GNSS/LPS based Online Control and Alarm System (GOCA) - Weiterentwicklungen zum integrierten Geomonitoring mit LowCost GNSS und inertial MEMS-Sensoren -

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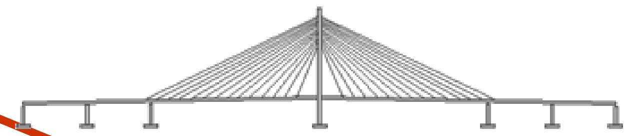
Geomonitoring

Environmental Monitoring

Atmosphere, Pedosphere, Lithosphere, Hydrosphere



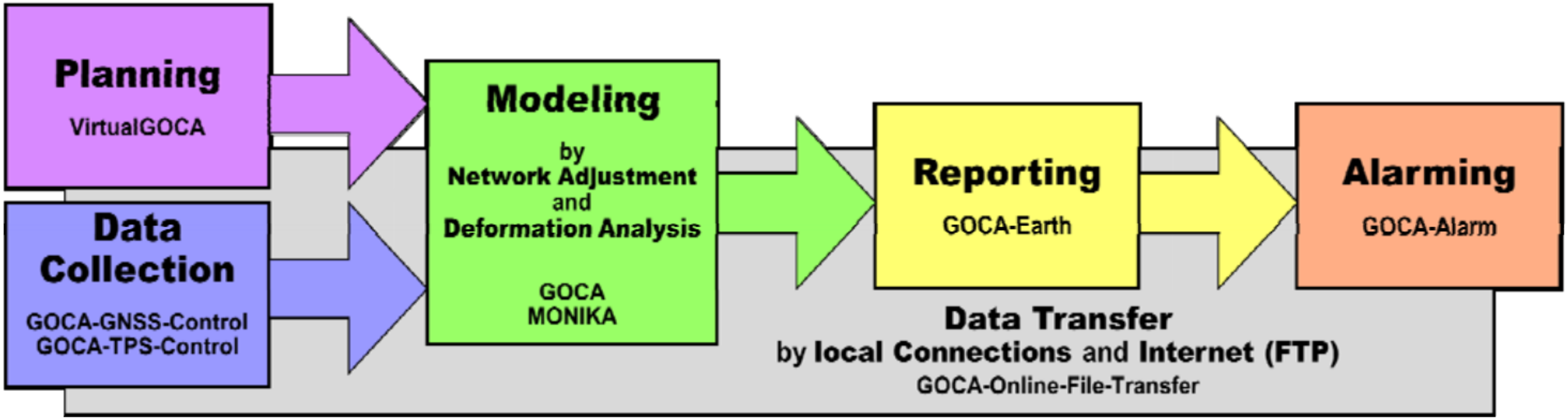
Natural Environment | **Manmade Objects**

Geomonitoring of Processes – Process-Chain

- **Dataregistration** (Sensornetworks, Data-Communication)
- **Modeling (Process-/Discipline-specific, Interdisciplinary)**
- **Reporting** (Visualisation, Protocols, GIS, Web)
- **Reaction** (Alarming, Countermeasurses)

GOCA – System und – Software (HSKA)

GOCA = GNSS/LPS based Online Control and Alarm System



- **Modeling**

  State Parametrization by Sensordata

  - Coordinates

  $$\mathbf{x}_R(t)\ \mathbf{x}_O(t)$$

  -Displacements

  $$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

  - Physical Parameters

  $$\mathbf{p}_K, \mathbf{p}_C, \mathbf{p}_M$$

- **Reporting**

  Numerical Protocols

  Graphics

  Web-GIS

- **Reaction / Alarm-Management**

  - Critical States
  - Predictions
  - Sensor-Alarm

Sensor and Parameter- Integration

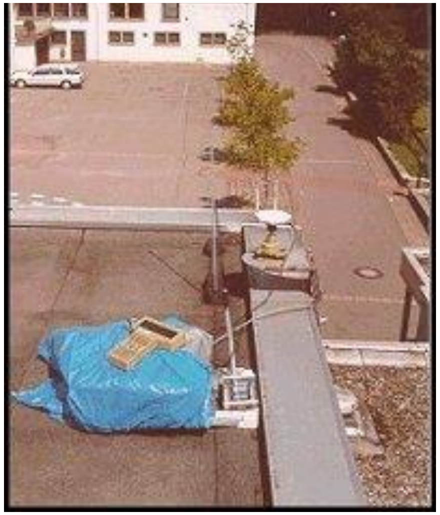
GOCA = GNSS/LPS based Online Control and Alarm System
Application Part I : Natural Environment

GOCA = GNSS/LPS based Online Control and Alarm System
Application Part II : Structural Monitoring

Monitoring of
Slow Processes, v ⟶ 0
FEM - Statics

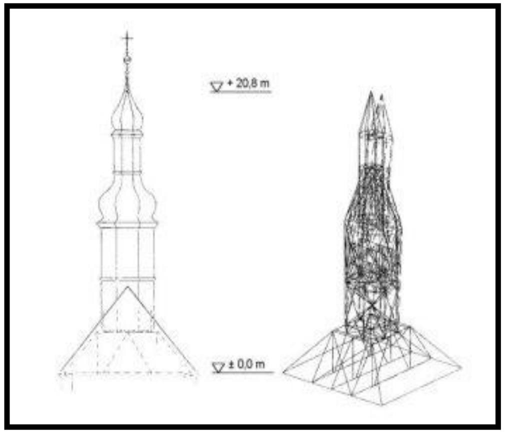
Statics & Dynamics

Monitoring of
Dynamic Processes
FEM - Vibrations of Buildings



GOCA Dam-Monitoring
Projects Example

GOCA-Project Robert
Bosch Hospital Stuttgart,
2011

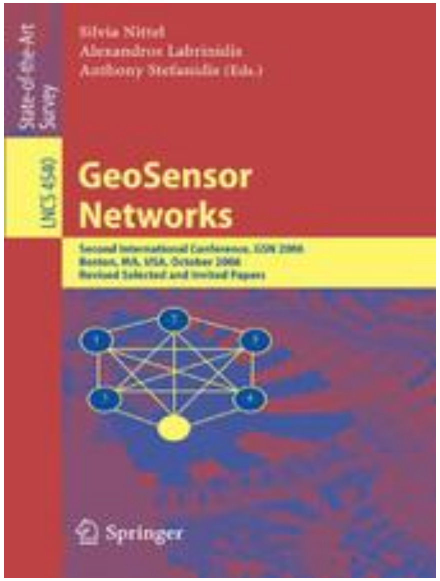


GOCA Data-Acquisition

Geomonitoring -

Chain Link 1

Geosensornetworks and Sensor-Nodes



Active Nodes/Sensors

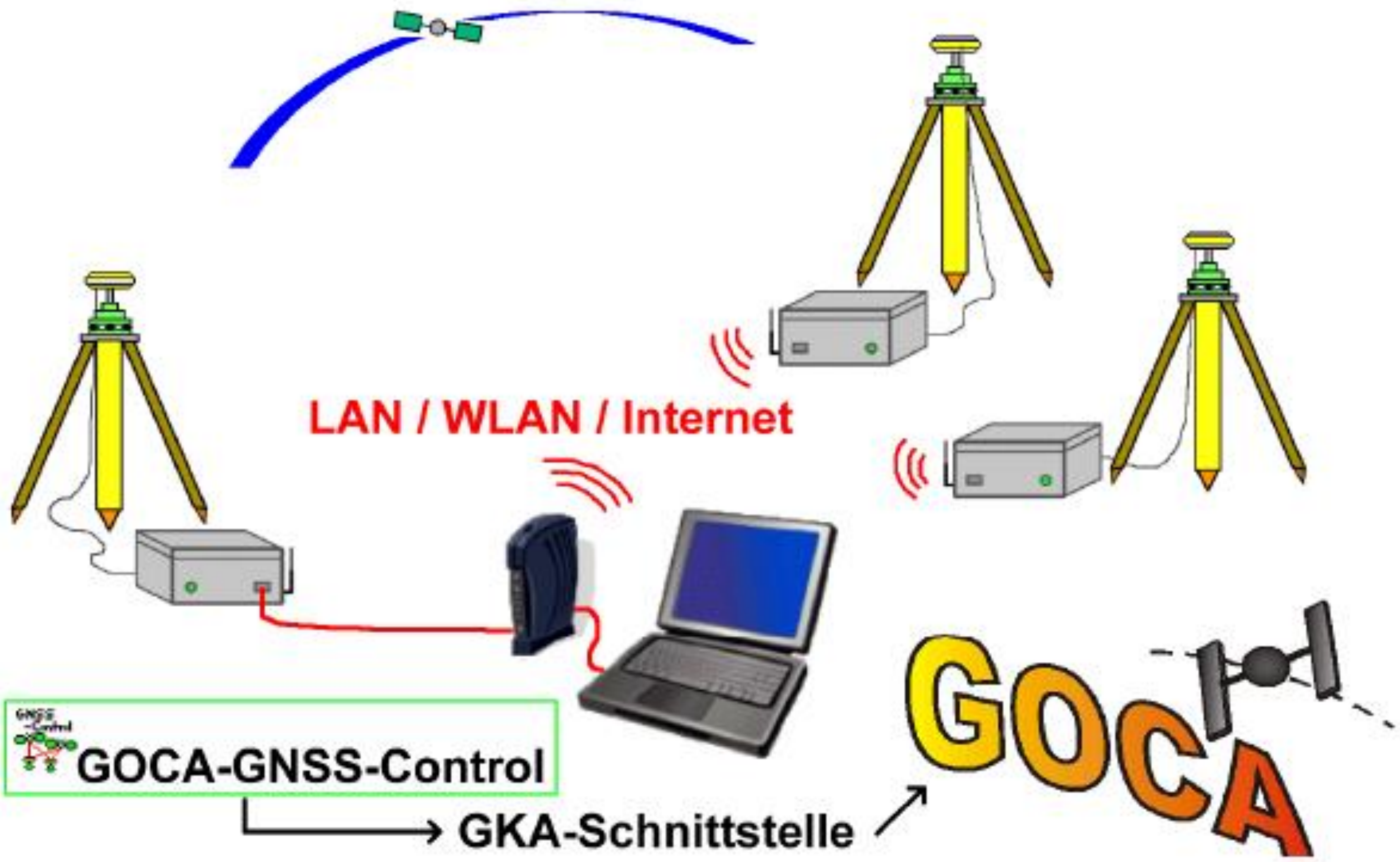
- Collect data actively themselves and send it further through the network

Passive Nodes/Sensors

- Collect and send data based on an external sensor control

GOCA GNSS-Control Software + Communication-Boxes

Any GNSS-Hardware – RTK- or Nearonline RINEX-Mode



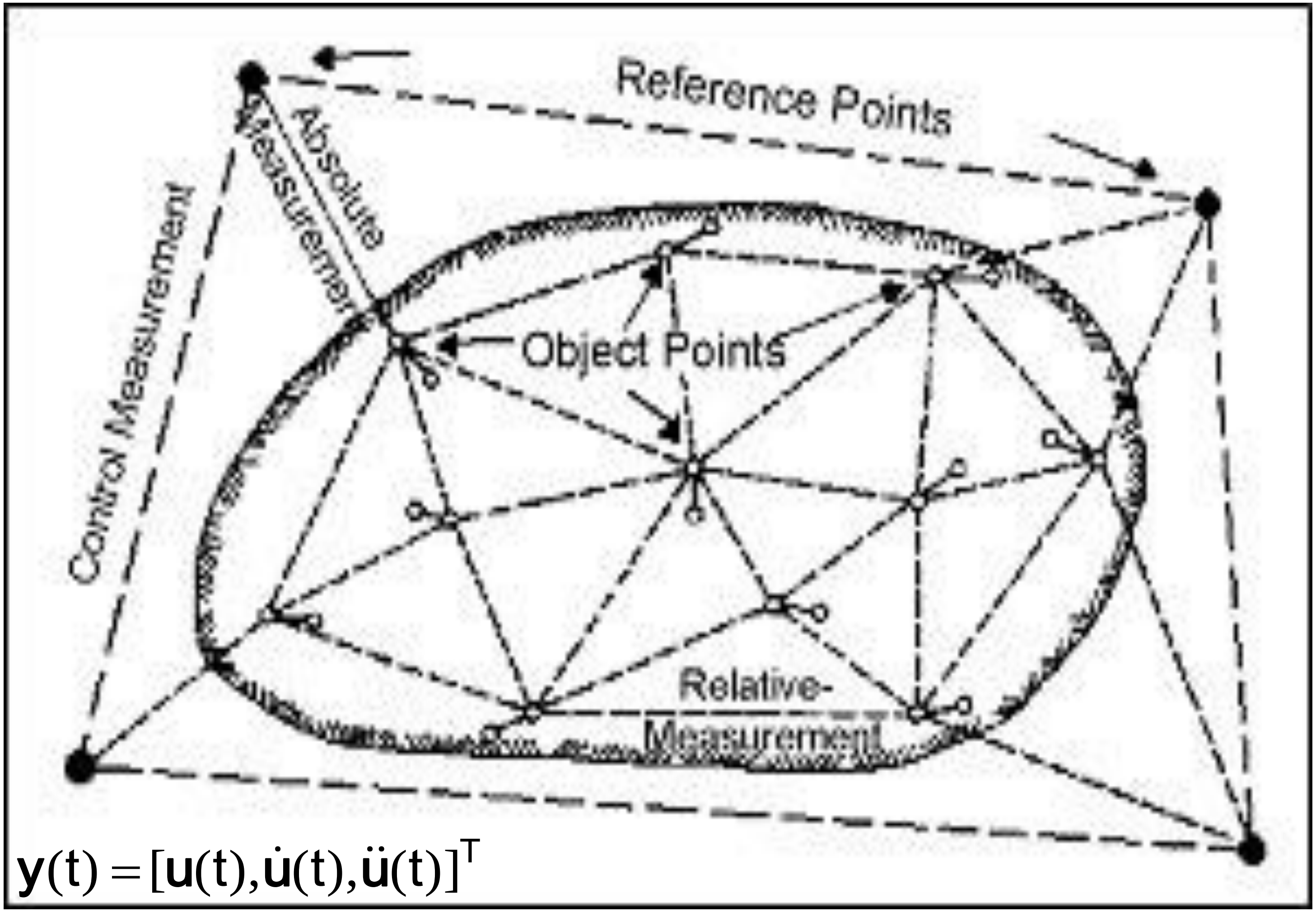
Geomonitoringkette mit GOCA-GNSS-Control

