Shape Inspection by Vision in Production

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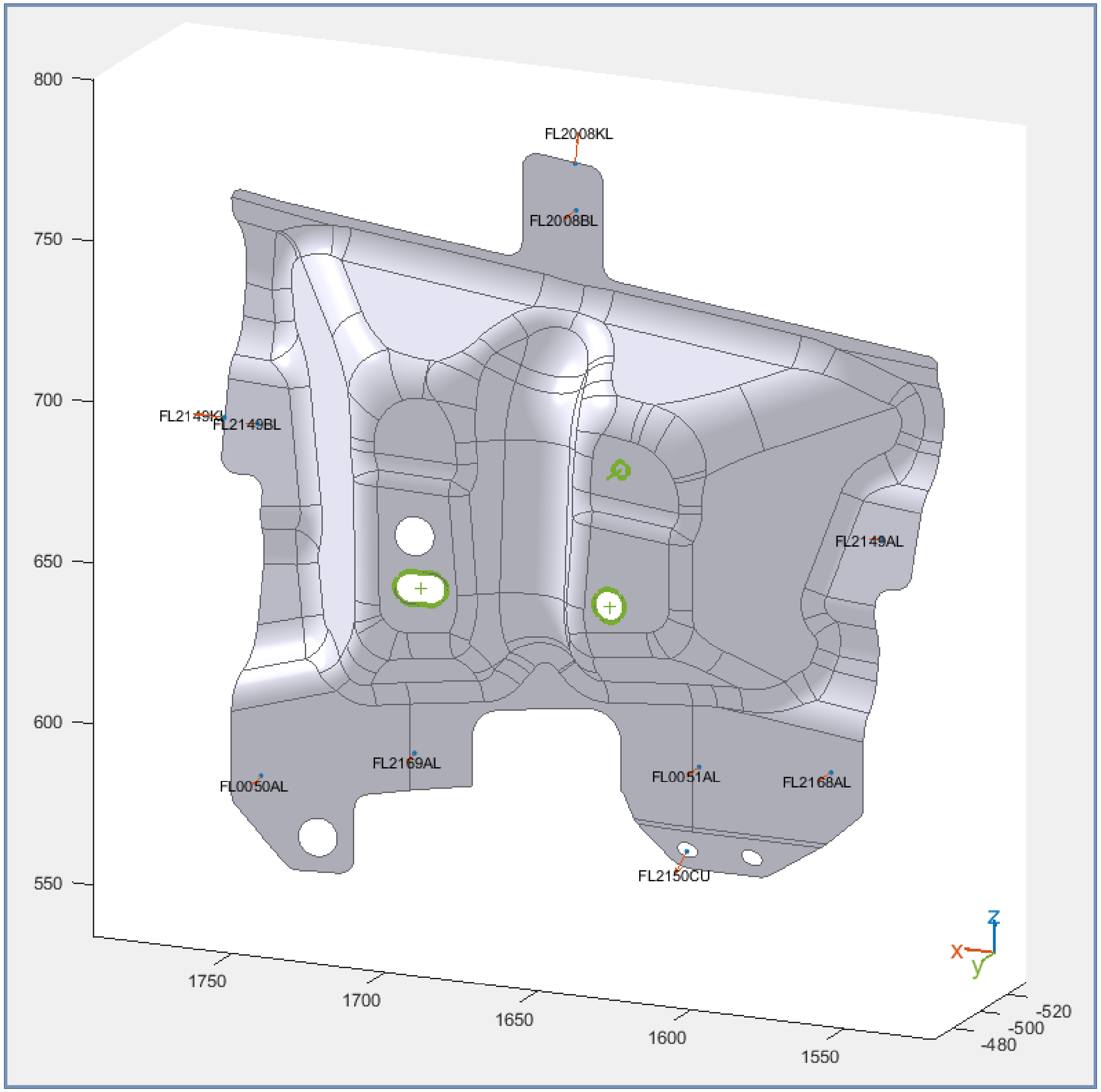
Luleå University of Technology, 23 November 2016


135
FLÄKT
Marco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z
x
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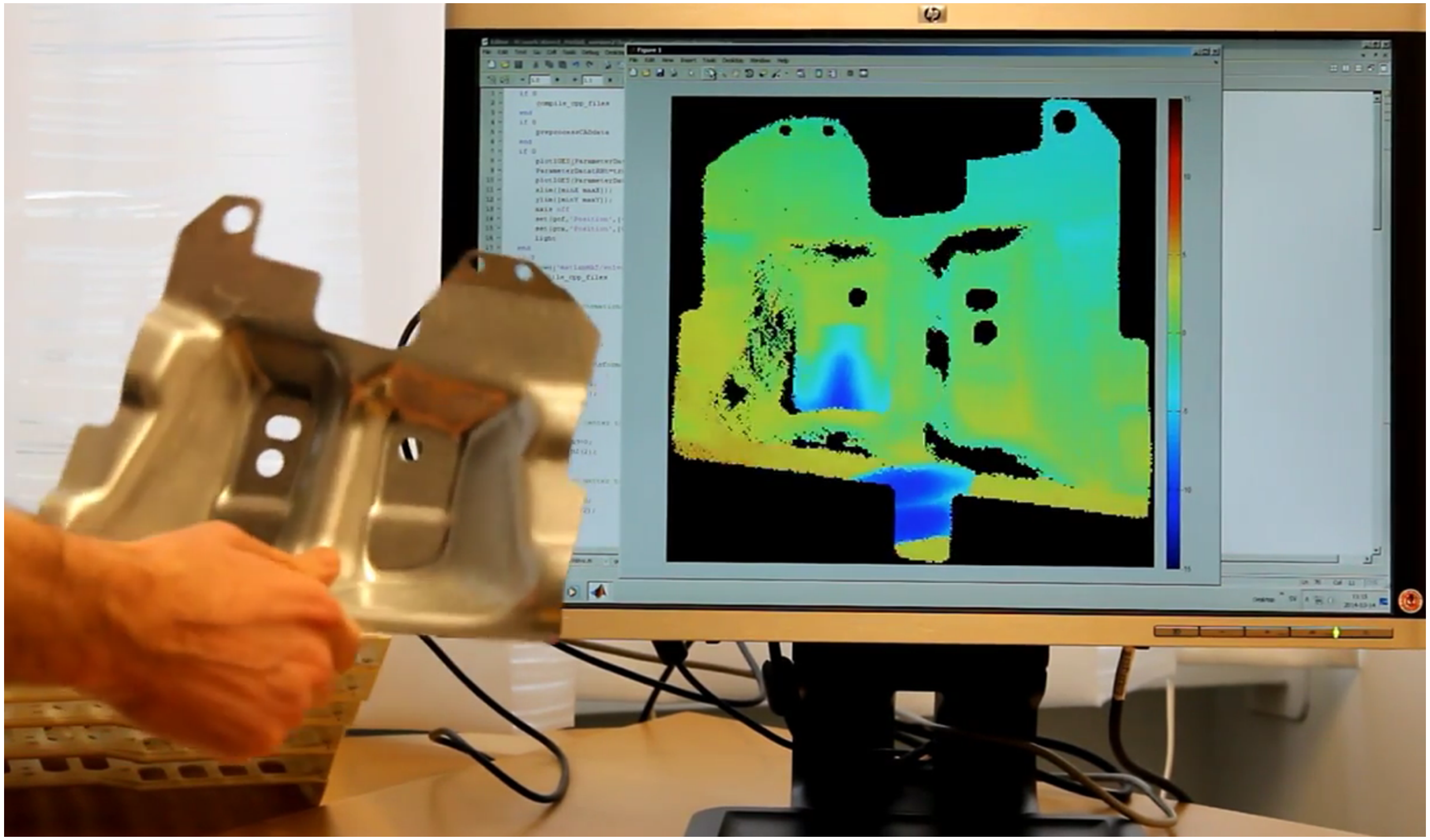
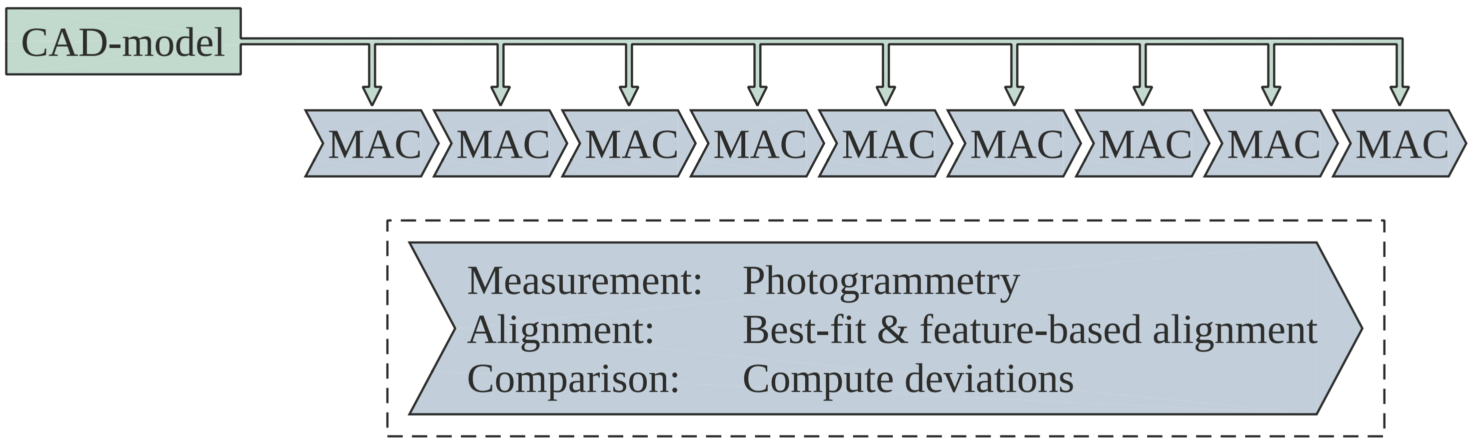
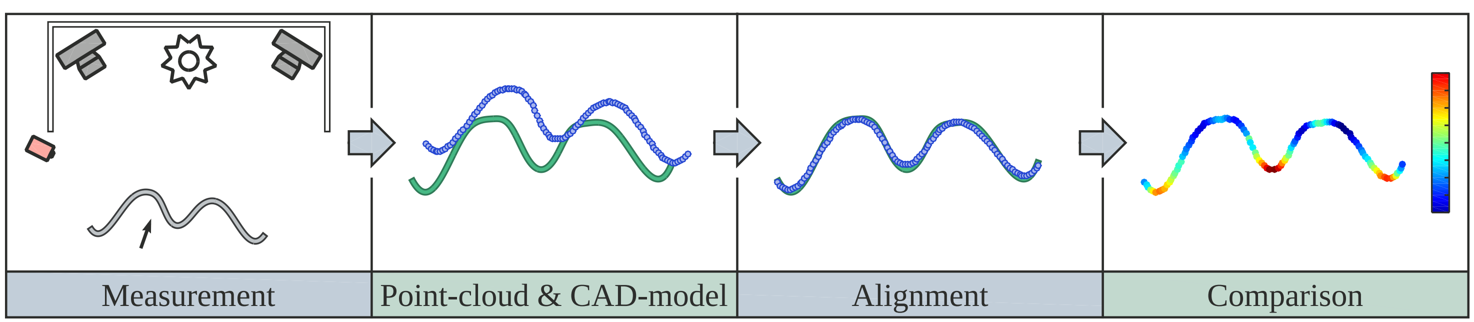
Video



