You!