GOCA-Sensordata-Modeling
Geodetic Geomonitoring
Chain Link 2

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2



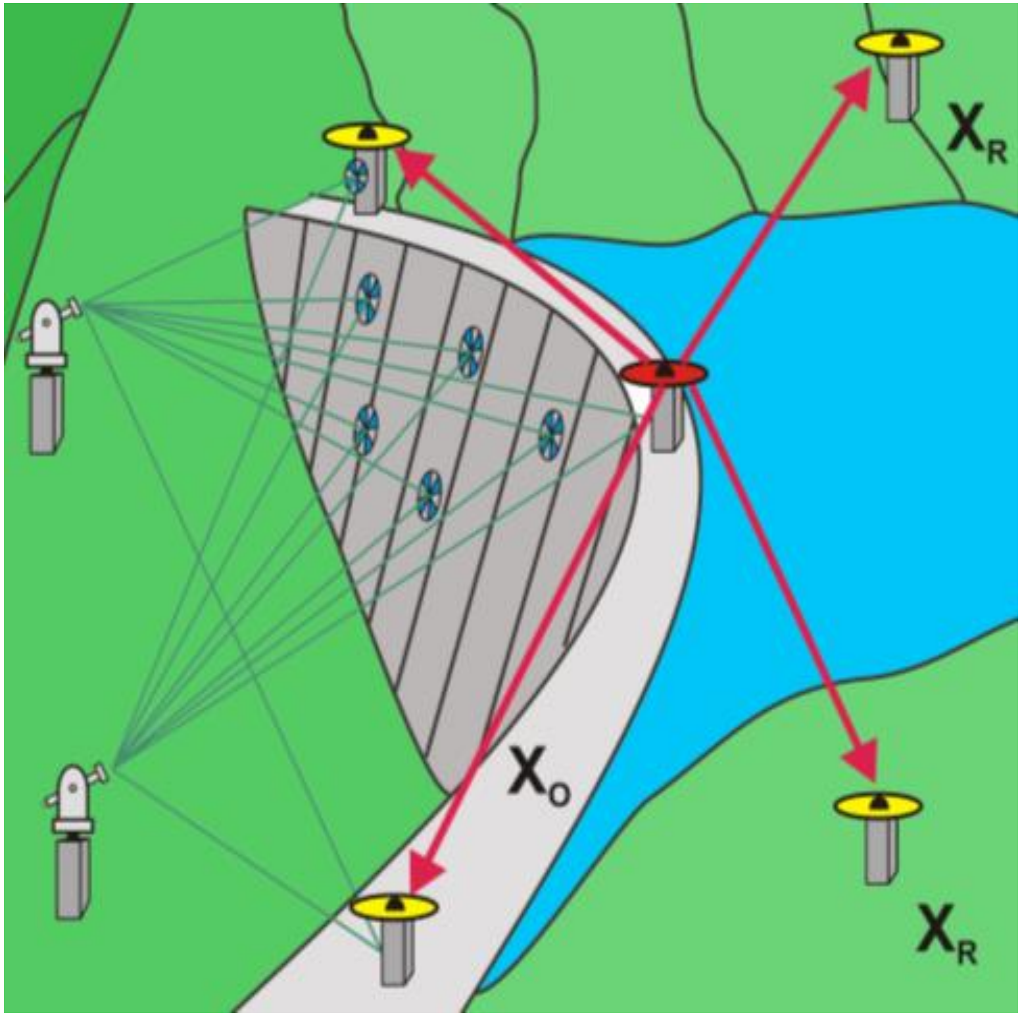
$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

Deformationsanalysis – Sensor Integration by Geodetic Network Adjustment (Pelzer, 1970)

GOCA = GNSS/LPS based Online Control and Alarm System
Geodetic Monitoring - Modeling as Chain-Link 2

Targets of GOCA-Project and of the GOCA-Software and -System

- Scaleable Online 3D Monitoring - permanent or non-permanent - using GNSS and LPS
- Online 3D georeferencing of object-point time series $x_O(t)$ in the datum (coordinate system) defined by the reference points x_R as holding for a Classical Absolute Geodetic Deformation Network
- Online Deformation Analysis and forecasting based on the object point time series $x_O(t)$
- Integrated Deformation Analysis Interfaces
- Automatical Alarming



$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

Absolute Deformation Network $y = (x_R, x_o(t))$

Geodetic Network Adjustment $y(t) = [u(t), \dot{u}(t), \ddot{u}(t)]^T$

Standard Sensors l=l(x)

GPS/GNSS , Total Stations

Optical and Hydrostatic Levels

Sensor-

Integration

Common Adjustment of redundant sensor observations *l(x,t)*: *Unique set of 3D-coordinates per object point and per epoch t*

$$\Delta Ho_{ij,GPS}(t) + v = \Delta\hat{H}o_{ij}(t)$$

$$\Delta Re_{ij,GPS}(t) + v = \Delta\hat{R}e_{ij}(t)$$

$$\Delta h_{ij,GPS}(t) + v = \Delta\hat{h}_{ij}(t)$$

$$r_{ij}(t) + v = \arctan\left(\frac{\Delta\hat{R}_{ij}}{\Delta\hat{H}_{ij}}\right)^t - \hat{o}$$

$$s_{ij}(t) + v = \left(\hat{m} \cdot \sqrt{\Delta\hat{R}_{ij}^2 + \Delta\hat{H}_{ij}^2}\right)^t$$

$$\Delta H_{ij}(t) + v = \Delta\hat{h}_{ij}(t) + \hat{A} \cdot \Delta Re_{init} + \hat{B} \cdot \Delta Ho_{Init} + \Delta\hat{m}_h \cdot \Delta h$$

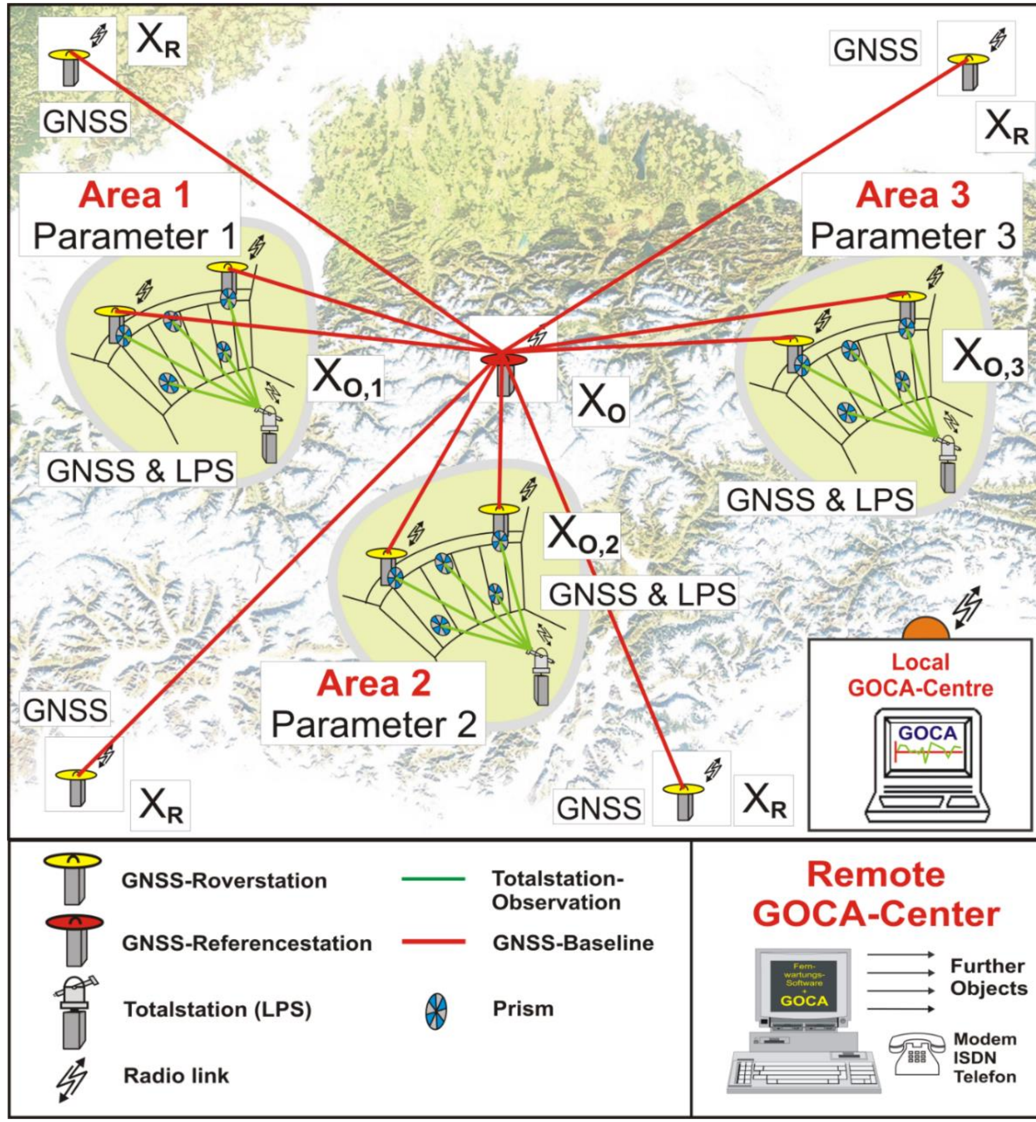
GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

GOCA-Software Modeling and Scalability in Space

- Pure GNSS Array
- Pure LPS Array
- <u>GNSS & LPS Array</u>
  - Several n Areas
  - GNSS as Reference-Frame X_R
  - Special ca : n=1 Area

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$



GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

Geodetic observation-related Deformationsanalysis - Standards

$y = (x_R; x_{0,1;} x_{02})$ – coordinates x(t)

$$(\mathbf{l}_1-\mathbf{l}_1(\mathbf{y}^0))+\mathbf{v}_1=\mathbf{A}_{R,1}\cdot d\mathbf{x}_R+\mathbf{A}_{O,1}\cdot d\mathbf{x}_{O,1}+\mathbf{0}\cdot d\mathbf{x}_{O,2}$$

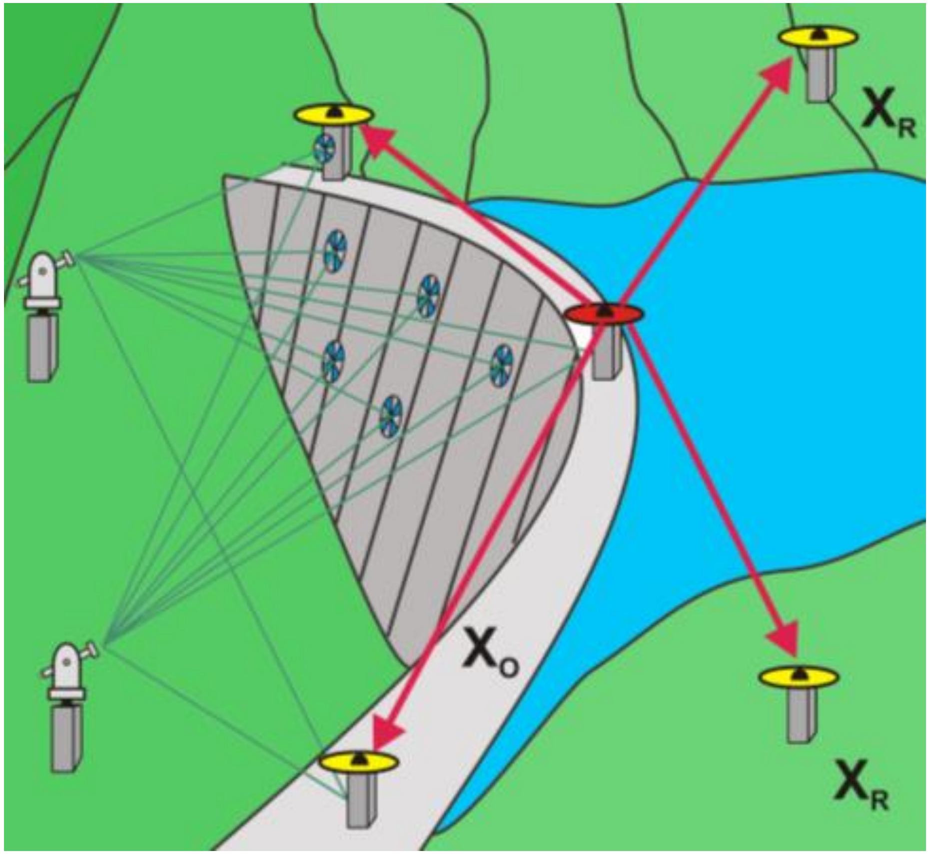
$$(\mathbf{l}_2-\mathbf{l}_2(\mathbf{y}^0))+\mathbf{v}_2=\mathbf{A}_{R,2}\cdot d\mathbf{x}_R+\mathbf{0}\cdot d\mathbf{x}_{O,1}+\mathbf{A}_{O,2}\cdot d\mathbf{x}_{O,2}$$

Least-Squares Adjustment (L2-Norm)

$$d\hat{\mathbf{y}} = (\mathbf{A}^T\mathbf{C}_l^{-1}\mathbf{A})^-\mathbf{A}^T\mathbf{C}_l^{-1}\cdot(\mathbf{l}-\mathbf{l}(\mathbf{y}^0))$$

$$\hat{\mathbf{y}}(t_1,t_2)=y^0+d\hat{\mathbf{y}}=\begin{bmatrix}\mathbf{x}_R^0+d\mathbf{x}_R\\ \mathbf{x}_{O1}^0+d\mathbf{x}_{O1}\\ \mathbf{x}_{O2}^0+d\mathbf{x}_{O2}\end{bmatrix}$$

$$\mathbf{C}y=\left[\begin{array}{c|cc}\mathbf{A}_R^T\mathbf{C}_l^{-1}\mathbf{A}_R & \mathbf{A}_R^T\mathbf{C}_l^{-1}\mathbf{A}_{O1} & \mathbf{A}_R^T\mathbf{C}_l^{-1}\mathbf{A}_{O2}\\ \hline \mathbf{A}_{O1}^T\mathbf{C}_l^{-1}\mathbf{A}_R & \mathbf{A}_{O1}^T\mathbf{C}_l^{-1}\mathbf{A}_{O1} & \mathbf{0}\\ \mathbf{A}_{O2}^T\mathbf{C}_l^{-1}\mathbf{A}_R & \mathbf{0} & \mathbf{A}_{O2}^T\mathbf{C}_l^{-1}\mathbf{A}_{O2}\end{array}\right]^-$$