YouTube https://youtu.be/Im7_mwpOk0E

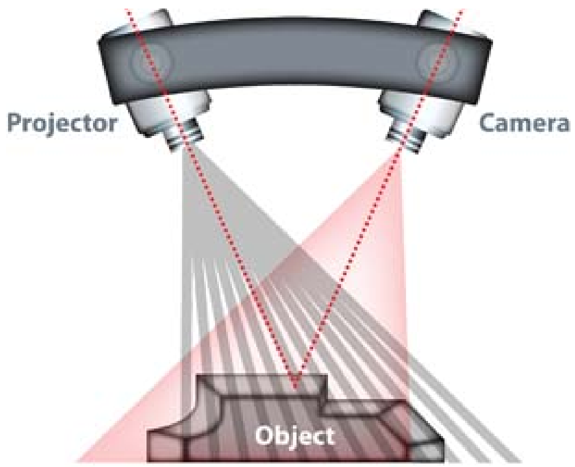
Repeated shape inspection



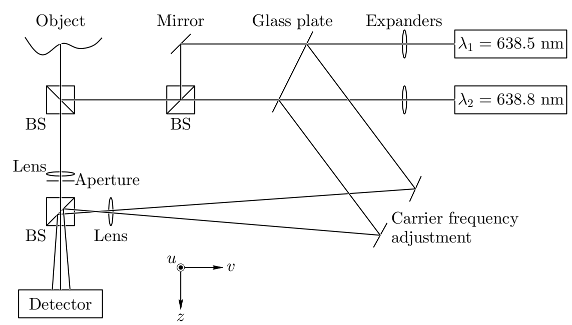


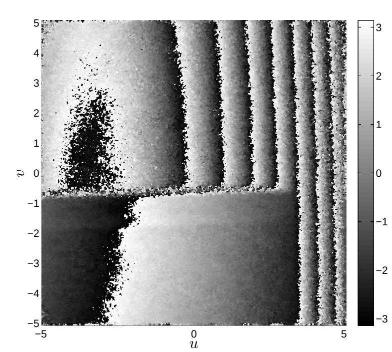
Shape measurement methods

Projection of pattern

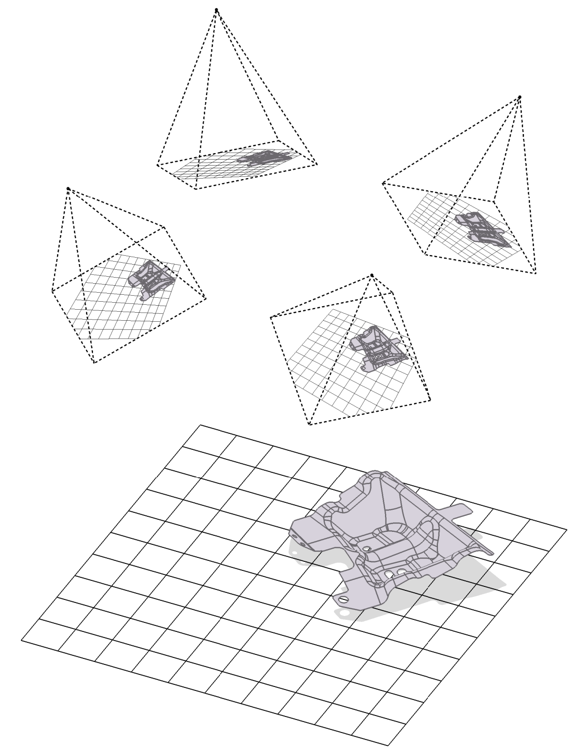


Holography

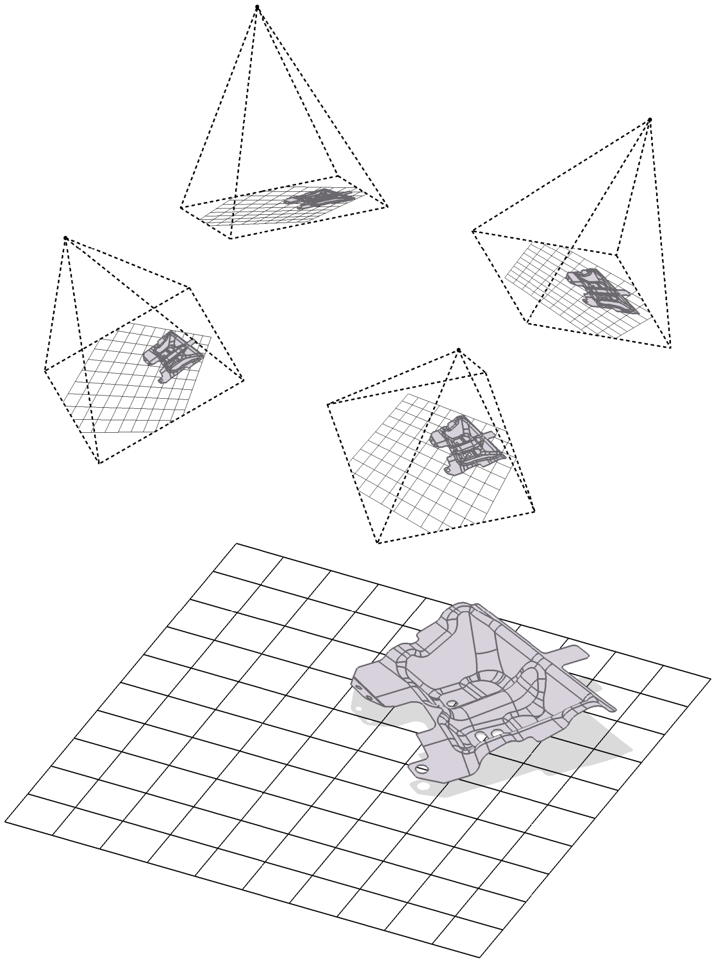