Discrete State-Parameters y

$x_o(t)$ - Objectpoint Coordinatse

$u_o(t,x_i)$ - Objektpoint Displacements

GOCA = GNSS/LPS based Online Control and Alarm System
Geodetic Monitoring - Modeling as Chain-Link 2

Mathematical Model: Relation between the Observation Data (l) und Object State Parameters y. Stochastical Models C_l of the Observation Errors ε at two general observation times (epochs) t_1 and t_2

$$\mathbf{l}(t_1) - \varepsilon(t_1) = \tilde{\mathbf{l}}(\mathbf{y}(t_1)) \quad ; \quad \mathbf{C}_l(t_1)$$

$$\mathbf{l}(t_2) - \varepsilon(t_2) = \tilde{\mathbf{l}}(\mathbf{y}(t_2)) \quad ; \quad \mathbf{C}_l(t_2)$$

Parameter- Estimation (after linearisation with approximative parameters y^0)

Approach: $$\sum_{i=1}^{n} \rho(\bar{v}_i) = \sum_{i=1}^{n} \rho\left((\mathbf{C}_l^{-\frac{1}{2}} \cdot \mathbf{A})_i \cdot d\hat{\mathbf{y}} - (\mathbf{C}_l^{-\frac{1}{2}} \cdot (\mathbf{l} - \mathbf{l}(\mathbf{y}^0)))_i \right) = \mathrm{Min}|_{d\hat{y}}$$

Choice of the Estimation Principle:

$$\rho(\bar{v}_i) = \frac{1}{2}\bar{v}_i^2 \quad \left(\rho(\bar{v}_i) = \frac{1}{2}|\bar{v}_i| \ldots \rho(\bar{v}_i) = \begin{cases} \frac{1}{2}\bar{v}_i^2 & \forall\ |\bar{v}_i| \le k \\ |\bar{v}_i| & \forall\ |\bar{v}_i| > k \end{cases} \right)$$

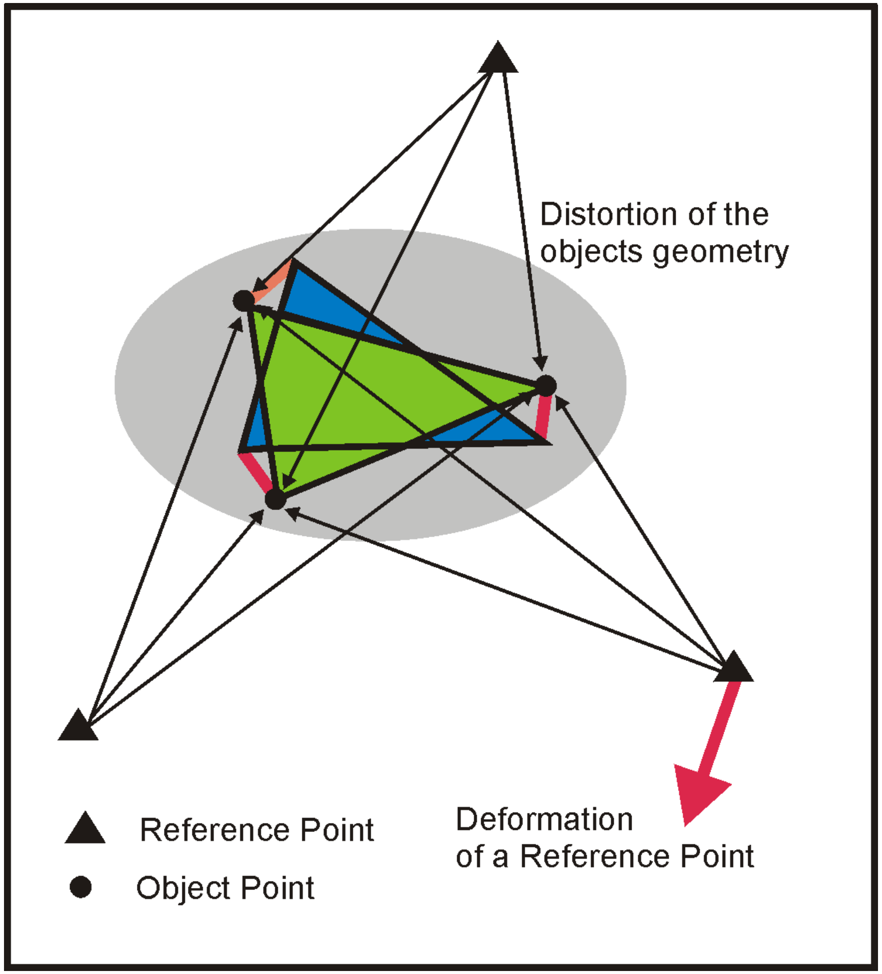
Result = State vector of Parameters y(t) $$\hat{y} = y^0 + d\hat{y}$$

Extended GMM for the Detection of instable reference points x_R

Standard

Congruency of Network between 2 different time spans I and II

Extended GMM



Extended GMM for the Detection of instable reference points x_R

Standard GMM : Congruency of Network between 2 different time spans I and II

Hypothesis: Stable Point i has moved between epoch I and epoch II

$$l + v' = A_R \cdot dx_R' + A_O \cdot dx_O' + l(x^0) + \begin{bmatrix} 0_I \\ A_{\nabla R,II} \end{bmatrix}_i \cdot \nabla x_{R_i}$$

$$= A \cdot dx' + l(x^0) + A_{\nabla R,i} \cdot \nabla x_{R,i}$$

A_R	Design-matrix of the stable reference-points
A_O	Design-matrix of the moving object-points
l	GPS/GNSS-baseline- or LPS-observations
v'	Residuals
x_R, x_O	Adjusted Reference- and object-point-coordinates
x^0	Approximate coordinates
dx_R, dx_O	Adjustment co-ordinate unknowns

Extended GMM for the Detection of instable reference points x_R

Test for the detection of significant deformations ∇_R of i-th reference-point
All quantities can be related to the non-extended original GMM

Teststatistics

$$\boldsymbol{T} = \frac{\nabla^{\boldsymbol{T}}_{\hat{X}_{R,i}} \cdot Q^{-1}_{\nabla_{\hat{X}R,i}} \cdot \nabla_{\hat{X}_{R,i}}}{\boldsymbol{b} \cdot \hat{\sigma}^2} \sim F_{b,r-b}$$

b — **Dimension of the network, b=2: plan, b=1:height**

$\nabla_{\hat{X}_{R,i}}$ — **estimated deformation at the reference-point x_R**

$Q_{\nabla_{\hat{X}_R}} = \left(A^T_{R,i} P Q_v P A_{R,i}\right)^{-1}$ — **Cofactor-Matrix of the deformation**

$\hat{\sigma}^2$ — **reduced a posteriori variance-factor**

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

➢ **Adjustment – Step1: Initialization = Determination of Reference Points**

* **Related additional Feature: Stastical Control of Stability of Referencepoints by means of Adjustment Techniques**

➢ **Adjustment - Step 2: Continuous Adjustment of Object Point Positions in the Reference Point Datum and Visualization of Objectpoint Time Series in Graphical Window.**

$$\mathbf{x}_O(t) \quad \mathbf{C}_O(t)$$

➢ **Adjustment - Step 3 : *GOCA - Deformationanalysis***

➢ **Online Moving Average Displacemets**

➢ **Online Displacement Estimation, Statistical Testing and Alarm Setting**

➢ **Online-Estimation of Displacement, Velocity and Acceleration based on a Kalman-Filtering. Computation of Alarm Probability for each Object Point.**

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

Running as Parallel Processes

GOCA = GNSS/LPS based Online Control and Alarm System
Geodetic Monitoring - Modeling as Chain-Link 2

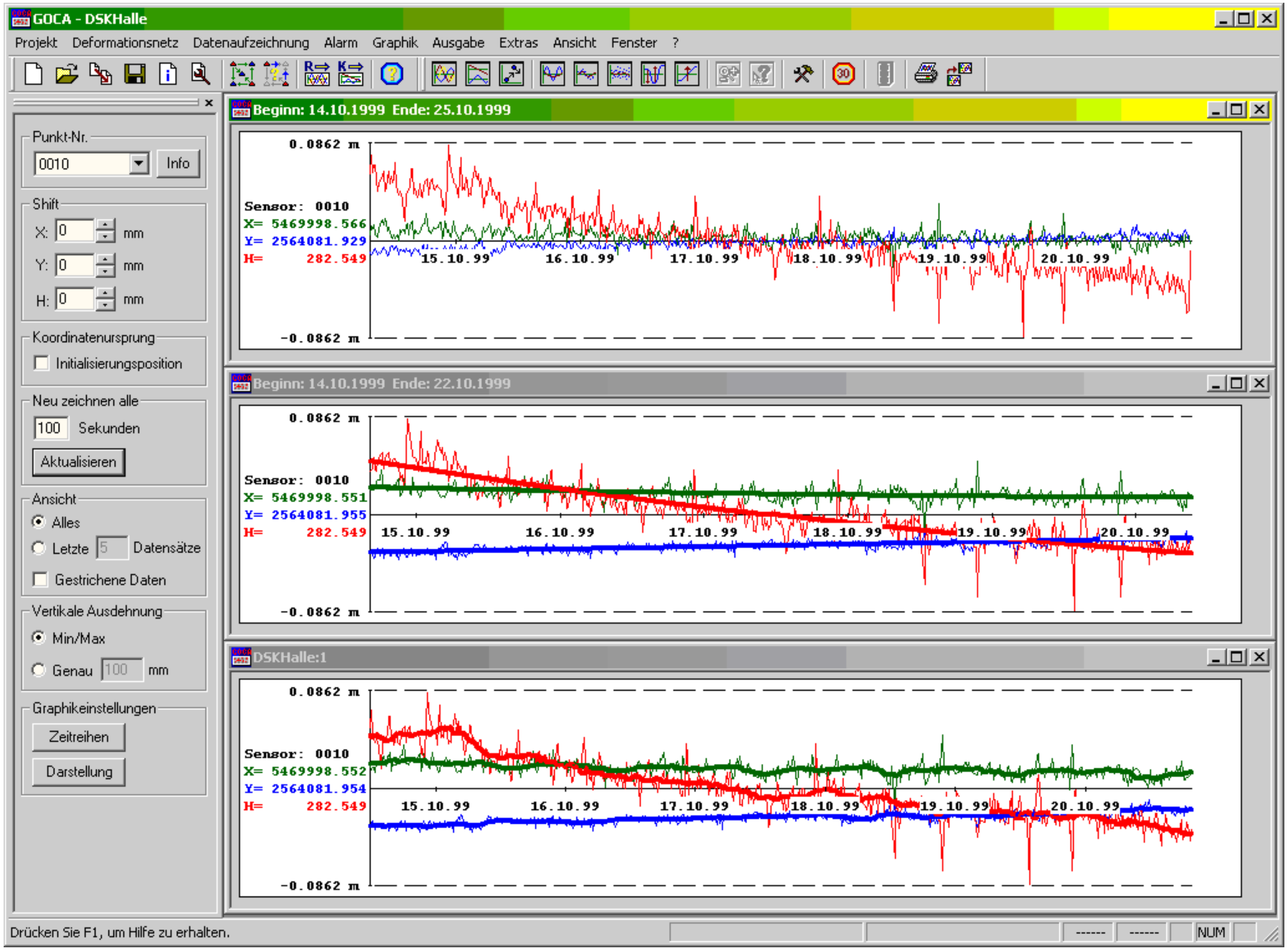
GOCA

Steps 2

and

Step 3

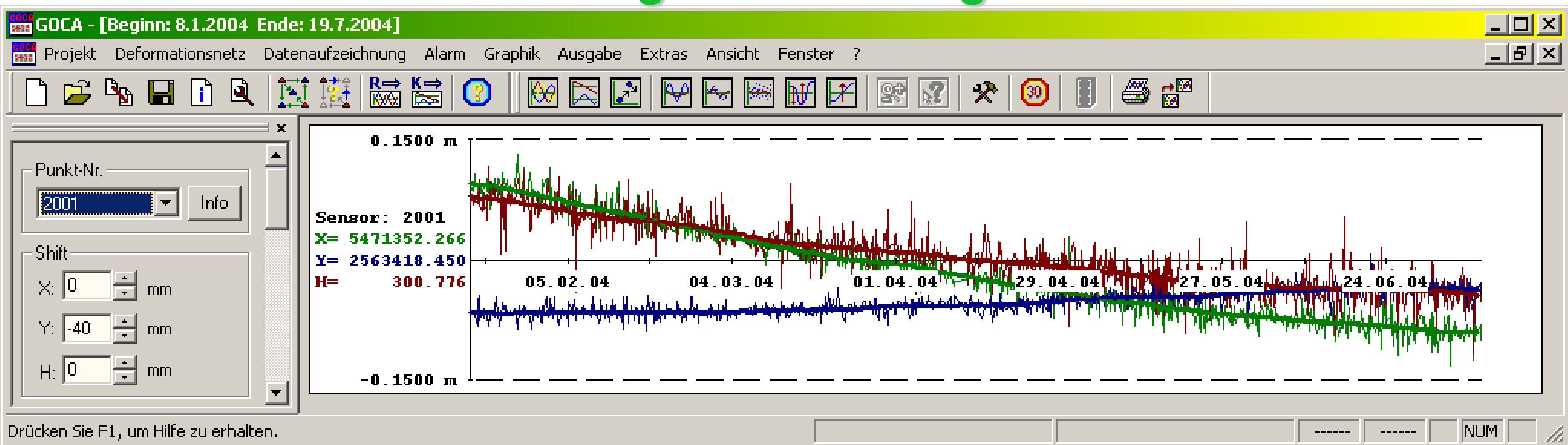
– MVE –
Least Squares and Robust Estimation