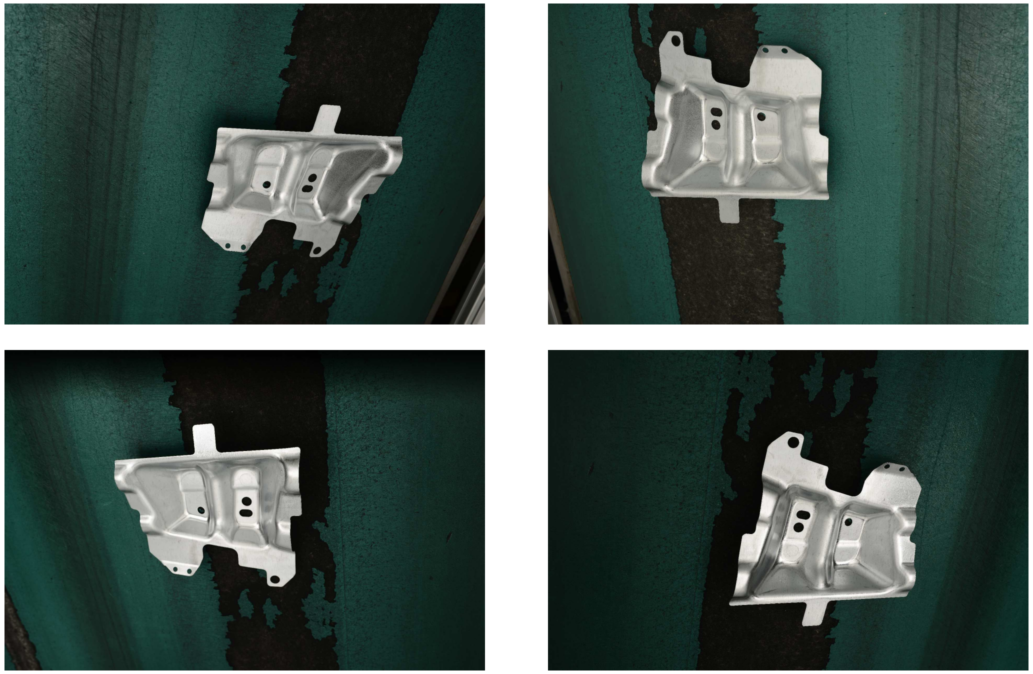


Photogrammetry



Photogrammetry

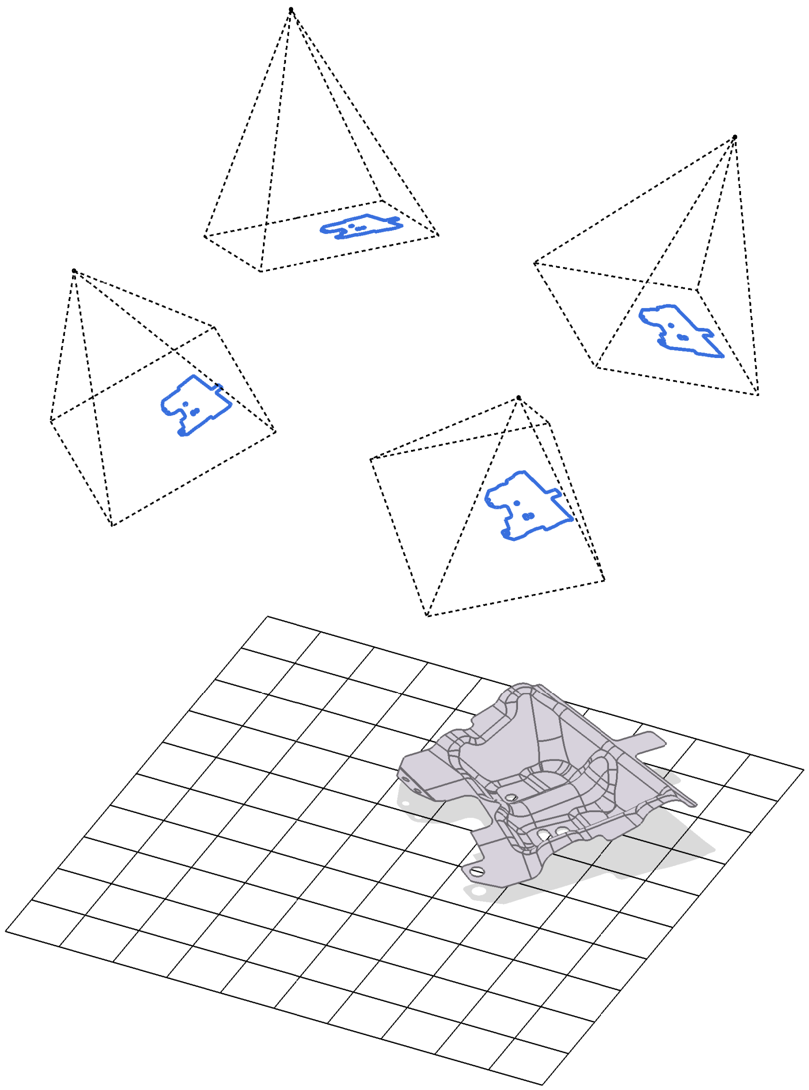




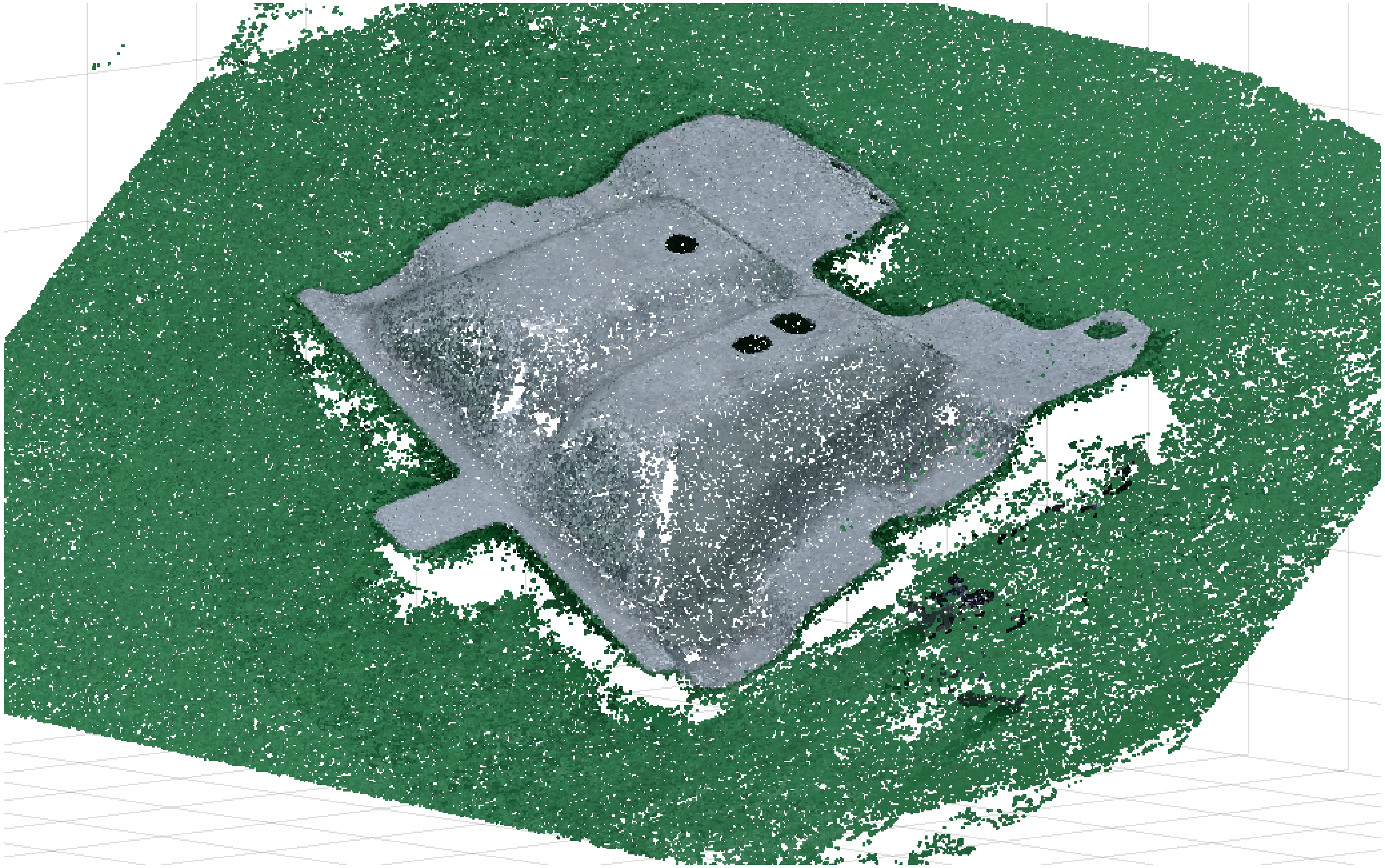
- Identification of homologous points

Photogrammetry

- Identification of homologous points
  - Edges
  - Surface texture
- No projected pattern is required
  - Diffuse illumination
  - Avoiding specular reflections