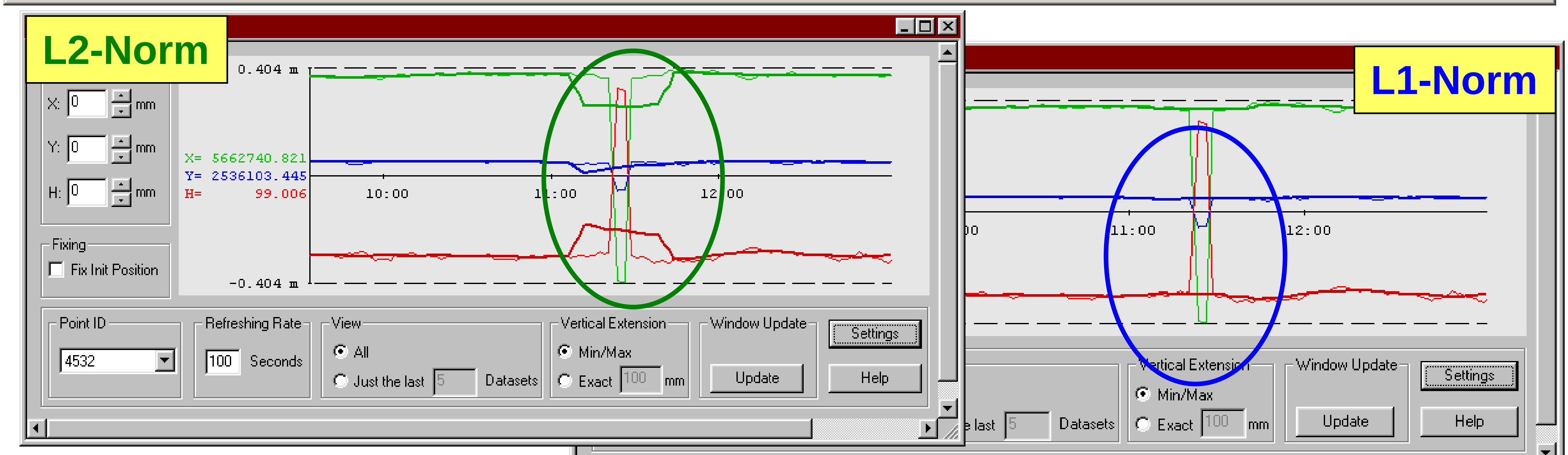


$$\mathbf{l}(t) + \mathbf{v} = \mathbf{E} \cdot \mathbf{y}(t) \quad \text{with} \quad \mathbf{y}(t) = MVE(t)$$

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

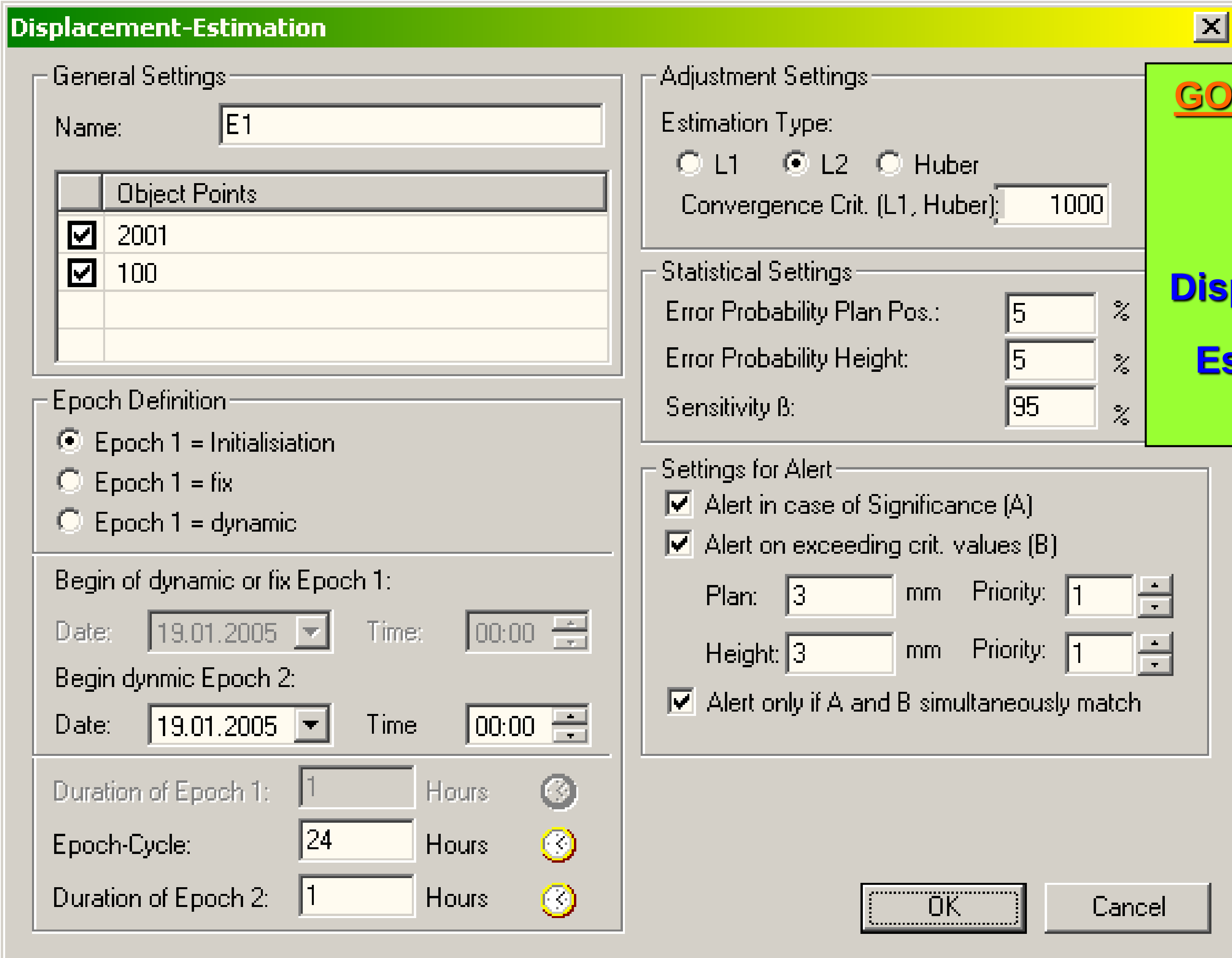




GOCA Steps 2 and Step 3 MVE

Least Squares (L2-Norm) and Robust Estimation L1-Norm

GOCA = GNSS/LPS based Online Control and Alarm System

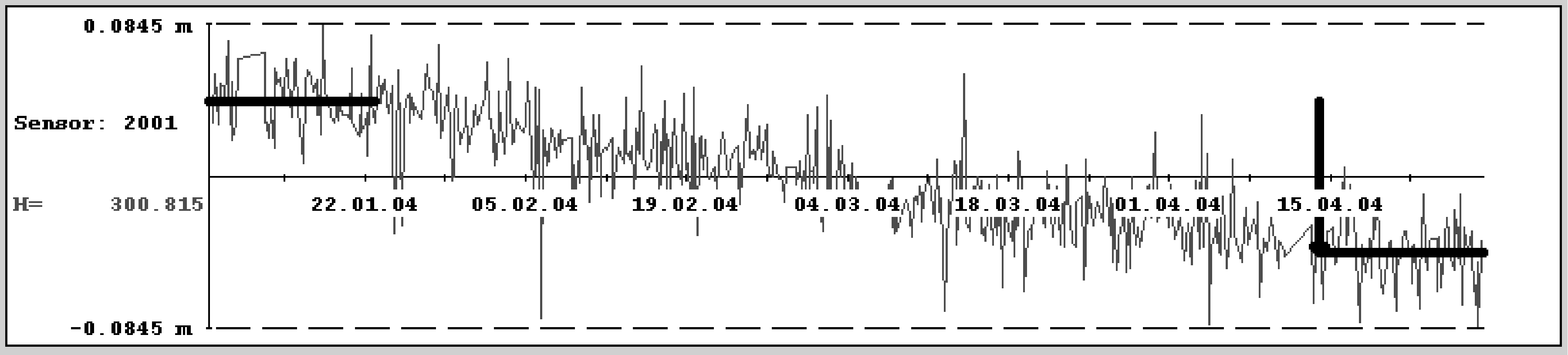


GOCA – Step 3

Online Displacement Estimation

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2



$$\begin{bmatrix} \mathbf{l}_{t_0} \\ \mathbf{l}_t \end{bmatrix} + \begin{bmatrix} \mathbf{v}_{t_0} \\ \mathbf{v}_t \end{bmatrix} = \begin{bmatrix} \mathbf{E}_1 & \mathbf{0} \\ \mathbf{E}_2 & \mathbf{E}_2 \end{bmatrix} \cdot \begin{bmatrix} \mathbf{x}_0 \\ \mathbf{u}(t) \end{bmatrix}$$

$$\mathbf{y}(t) = (\mathbf{x}_o, \mathbf{u}(t))^T$$

GOCA Step 3 – Online Displacement Estimation

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

GOCA Step 3

Online Kalman-Filtering

1.)

$$\begin{bmatrix} \mathbf{u}(t) \\ \dot{\mathbf{u}}(t) \\ \ddot{\mathbf{u}}(t) \end{bmatrix} = \begin{bmatrix} \mathbf{I} & [\Delta t] & \left[\frac{1}{2}\Delta t^2\right] \\ 0 & \mathbf{I} & [\Delta t] \\ 0 & 0 & \mathbf{I} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{u}(t-\Delta t) \\ \dot{\mathbf{u}}(t-\Delta t) \\ \ddot{\mathbf{u}}(t-\Delta t) \end{bmatrix} \qquad \mathbf{C}_y(t)_{t-dt}$$

2.)

$$\mathbf{l}(t) = \mathbf{l}(\mathbf{y}(t)) =: \mathbf{u}(t) = \mathbf{x}_O(t) - \mathbf{x}_O(t_0) \qquad \mathbf{C}_l = \mathbf{C}_{x_O}(t) + \mathbf{C}_{x_O}(t_0)$$

„Parameter-Integration" !

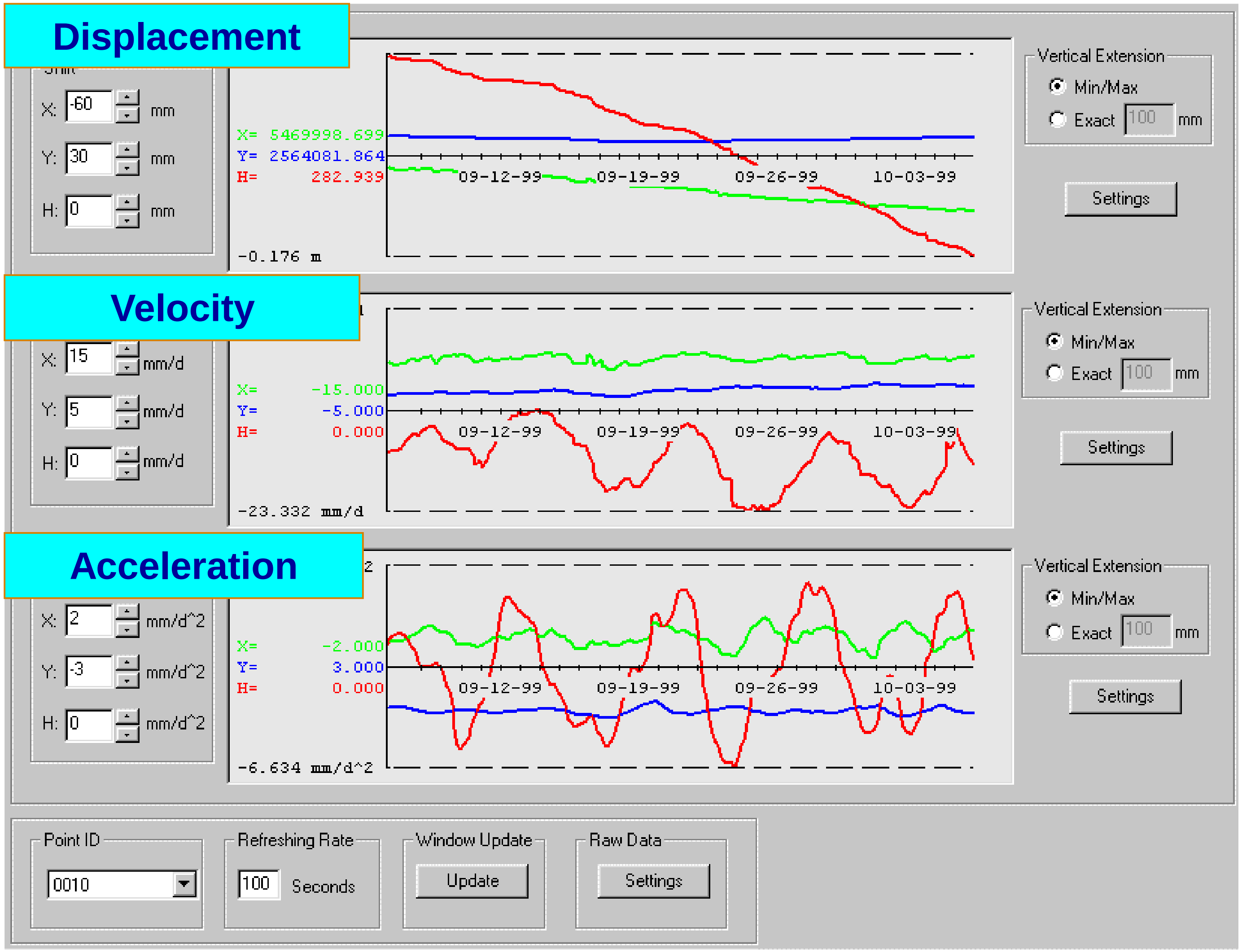
$$\mathbf{y}(t) = [\mathbf{u}(t)]^T \quad \Longrightarrow \quad \mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

GOCA Step 3

Online Kalman-Filtering



GOCA Step 3

Online Kalman-Filtering

Prediction and Early Warning by "Simple" Kalman-Filtering

Using the system equation

$$\mathbf{x}(t) = \begin{bmatrix} \mathbf{u}(t) \\ \dot{\mathbf{u}}(t) \\ \ddot{\mathbf{u}}(t) \end{bmatrix} = \begin{bmatrix} \mathbf{I} & [\Delta t] & \left[\frac{1}{2}\Delta t^2\right] \\ \mathbf{0} & \mathbf{I} & [\Delta t] \\ \mathbf{0} & \mathbf{0} & \mathbf{I} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{u}(t-\Delta t) \\ \dot{\mathbf{u}}(t-\Delta t) \\ \ddot{\mathbf{u}}(t-\Delta t) \end{bmatrix}$$

to predict from a present state $\mathbf{u}(t-\Delta t)$ the future critical state.

$\mathbf{u}(t) = \mathbf{u}_{krit}$ provides the early warning time Δt .

GOCA-Sensordata-Modeling
Geodetic Geomonitoring
Chain Link 3
„Reporting“
and
Chain Link 4
„Alarmmanagement

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Reporting as Chain-Link 3

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Modeling as Chain-Link 2

- **Numerical Results of GOCA - Displacment-Estimation**

```
Ergebnis der Verschiebungsschätzung:
Zeit =  26.06.2003 00:59:00       Rechts                =  -0.0007
                                  TRechts               =      1.3
                                  Kritischer Wert       =      3.3
                                  Genauigkeit           =  0.00055
                                  Konfidenzbereich      =  0.00183
                                  Sensitivitätsbereich=    0.00255
Zeit =  26.06.2003 00:59:00       Hoch                  =  -0.0011
                                  THoch                 =      1.3
                                  Kritischer Wert       =      3.3
                                  Genauigkeit           =  0.00080
                                  Konfidenzbereich      =  0.00265
                                  Sensitivitätsbereich=    0.00368
Zeit =  26.06.2003 00:59:00       Hoehe                 =  -0.0048
                                  THoehe                =      3.7
                                  Kritischer Wert       =      3.3
                                  Genauigkeit           =  0.00130
                                  Konfidenzbereich      =  0.00433
                                  Sensitivitätsbereich=    0.00601
                              *** signifikant
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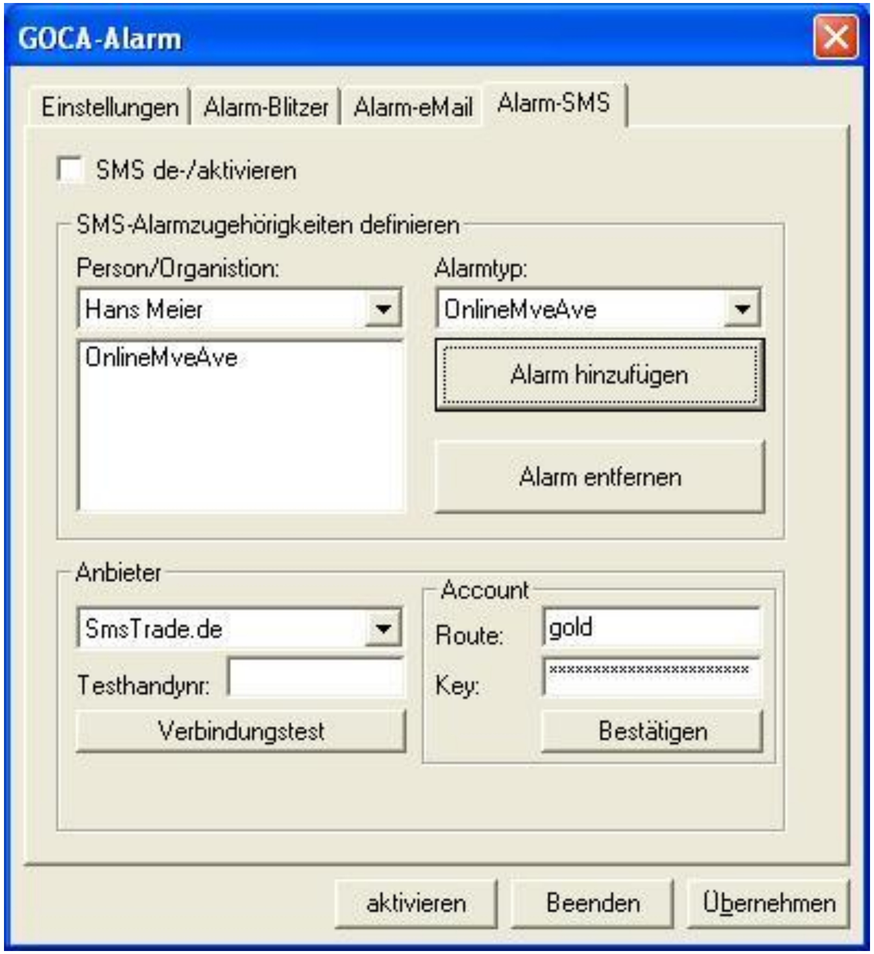
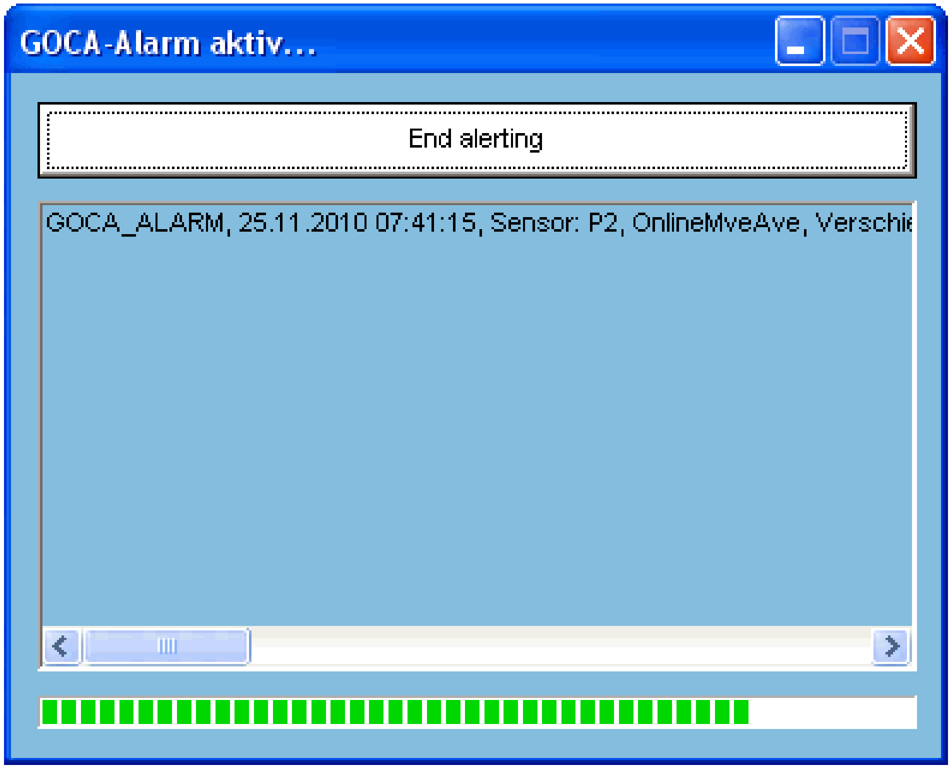
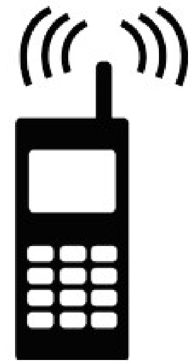
GOCA = GNSS/LPS based Online Control and Alarm System
Geodetic Monitoring - Alarmmanagement as Chain-Link 4

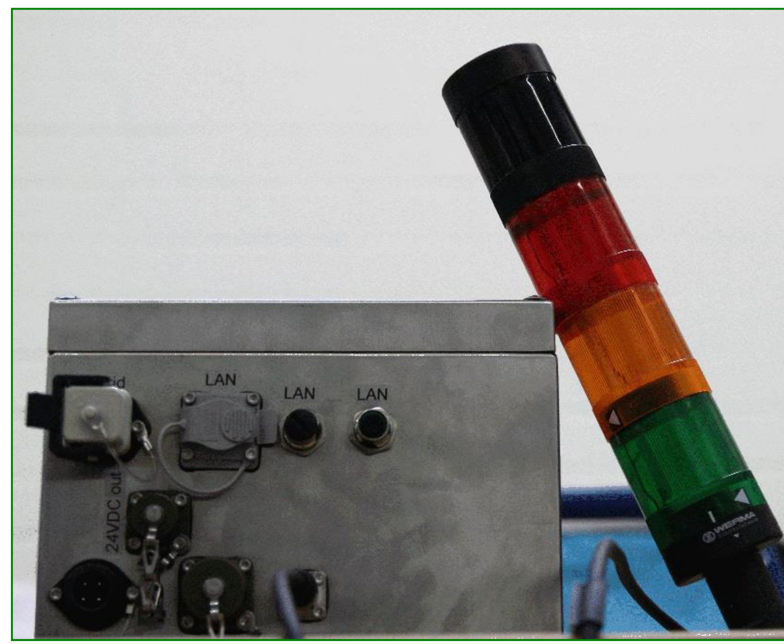


GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - Alarmmanagement as Chain-Link 4

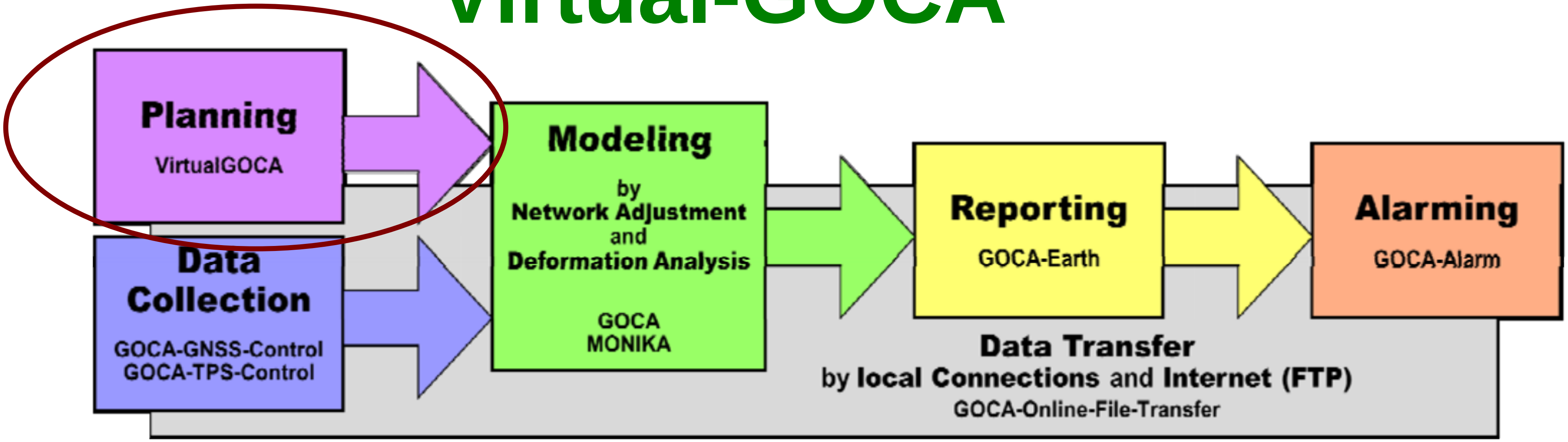


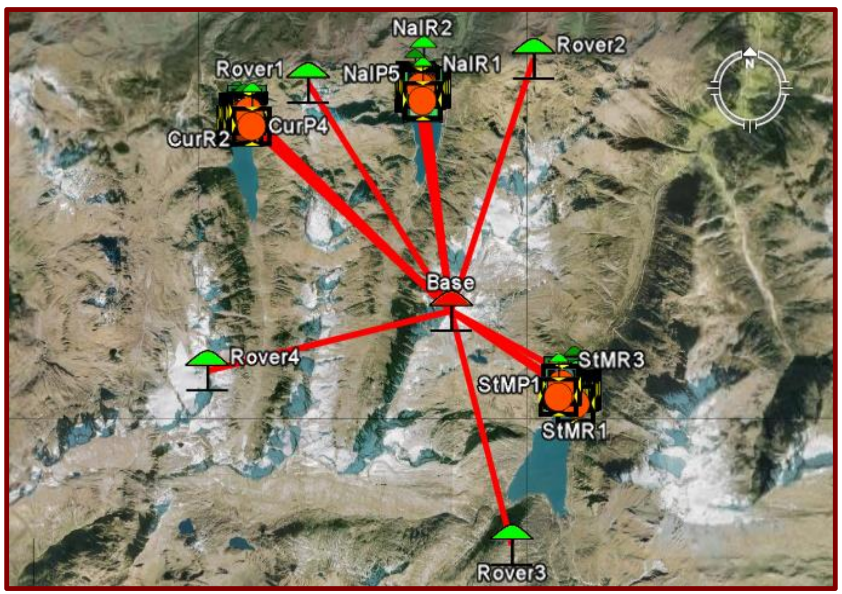




GOCA = GNSS/LPS based Online Control and Alarm System

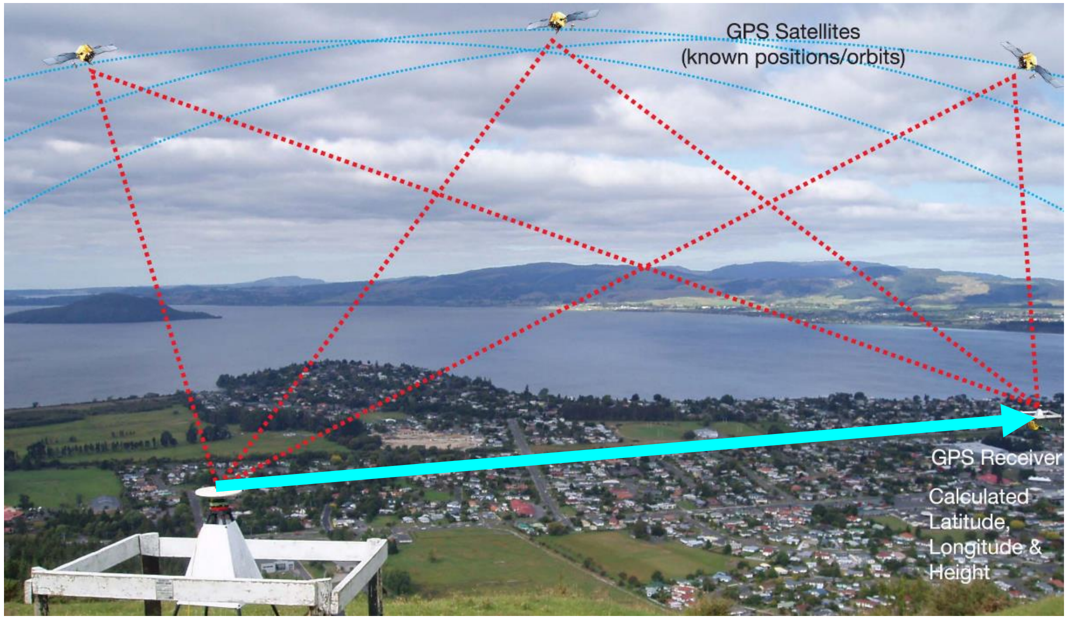
Virtual-GOCA





VirtualGOCA – Sensordata-Generation

3D-Integrated Geodesy



GNSS-Baselines

$$\mathbf{b} = \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \mathbf{x}_{Rover} - \mathbf{x}_{Base}$$

Stochastic Model – Covariane-Matrix of Baselinevectors b

$$\mathbf{C_b} = \mathbf{F} \cdot \begin{pmatrix} (\sigma_N/(M+h))^2 & 0 & 0 \\ 0 & (\sigma_E/((N+h)\cdot\cos B)^2 & 0 \\ 0 & 0 & \sigma_h^2 \end{pmatrix} \cdot \mathbf{F}^T$$

$$\mathbf{F} = \begin{bmatrix} -(M+h)\cdot\sin B\cdot\cos L & -(N+h)\cdot\cos B\cdot\sin L & \cos B\cdot\cos L \\ -(M+h)\cdot\sin B\cdot\sin L & (N+h)\cdot\cos B\cdot\cos L & \cos B\cdot\sin L \\ (M+h)\cdot\cos B & 0 & \sin B \end{bmatrix}$$

VirtualGOCA – Sensordata-Generation

3D-Integrated Geodesy