Point cloud

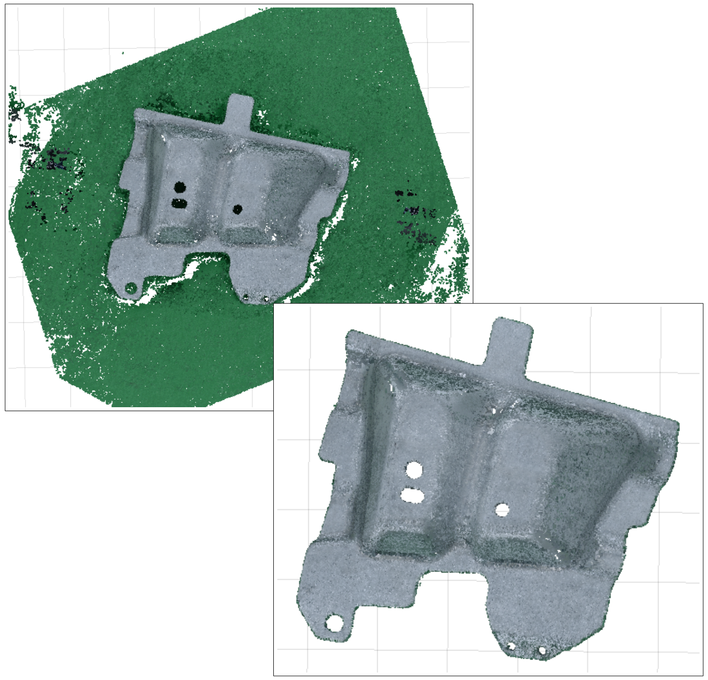


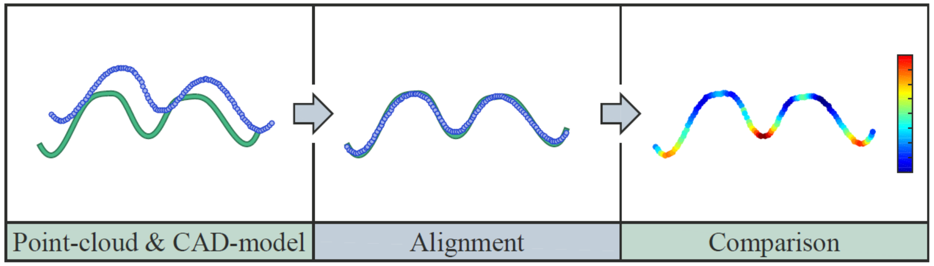
Photogrammetry

- 👍 Enables shape measurements on moving objects ($\sim$ 1 m/s)
- 👍 High spatial resolution
- 👎 Long computational time