$$\mathbf{l}_{ij}^{LAV,i} = \mathbf{D}_i(\varphi_i,\lambda_i)\cdot\begin{bmatrix}\Delta x\\ \Delta y\\ \Delta z\end{bmatrix}_{ij}^{ECEF} + \begin{bmatrix}0\\ 0\\ -i\end{bmatrix}^{LAV,i} + \mathbf{D}_i(\varphi_i,\lambda_i)\cdot\mathbf{D}_j(\varphi_j,\lambda_j)^T\cdot\begin{bmatrix}0\\ 0\\ t\end{bmatrix}^{LAV,j}$$

$$\mathbf{l}_{ij}^{LAV,i} = \begin{bmatrix}\Delta u\\ \Delta v\\ \Delta w\end{bmatrix}_{ij}^{LAV,i}$$

TPS Total-stationen

$$s_{ij} = \sqrt{\Delta u^2 + \Delta v^2 + \Delta w^2}$$

Strecke

$$r_{ij} = \arctan\left(\frac{\Delta v}{\Delta u}\right) - o_i$$

Richtung

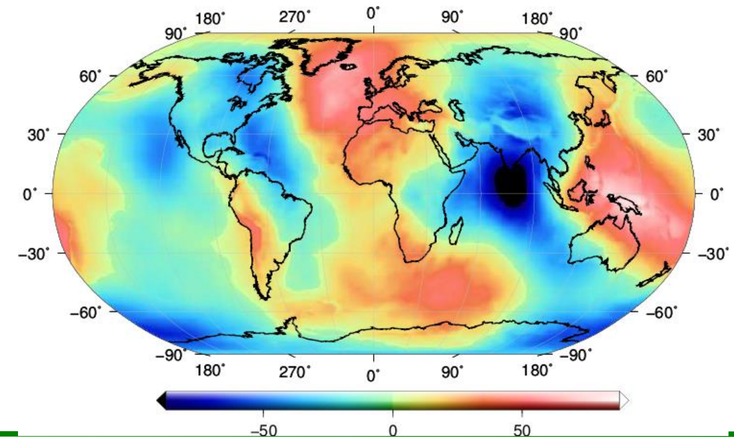
$$z_{ij} = \arctan\left(\frac{\sqrt{\Delta u^2 + \Delta v^2}}{-\Delta w}\right) - \frac{s_{ij}}{2R}\cdot k$$

Zenitdistanz

$$\mathbf{D}_e^{LAV} = \begin{bmatrix}-\cos\lambda\cdot\sin\varphi & -\sin\lambda\cdot\sin\varphi & \cos\varphi\\ -\sin\lambda & +\cos\lambda & 0\\ \cos\lambda\cdot\cos\varphi & \sin\lambda\cdot\cos\varphi & \sin\varphi\end{bmatrix}$$

Geopotenzial-Modell W (C_{nm}; S_{nm})

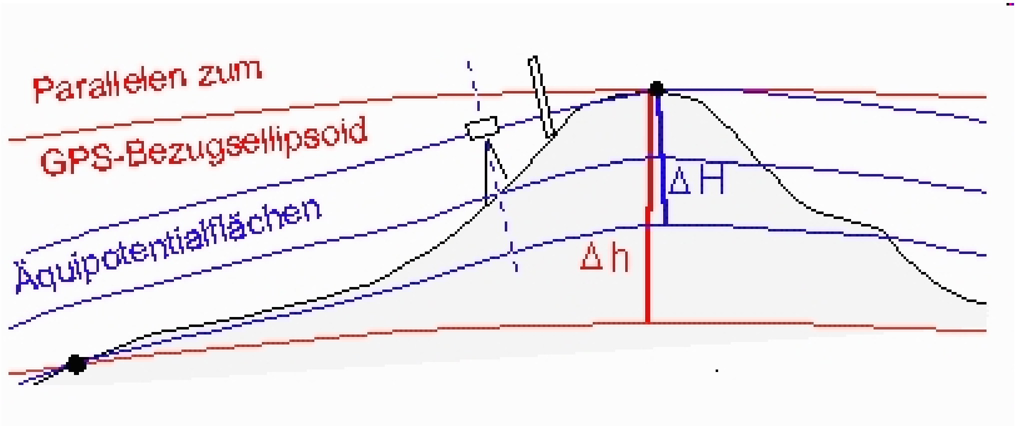
$$\varphi = \arctan\frac{-W_z}{\sqrt{W_x^2 + W_y^2}} \qquad \lambda = \arctan\left(\frac{W_y}{W_x}\right)$$

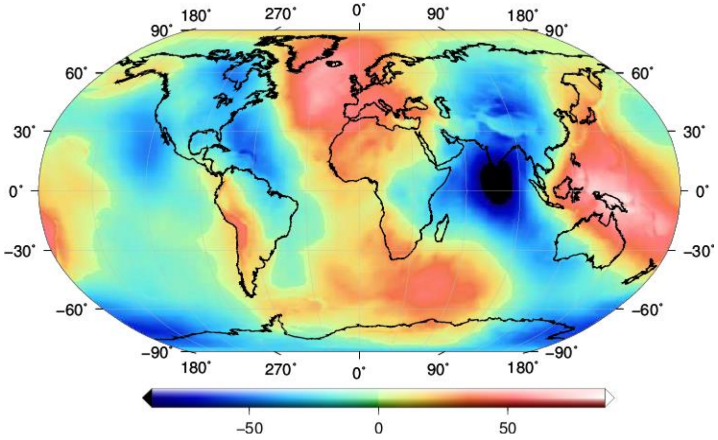


VirtualGOCA – Sensordata-Generation

3D-Integrated Geodesy

Hydrostatic Levels
and
Automatic Levels





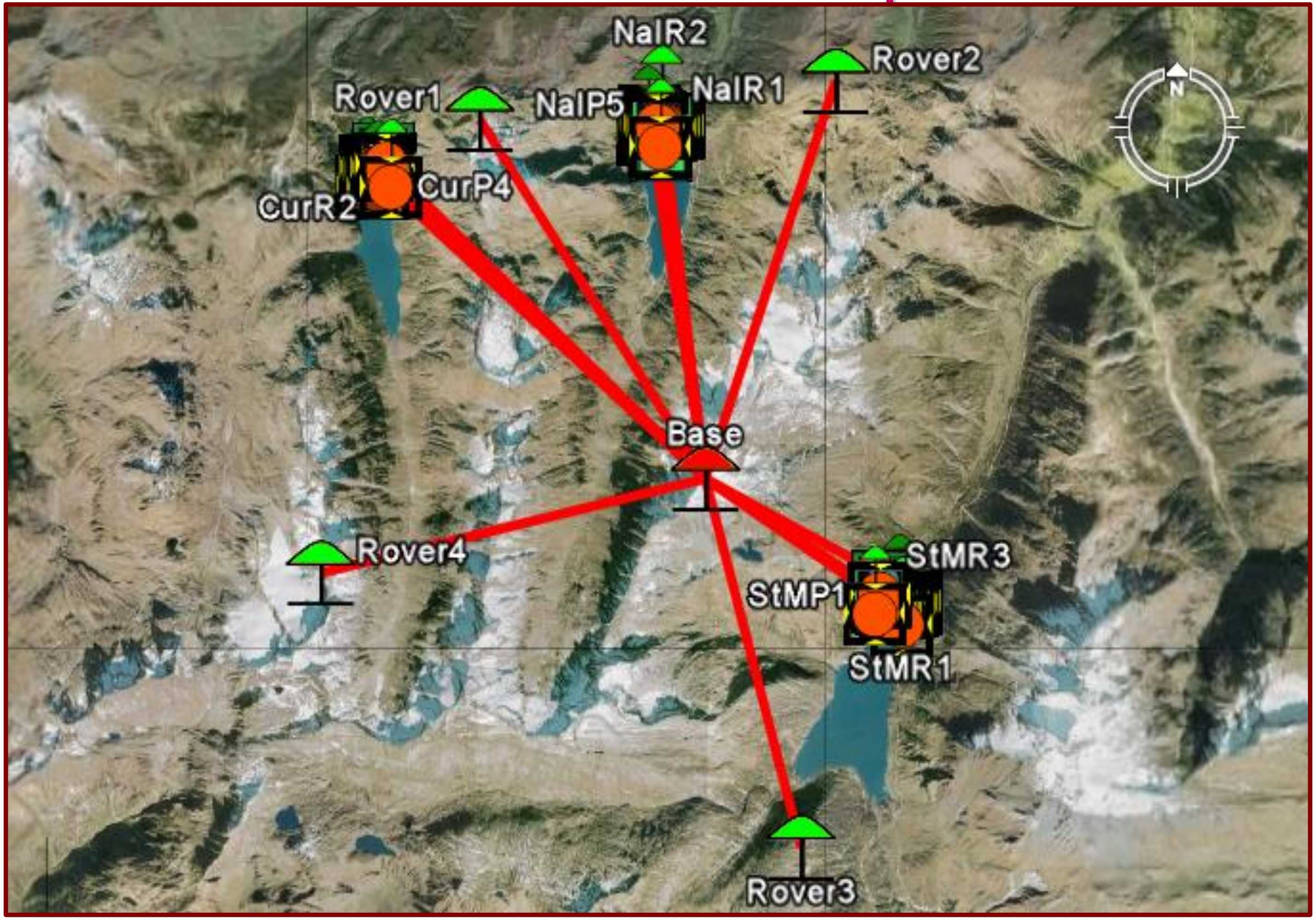
Geopotential-Model W (C_{nm}; S_{nm})

$$\Delta H_{ij} = H_j - H_i = (h_j - N_j) - (h_i - N_i) = (h_j - \left(\frac{(W-U)_P}{\gamma_Q}\right)_j) - (h_i - \left(\frac{(W-U)_P}{\gamma_Q}\right)_i)$$

Quasigeoid-Theory of Molodenski

VirtualGOCA – Planing of Deformationscenarios

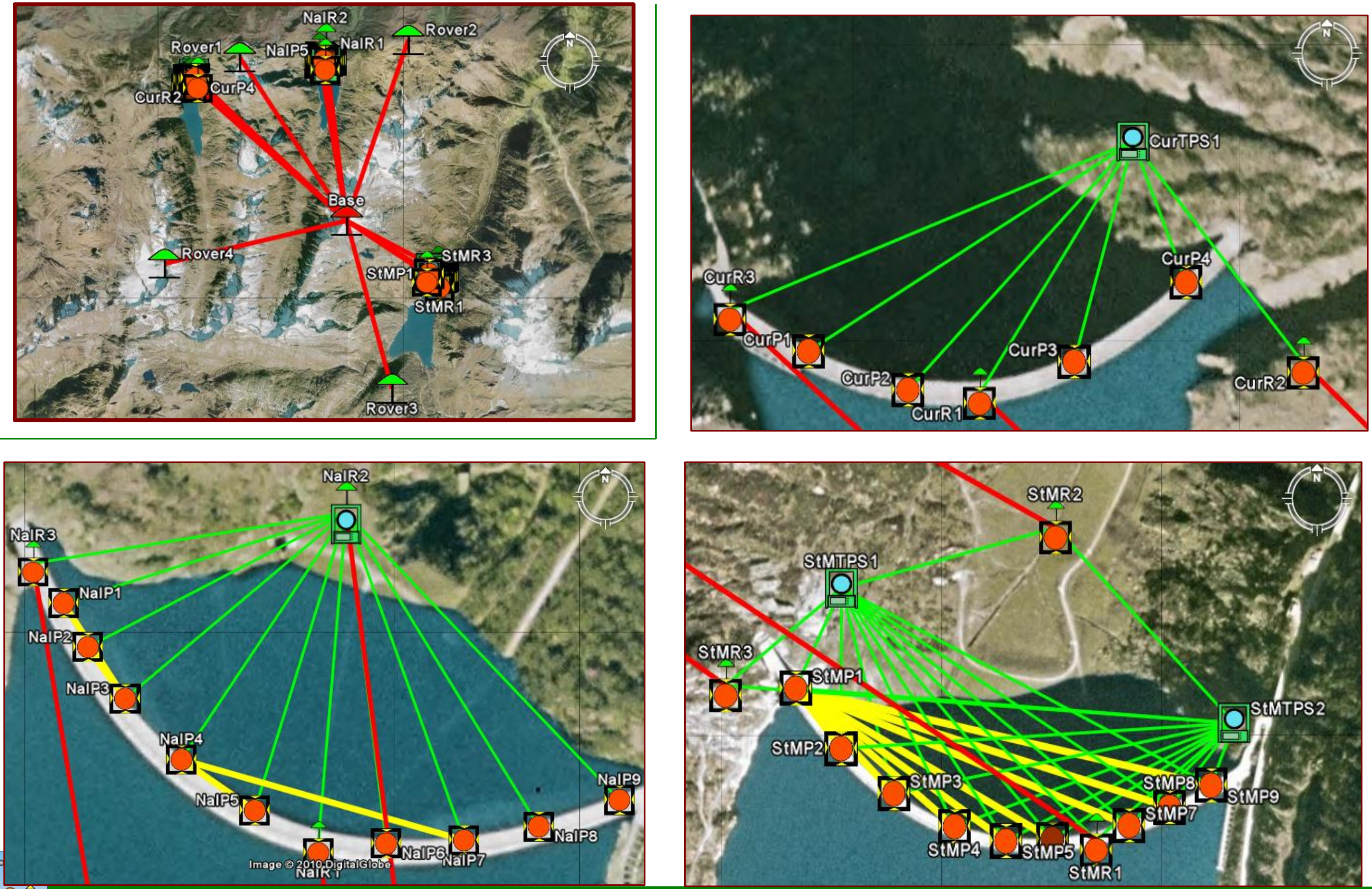
Virtual GOCA-Software Example



GNSS/LPS Geomonitoring-Networ „Gotthard-Tunnel Massiv“ with Hydropower-Lakes Curnera (left), Nalps (top) and Santa Maria (right)

VirtualGOCA – Sensor-Data Generation

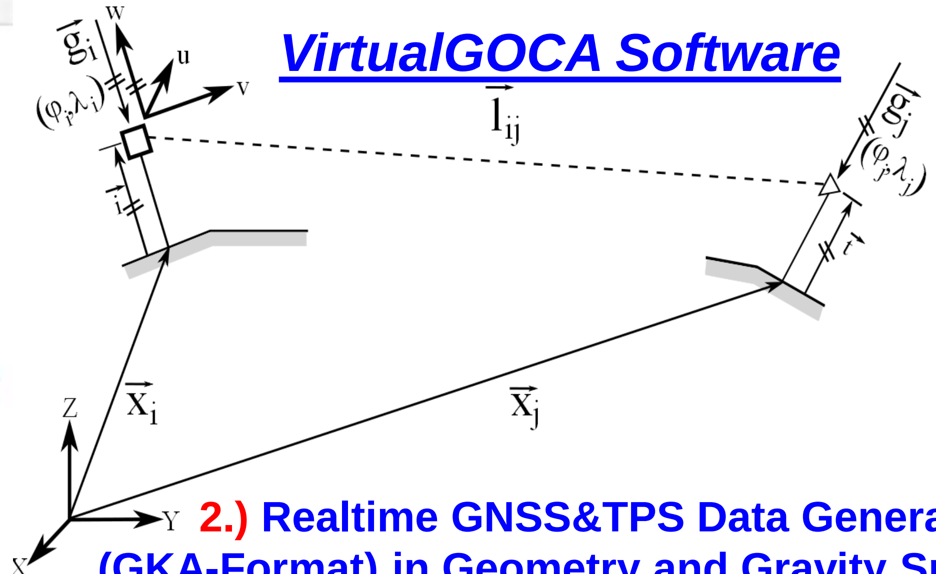
Virtual GOCA-Software Example - Sensordesign



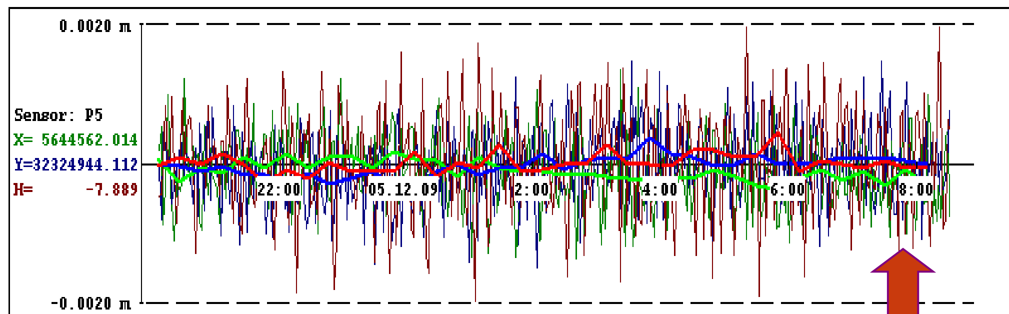
VirtualGOCA – Sensor-Data Generation

VirtualGOCA Software

1.) Virtual Monitoring Array Generation and Visualisation using GoogleEarth®



2.) Realtime GNSS&TPS Data Generation (GKA-Format) in Geometry and Gravity Space

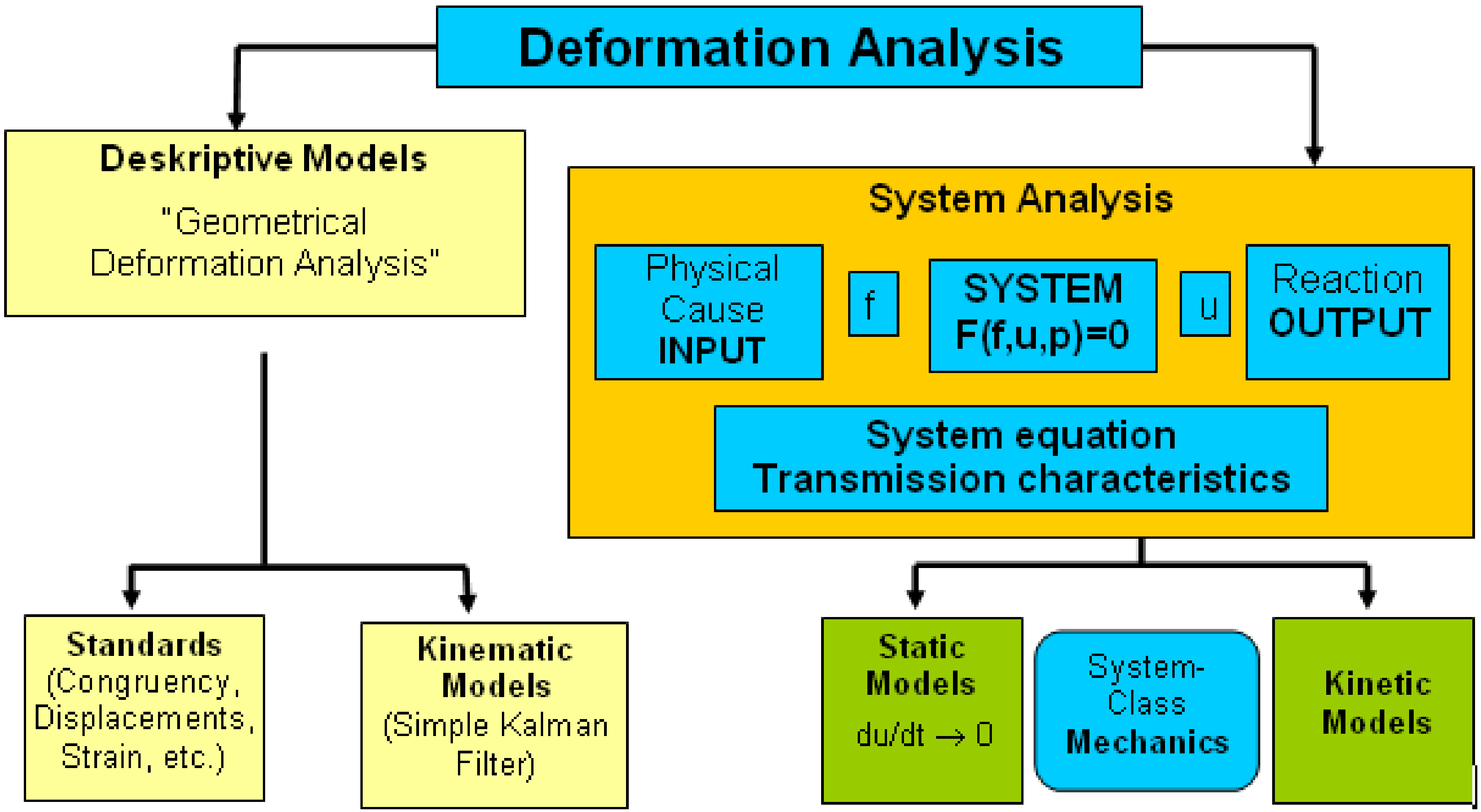


3.) GKA- Data Processing & Analysis‘ with GOCA-Software: Array Design Planing, Accuracy & Sensitivity Analysis! A priori Quality Assurance for Monitoring Concepts and Arrays! Efficient Monitoring Software Development & Evaluation! No costs for Physical Test Arrays. SW Benchmarktest! ...)

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis

Geodetic Monitoring – Interdisciplinary Contributions



Jäger/Kälber, 2001

Integrated Deformation-Analysis

„Virtual Sensor Models“

„Complex Deformation Models“

(old name)

„Parameter-Integration“ !

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T \Longrightarrow [\mathbf{f}(t) \text{ or } \mathbf{p}(t)]$$

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - GOCA-Virtual-Sensor Modeling

General observation input l(t) for virtual sensors

$$"\mathbf{l}(t)" =: [\mathbf{x}(t), \mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T$$ and covariance matrix $\mathbf{C}_l$

= Basic state vector and stochastical model of a geodetic monitoring