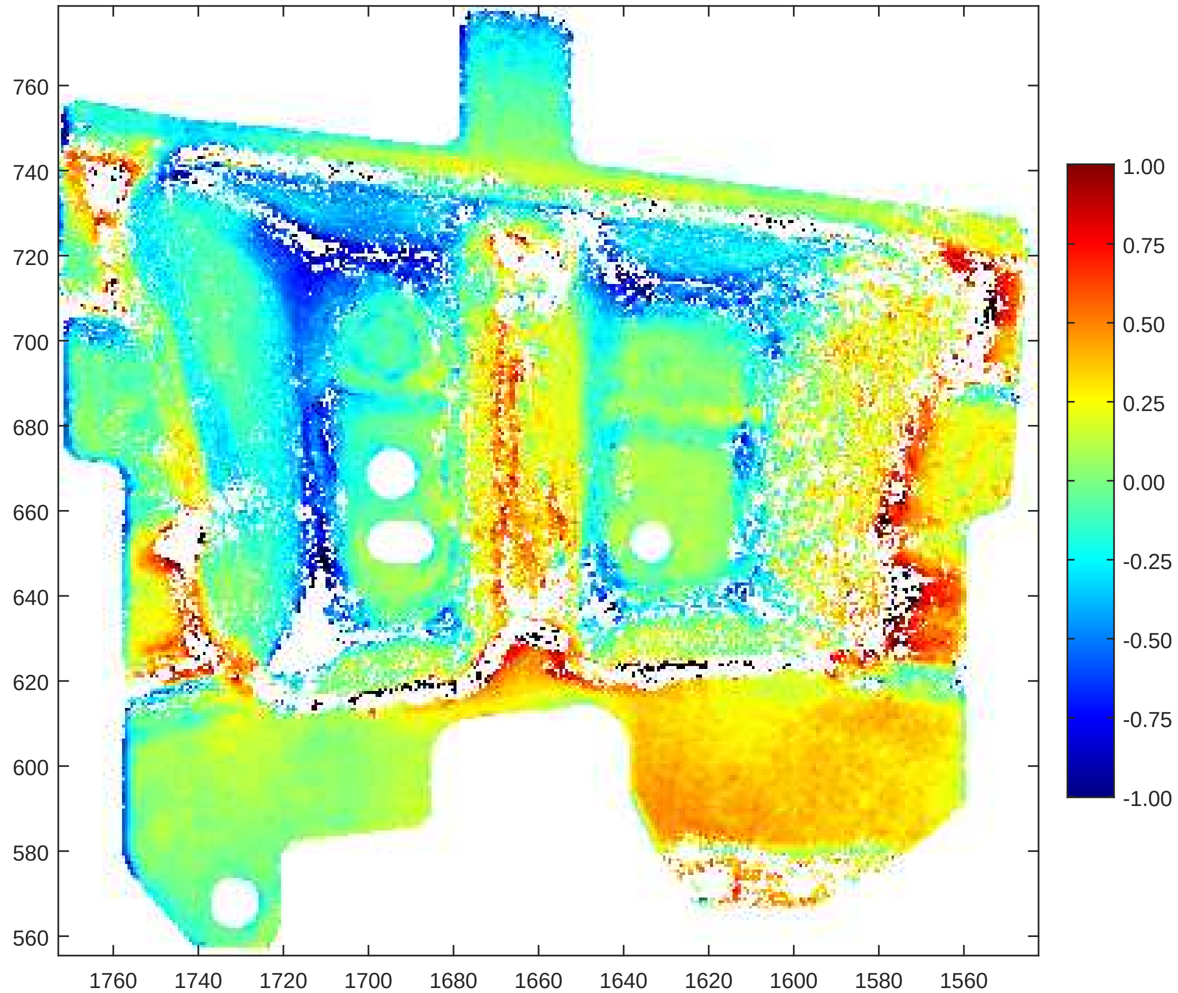
Outline of analysis

1. Background removal
2. Alignment
3. Comparison

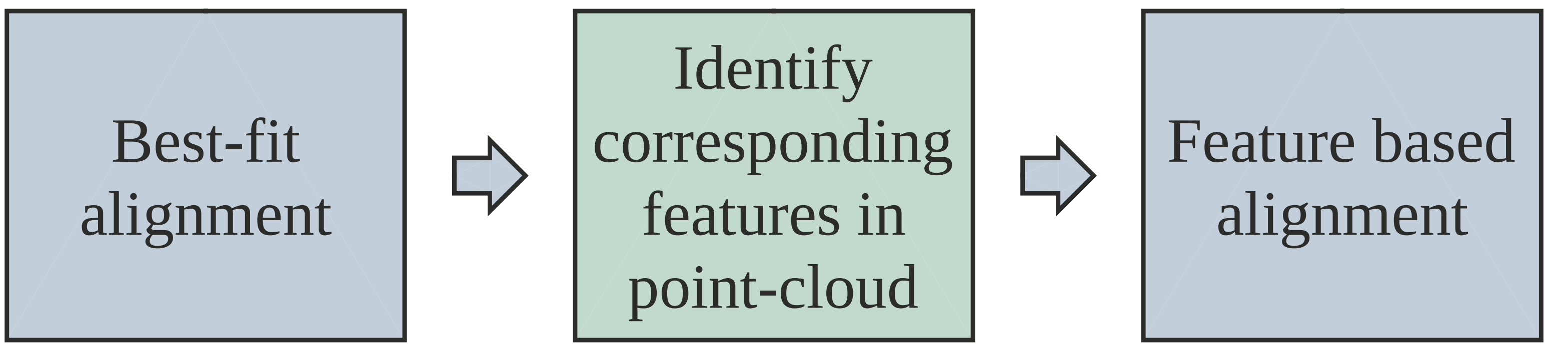




Result: deviations in mm



Alignment process



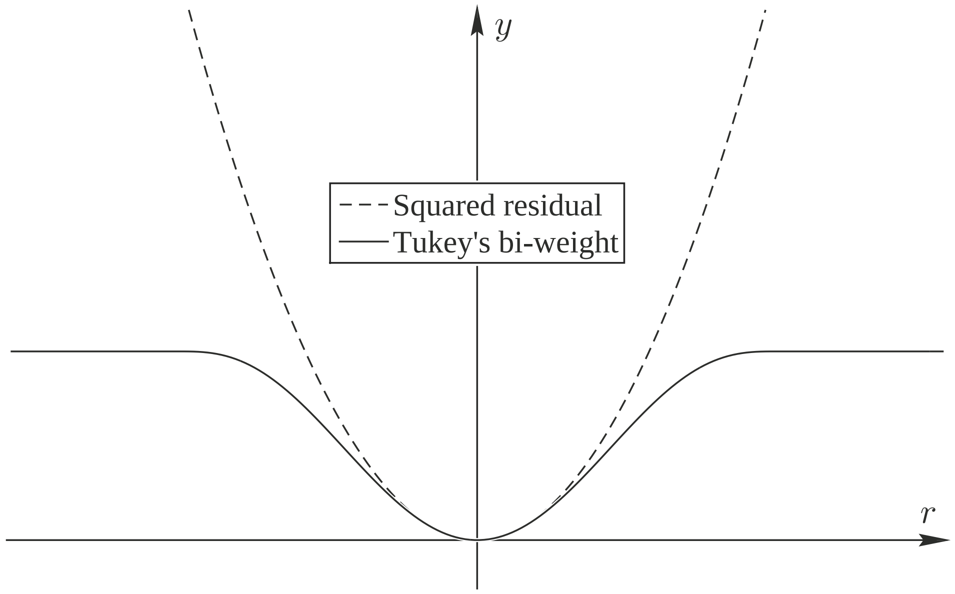
Robust estimation

Estimation of rigid body transformation

$$\min_{\mathbf{R},\mathbf{t}} \sum_{i=1}^{N} \varrho(\mathrm{d}(\mathbf{R}\mathbf{p}_i + \mathbf{t}, S)) \, ,$$

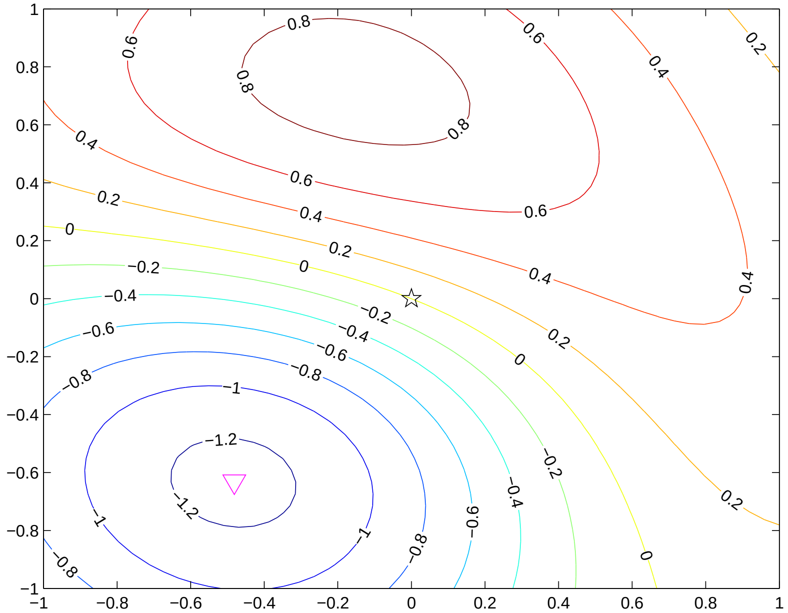
$\mathrm{d}(\mathbf{p}, S)$ distance operator, ϱ robust criterion function

$$\varrho_{\mathrm{Tu}}(r) = \begin{cases} \frac{\kappa_{\mathrm{Tu}}^2}{6}\{1 - (1 - \frac{r^2}{\kappa_{\mathrm{Tu}}^2})^3\} & \text{if } |r| \leq \kappa_{\mathrm{Tu}} \, , \\ \frac{\kappa_{\mathrm{Tu}}^2}{6} & \text{if } |r| > \kappa_{\mathrm{Tu}} \end{cases}$$



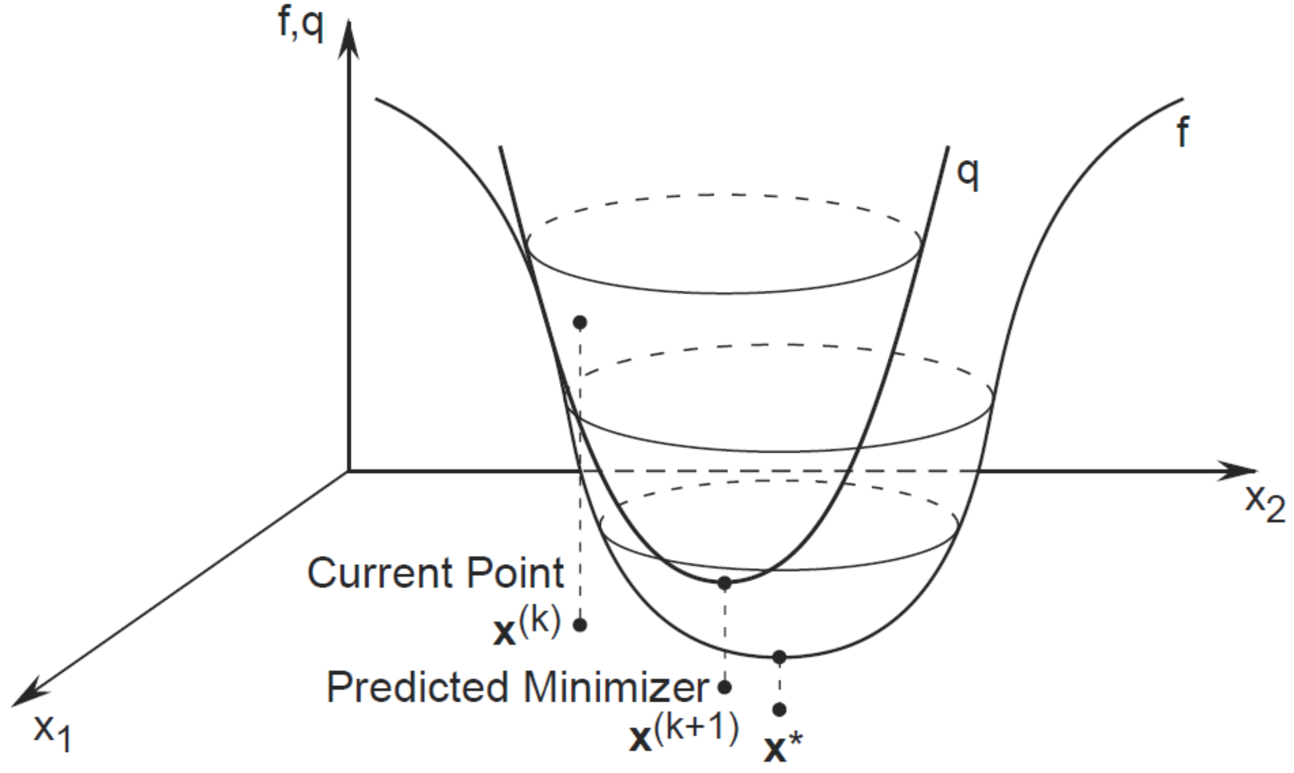
Optimization

- Finding the maximum/minimum of an objective function
  - Constrained
  - Unconstrained