1.) "Virtual Sensor" / Complex Deformation Model as Forward Computation

$$f = f(l(t))$$ - n-dimensional function, with

$$F = [\ldots\ldots \frac{\partial f_i}{\partial l_j} \ldots] \text{ and } \mathbf{C}_f = \mathbf{F} \cdot \mathbf{C}_l \cdot \mathbf{F}^T$$

Significance test for the **f** based on the following n-dimensional Fisher test

$$T = \frac{(\mathbf{f} - E(\mathbf{f}))^T \cdot \mathbf{C}_f^{-1} (\mathbf{f} - (E(\mathbf{f}))}{n} \sim F_{n,\infty} \overset{?}{\leq} c(\alpha)$$

2.) "Virtual Sensor" as parameter- estimation with parameters p

Functional model: $\mathbf{l}(t) + \mathbf{v} = \mathbf{l}(\hat{\mathbf{p}})$

Stochastical model: $\mathbf{C}_l$

GOCA

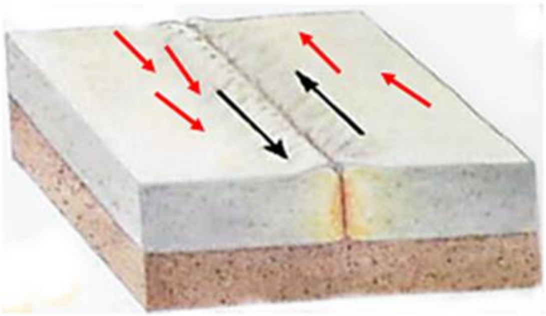
„Virtual Sensor Models"

(„Complex Deformation Modeling")

GOCA = GNSS/LPS based Online Control and Alarm System

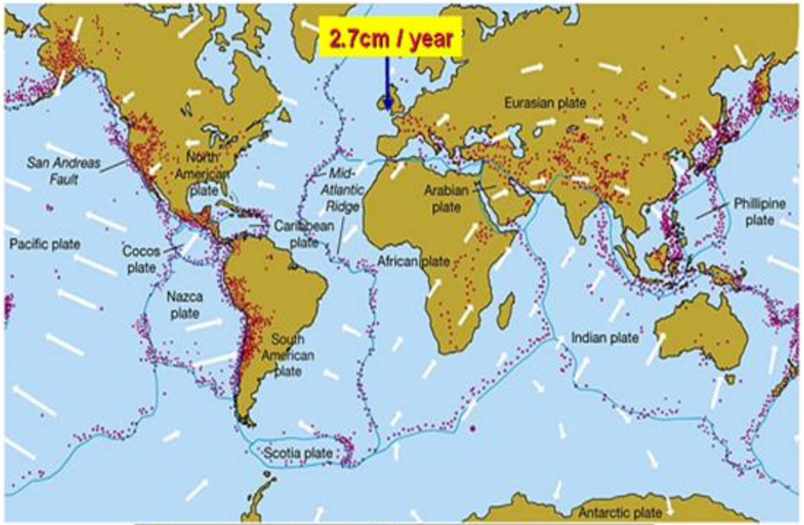
Geodetic Monitoring - GOCA-Virtual-Sensor Modeling

Fault- Modeling



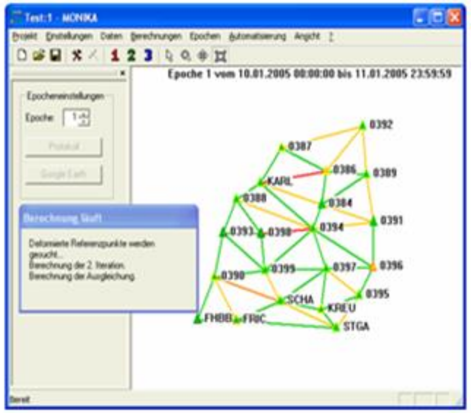
Torsion Modeling

Geophysical Models of Datum-drift and Plate-Movement Rates



$$x(t_1)_{ITRF\,zz,t_1} = (1+\Delta m)\cdot \mathbf{R}(\varepsilon_x,\varepsilon_y,\varepsilon_z)\cdot \mathbf{x}(t_1)_{ITRFyy,t_1} + \mathbf{t}$$

$$\mathbf{x}(t_2)_{ITRFzz,t_2} = \mathbf{x}(t_1)_{ITRFzz,t_1} + \left(\left((\dot{\mathbf{R}} + \Delta\dot{m})\cdot \mathbf{x}(t_1)_{ITRFzz,t_1} + \dot{\mathbf{t}}\right) + \left(\dot{\mathbf{R}}_{P(j)}\cdot \mathbf{x}(t_1)_{ITRFzz,t_1}\right)\right)\cdot (t_2 - t_1)$$



Geodynamic Modeling

www.monika.ag

GOCA = GNSS/LPS based Online Control and Alarm System

Geodetic Monitoring - GOCA-Virtual-Sensor Modeling

GOCA

„Virtual Sensor Models“

e.g.

Subsidence

Surfaces

GOCA

Kremlin

Project

Projekt: Monitoring des Moskauer Kreml

Das "Geodätische Monitoring des Moskauer Kreml" ist ein gemeinsames Projekt des am **Institut für Angewandte Forschung (IAF)** der Hochschule Karlsruhe (HSKA) angesiedelten **GOCA-Projekts**, des **Instituts für Geodynamik** der Moscow State University of Cartography and Geodesy (MIIGAIK) und der Moskauer Firma GfK. Mit der GOCA-Software und dem im Rahmen einer Masterthesis entwickelten Modul GOCA-Virtual-Sensor erfolgte die Deformationsanalyse und Visualisierung der bis in die jüngere Zeit hineinreichenden historischen Nivellementdaten unter Ermittlung des zeitlichen Verlaufs von Höhenänderungen. Künftig wird die Zustandsschätzung der historischen Gebäude und Anlagen des Moskauer Kreml unter Einsatz der GOCA-Software in einem zusammenhängenden auf externe Referenzpunkte gestützten dreidimensionalen hybriden Sensornetz (GNSS, LPS, Schlauchwaagen etc.) automatisiert erfolgen.

Softwaretechnologie GOCA-Virtual-Sensor

GOCA-Virtual-Sensor greift über eine offene Schnittstelle auf die in jeweils zusammenhängenden Referenzkoordinatensystemen und auf der Basis von geodätischen Netzausgleichungen ermittelten Verschiebungszustände der Geomonitoringpakete GOCA (www.goca.info) und MONIKA (www.monika.ag) zu, (siehe Abb. unten).

Virtuelle Sensoren sind Algorithmen, die nicht oder schwer messbare Größen unter Verwendung von Messwerten realer Sensoren in Verbindung mit unterschiedlichen numerischen Modellen ableiten.