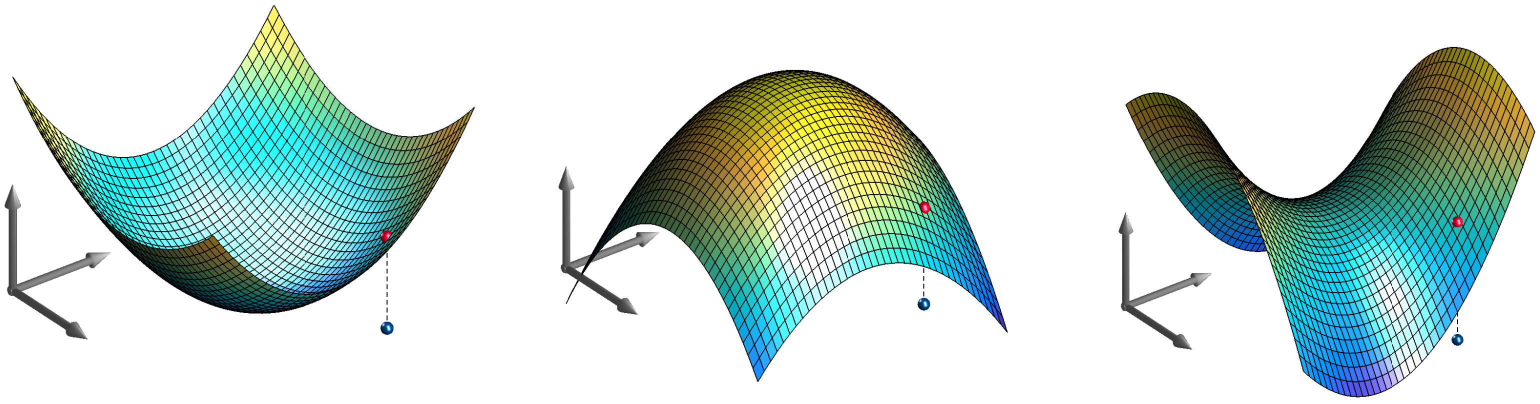
Newton's method

- Quadratic approximation of objective function at current point



Newton's method

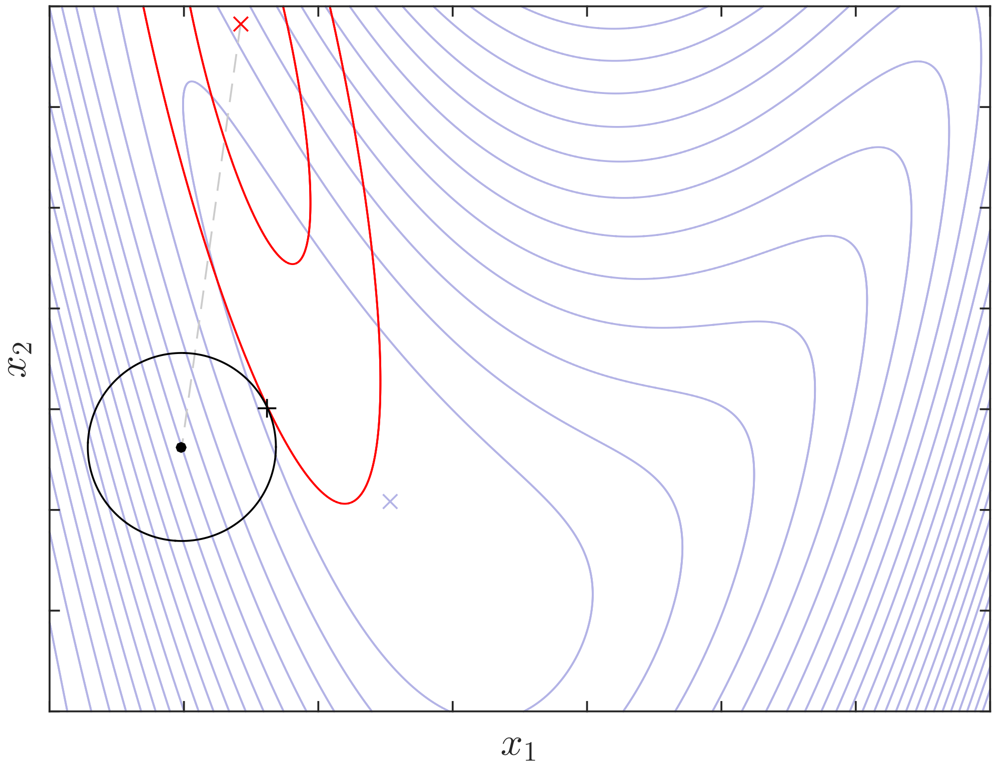
- Advantage if Hessian is positive definite
- Linesearch procedure
- Fast asymptotic convergence



Positive definite Negative definite Indefinite

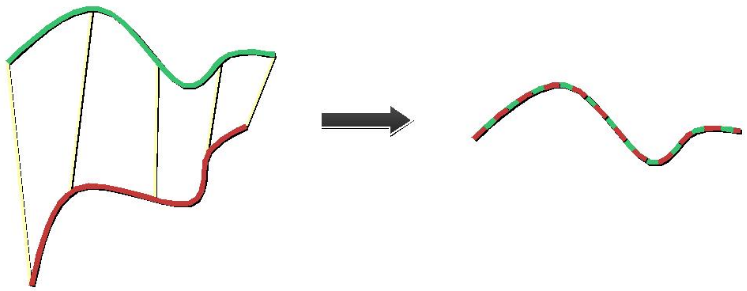
Trust-region method

- Model function (quadratic)
- Restricted to a region in the domain



ICP-algorithm, estimation of R, t

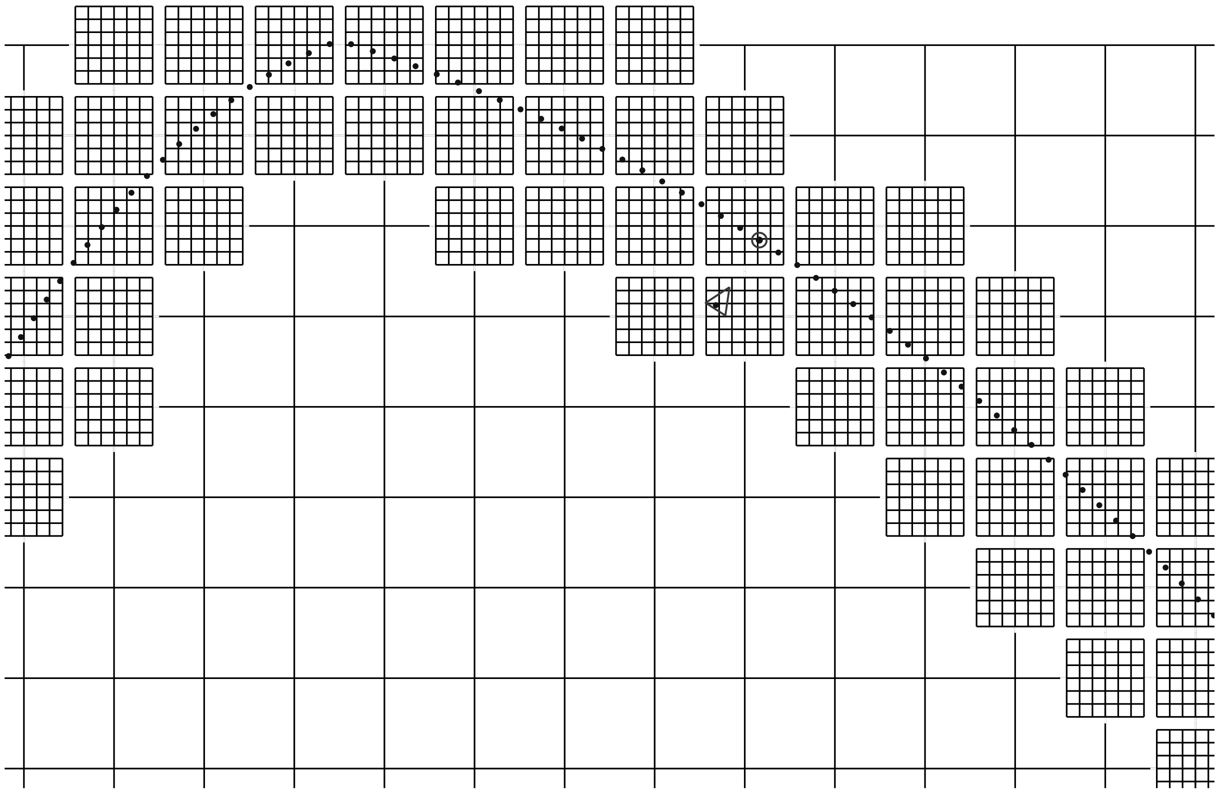
repeat
  Find closest points
  Find an appropriate update of the rigid body transformation
until convergence



- Point-to-point distance minimization
- Point-to-plane distance minimization

- Pottmann, H. et al., "Geometry and Convergence Analysis of Algorithms for Registration of 3D Shapes", International Journal of Computer Vision (2006) 67: 277–296

Fast closest point search



Pre-processed CAD-model

- Bergström, P., Edlund, O. & Söderkvist, I., “Repeated surface registration for on-line use”, The International Journal of Advanced Manufacturing Technology (2011) 54: 677–689

Robust ICP-algorithm

Point-to-point distance minimization

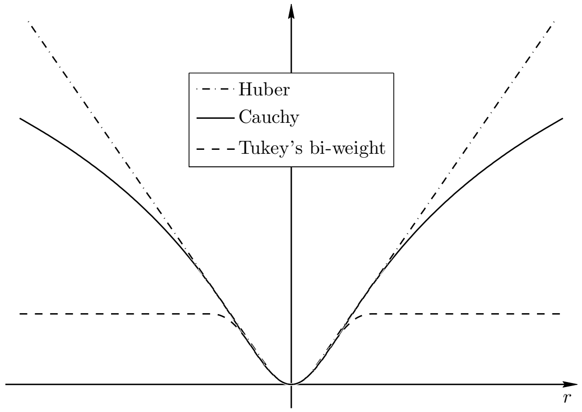
repeat
Find closest points
Find an appropriate update of the rigid body transformation
until convergence

- Bergström, P. & Edlund, O., "Robust registration of point sets using iteratively reweighted least squares", Computational Optimization and Applications (2014) 58: 543–561

Criterion function ϱ

Let $\psi(r) = \varrho'(r)$. A criterion function ϱ belongs to a set $\mathcal{Q}$ if the following conditions are fulfilled:

1. $\varrho(r)$ is an even function and $\boldsymbol{C}^1$-continuous on $\mathbb{R}$ where $\varrho(0) = 0$,
2. $\varrho(r)$ is monotonically increasing on $[0, \infty)$,
3. $\psi(r)/r$ is monotonically decreasing and bounded above on $(0, \infty)$.



A weight function w is defined as

$$w(r) = \begin{cases} \dfrac{\psi(r)}{r} & \text{if } r \neq 0 \\ \lim\limits_{r \to 0} \dfrac{\psi(r)}{r} = \psi'(0) & \text{if } r = 0 \end{cases}$$

A quadratic approximation to $\varrho(s)$ about $s = r$ is

$$\eta(s, r) = \begin{cases} \varrho(r) - \frac{\psi(r)}{2} r + \frac{\psi(r)}{2r} s^2 & \text{if } r \neq 0 \\ \frac{\psi'(0)}{2} s^2 & \text{if } r = 0 \end{cases}$$

$\eta(s, r) = \varrho(r)$, $\frac{\partial}{\partial s}\eta(s, r) = \psi(r)$ at $s = r$,

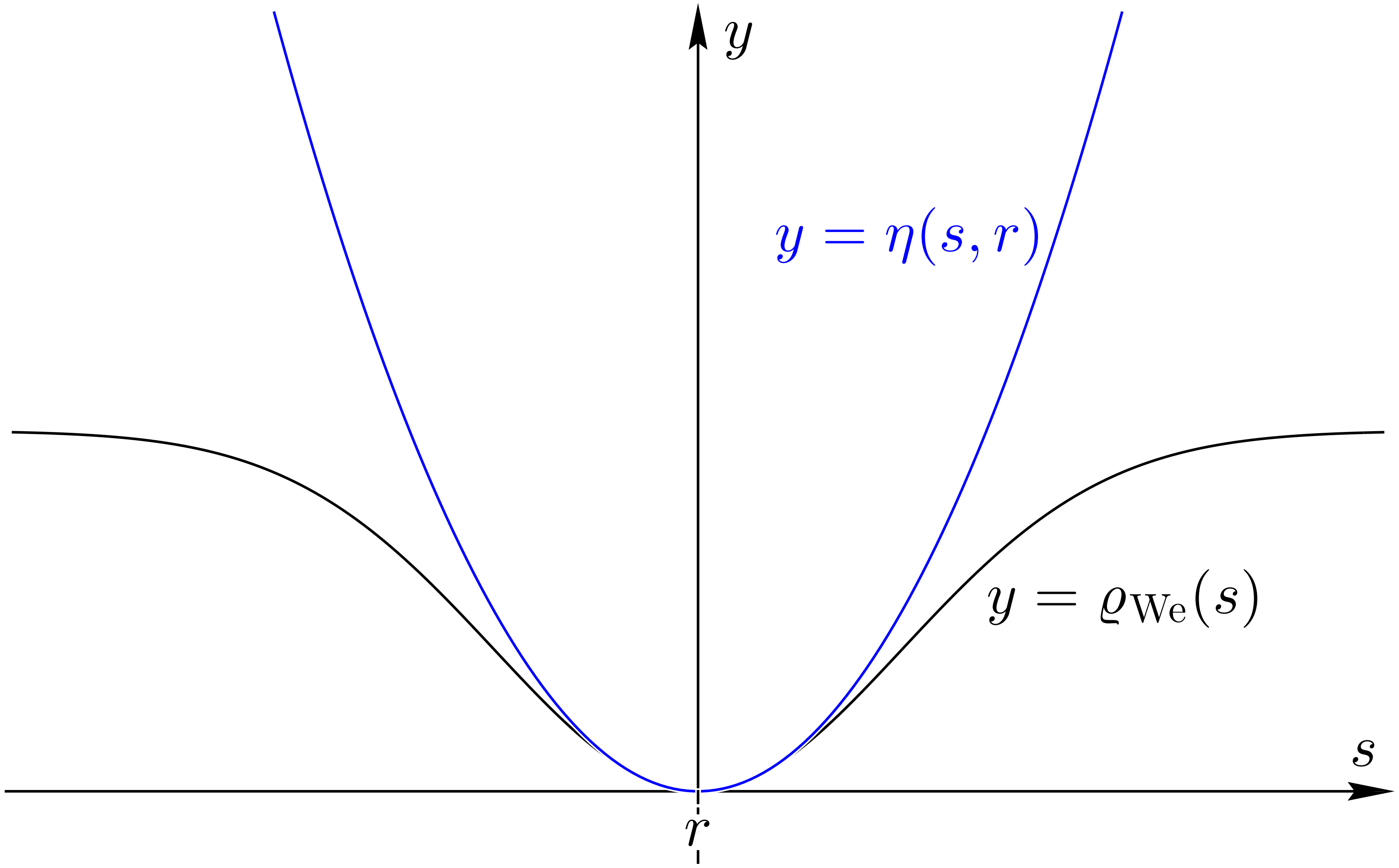
$\frac{\partial}{\partial s}\eta(s, r) = w(r)s \;\; \forall s, r \in \mathbb{R}$

Lemma
For all criterion functions $\varrho \in \mathcal{Q}$ the corresponding quadratic approximation $\eta(s,r)$ fulfills $\eta(s,r) \geq \varrho(s) \;\; \forall s,r \in \mathbb{R}$.

A proof is given in

- Bergström, P. & Edlund, O., “Robust registration of point sets using iteratively reweighted least squares”, Computational Optimization and Applications (2014) 58: 543–561

Quadratic approximation



Finding a rigid body transformation

$$[\mathbf{R}^*, \mathbf{t}^*] = \arg\min_{\mathbf{R},\mathbf{t}} g(\mathbf{R}, \mathbf{t})$$

$$g(\mathbf{R}, \mathbf{t}) = \sum_{i=1}^{N} w_i \|\mathbf{R}\mathbf{p}_i + \mathbf{t} - \mathbf{y}_i\|_2^2$$

$$g(\mathbf{R},\mathbf{t}) =$$

$$\sum_{i=1}^{N} w_i \|\mathbf{p}_i - \bar{\mathbf{p}}\|_2^2 + \sum_{i=1}^{N} w_i \|\mathbf{y}_i - \bar{\mathbf{y}}\|_2^2 + \hat{w}\|\mathbf{R}\bar{\mathbf{p}} + \mathbf{t} - \bar{\mathbf{y}}\|_2^2 - 2\hat{w}\,\mathrm{trace}(\mathbf{RC})$$

where

$$\hat{w} = \sum_{i=1}^{N} w_i \,, \;\; \bar{\mathbf{p}} = \frac{1}{\hat{w}} \sum_{i=1}^{N} w_i \mathbf{p}_i \,, \;\; \bar{\mathbf{y}} = \frac{1}{\hat{w}} \sum_{i=1}^{N} w_i \mathbf{y}_i$$

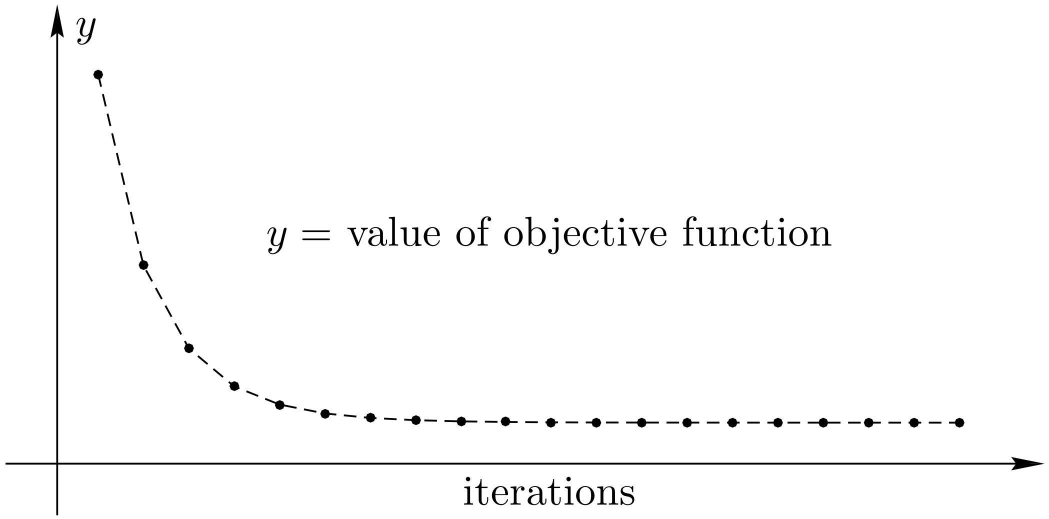
$$\mathbf{C} = \frac{1}{\hat{w}} \sum_{i=1}^{N} [\, w_i \mathbf{p}_i \mathbf{y}_i^{\mathrm{T}} \,] - \bar{\mathbf{p}}\bar{\mathbf{y}}^{\mathrm{T}} \in \mathbb{R}^{3\times 3}$$

Properties of the un-weighted rigid body transformation problem

- Söderkvist, I., “Perturbation Analysis of the Orthogonal Procrustes Problem”, BIT (1993) 33: 687–694

Convergence

- Convergence of the objective function
- Optimality condition eventually satisfied



Robust ICP-algorithm

Point-to-plane distance minimization, trust region approach

Finding a rigid body transformation using

$$v(\mathbf{z}) = \sum_{i=1}^{N} \varrho\Big(\mathbf{n}_i^{\mathrm{T}}\big(\mathbf{R}(\mathbf{z})\mathbf{p}_i + \mathbf{t}(\mathbf{z}) - \mathbf{y}_i\big)\Big)$$

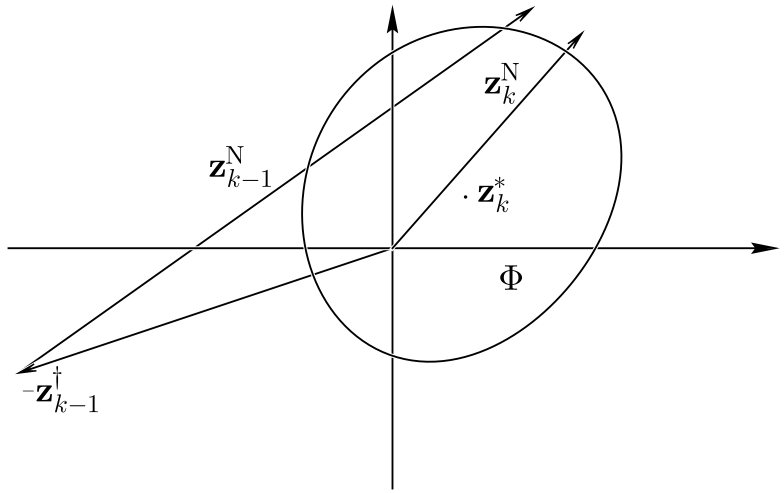
A second-order approximation to the function v about $\mathbf{z} = \mathbf{0}$ with the constant term excluded

$$q(\mathbf{z}) = \mathbf{a}^{\mathrm{T}}\mathbf{z} + \frac{1}{2}\mathbf{z}^{\mathrm{T}}\mathbf{H}\mathbf{z}$$

Trust region subproblem

$$\min_{\mathbf{z}\in\Phi} \mathbf{a}^{\mathrm{T}}\mathbf{z} + \frac{1}{2}\mathbf{z}^{\mathrm{T}}\mathbf{H}\mathbf{z}$$

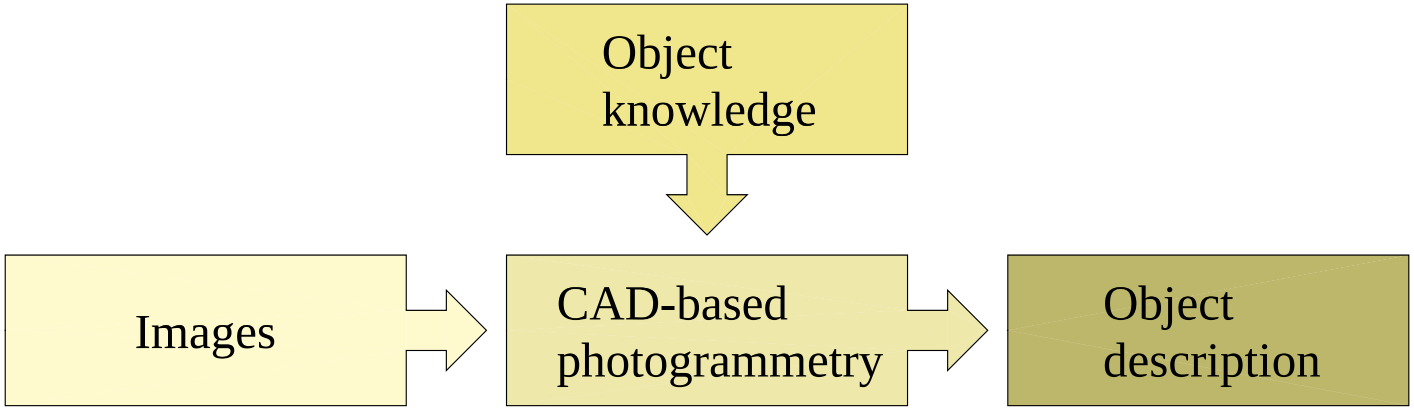
Region Φ derived from weighted point-to-point distances

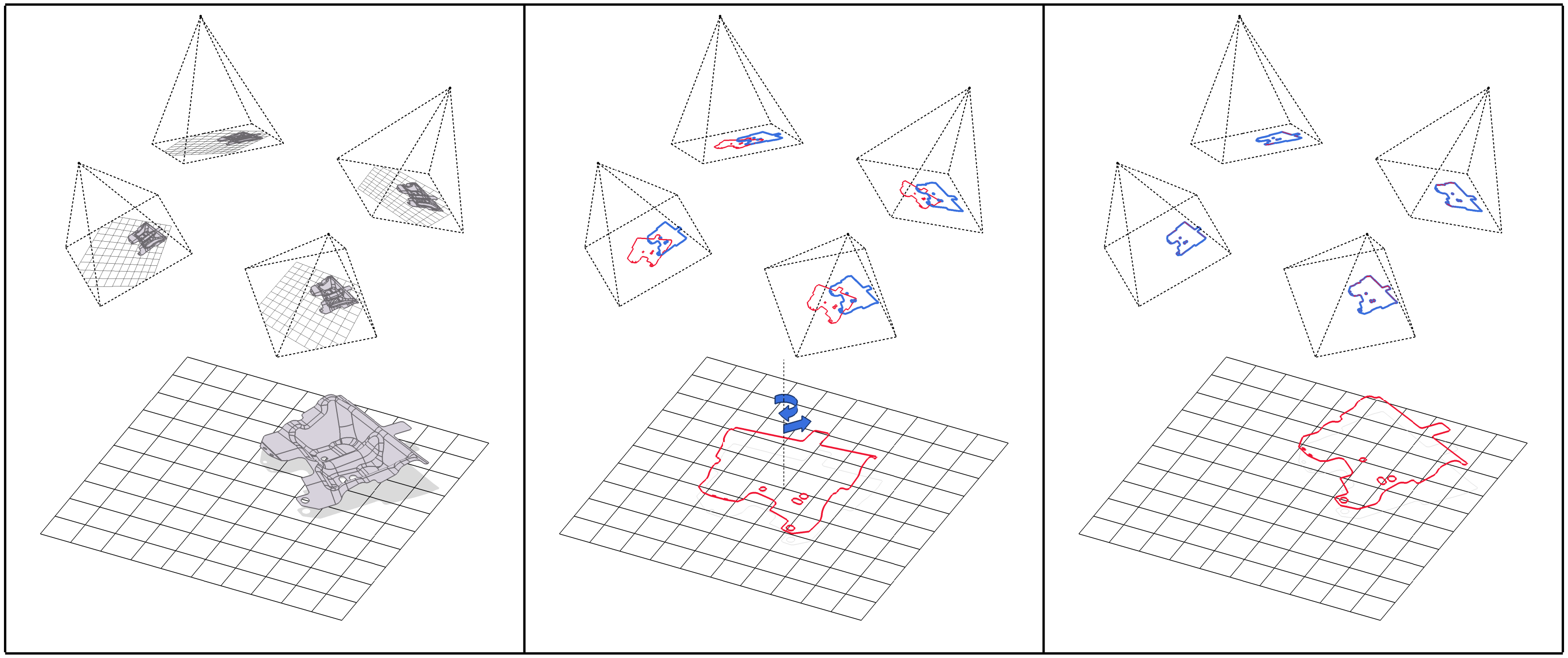


- Bergström, P. & Edlund, O., “Robust registration of surfaces using a refined iterative closest point algorithm with a trust region approach”, Numerical Algorithms (2016), doi:10.1007/s11075-016-0170-3

Future work

- CAD-based photogrammetry
  - Nominal shape is known
  - Faster identification of homologous points
  - High precision edge detection





Questions?