Ziel der Softwareentwicklung von GOCA-Virtual-Sensor ist, einen Katalog für virtuelle Sensoren mit dem Schwerpunkt auf geometrische Modelle in den Fachschalen Geodynamik, lokale Geotechnik und Bautechnik zu erstellen. Dieser Katalog ist bis hin zu Systemanalyse basierten Ansätzen (z.B. FEM) beliebig erweiterbar. Auf der Grundlage des entwickelten Modellkataloges bildet das Softwaremodul GOCA-Virtual-Sensor die Basis für die Realisierung virtueller Sensoren im geodätischen Monitoring. Im vorliegendem Projekt „Monitoring des Moskauer Kreml" werden die gemessenen Nivellementdaten nach der netzausgleichungsbasierten

II. Deformationsanalyse mit GOCA

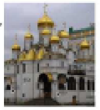
Der virtuelle Sensor zur Berechnung von Setzungen bzw. Hebungen kann typischerweise im Bereich der Bergschadenskunde auf Grund von Bergbautätigkeiten oder auch zur Bauwerksüberwachung, wie im Projekt "Monitoring des Moskauer Kreml", eingesetzt werden.

Im vorliegenden Projekt handelt es sich ausschließlich um Nivellementdaten, die in Präzisionsnivellements in der Zeitspanne von 1936 bis 1998 beobachtet wurden. Die Auswertung mit der GOCA-Software liefert in den GOCA-Ausgleichungsstufen I und II die in einem einheitlichen Referenzkoordinatensystem georeferenzierten Objektpunktpositionen (FIN-Daten). Diese können in der simultan zur Monitoring-Stufe II laufenden GOCA Stufe III weiteren Deformationsanalyse-Zustandsschätzungen (Moving-Average, Verschiebungsschätzung, Kalmanfilterung) unterzogen werden, oder über die FIN-Schnittstelle online oder postprocessed mit GOCA-Virtual-Sensor weiter analysiert werden. Als Gegenstand dieser Posterpräsentation wurde die Analyse auf zwei repräsentative historische Gebäude des Kremls beschränkt. Nachfolgend sind zunächst die Ergebnisse von GOCA dargestellt.

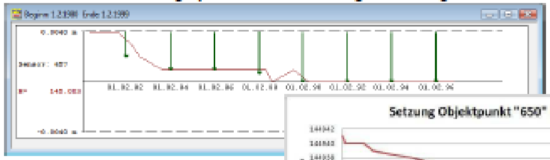
Moskauer Kreml – Übersichtskarte

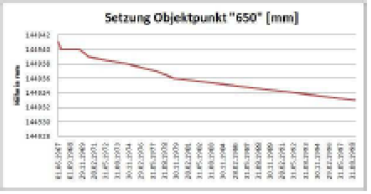
Gebäude 1 - Zarenglocke

Gebäude 2 – Mariä-Verkündigungs-Kathedrale



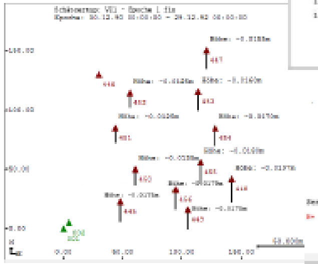
Gebäude 2 - Zeitreihengraphik mit Verschiebungsschätzung



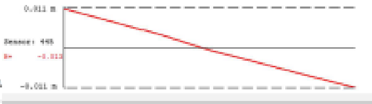


Gebäude 2 - Setzungsverhalten 1967-1998

Gebäude 1 - Bauwerksgraphik mit Verschiebungsschätzung



Gebäude 1 - Kalmanfilterung 1981-1998



Integrated Deformation-Analysis
System Analysis
Structural Health Monitoring

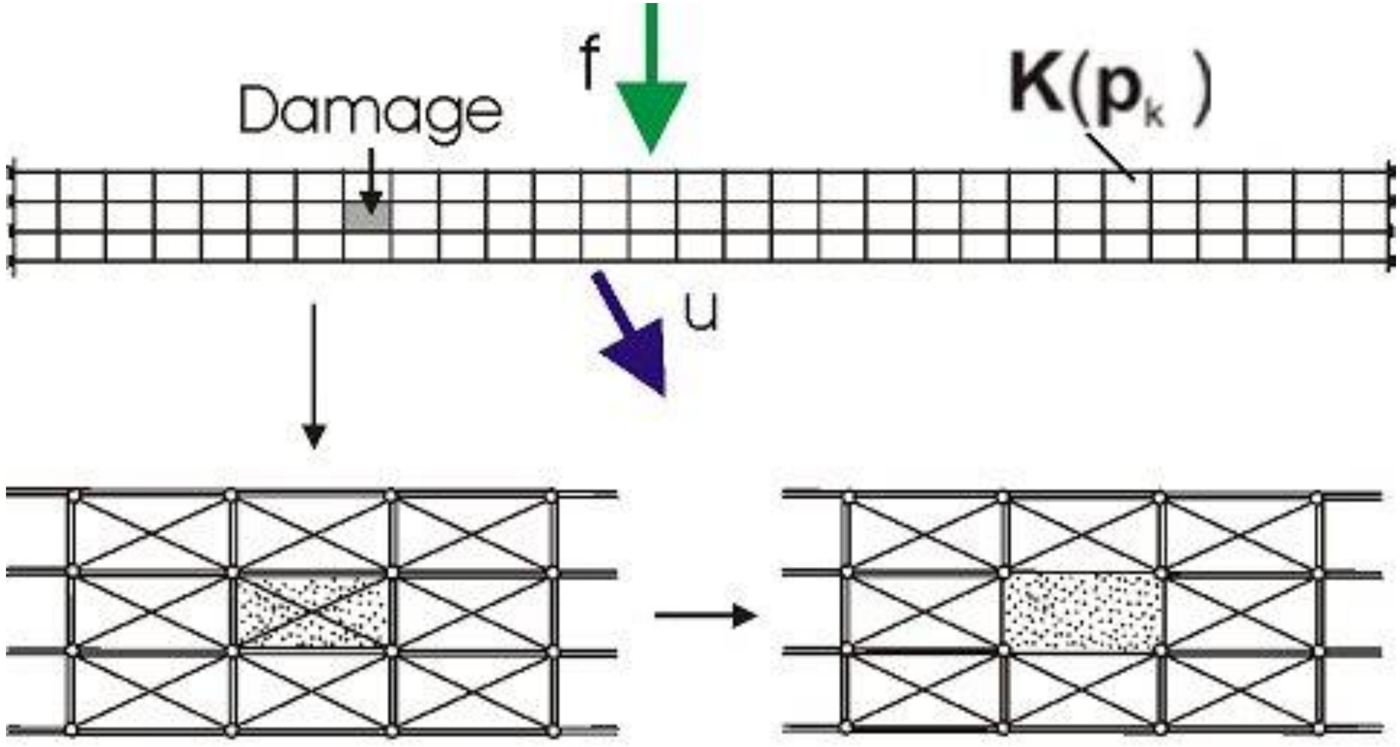
Physical Parameter Integration

Theory

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Static FEM Approach

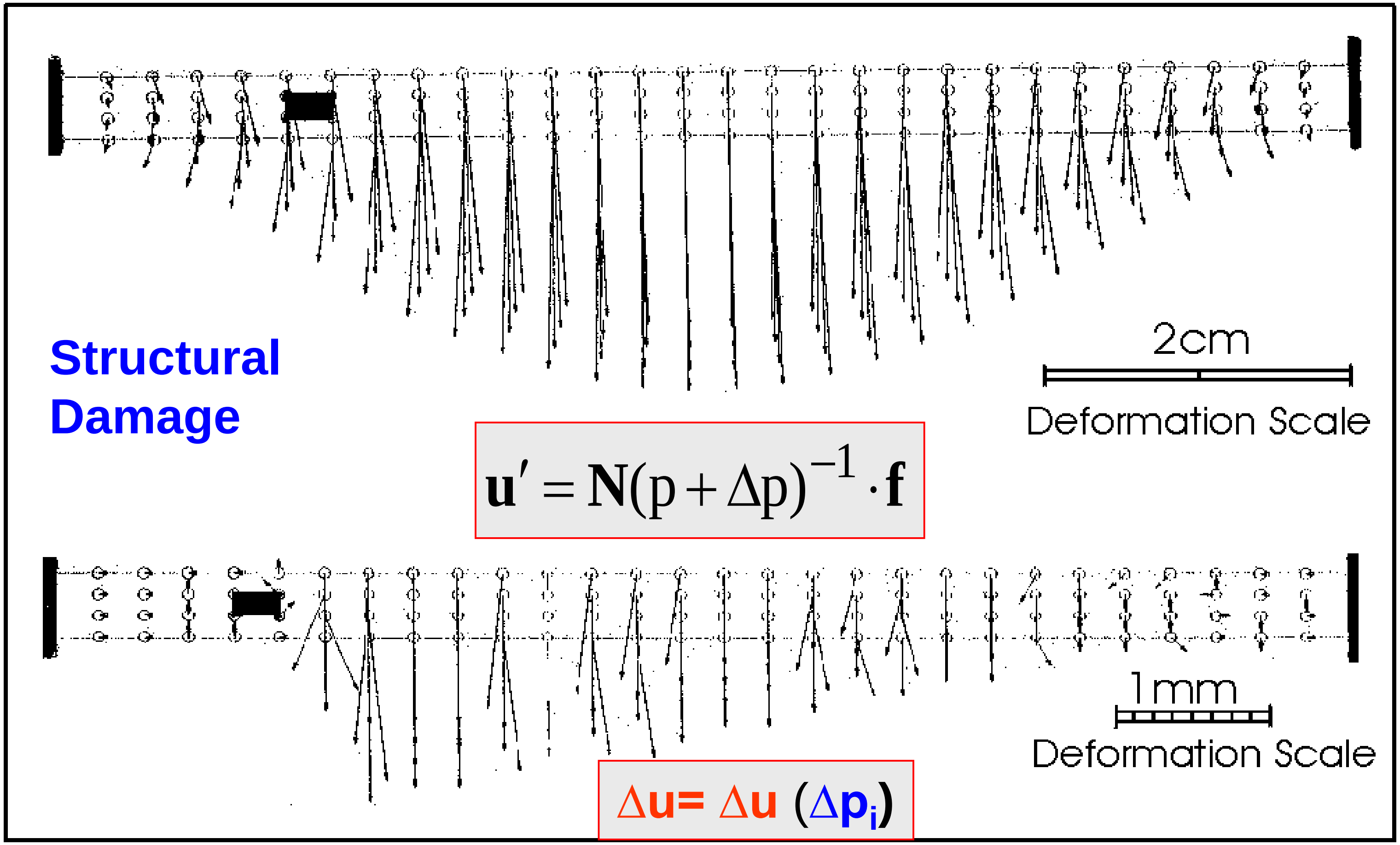
$$\mathbf{u}_{FEM} = \mathbf{K}(\mathbf{p}_k)^{-1} \cdot \mathbf{f}$$



$$\mathbf{u}(\Delta\mathbf{p}_k)_{geod} = \mathbf{u}_{FEM} - \mathbf{K}(\mathbf{p}_k)^{-1} \cdot d\mathbf{K}(\Delta\mathbf{p}_k)) \cdot \mathbf{K}(\mathbf{p}_k)^{-1} \cdot \mathbf{f} = (\mathbf{I} - \mathbf{K}(\mathbf{p}_k)^{-1} \cdot d\mathbf{K}(\Delta\mathbf{p}_k)) \cdot \mathbf{K}(\mathbf{p}_k)^{-1} \cdot \mathbf{f}$$

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Static FEM Approach



$$\mathbf{u}' = \mathbf{N}(\mathrm{p} + \Delta \mathrm{p})^{-1} \cdot \mathbf{f}$$

$$\Delta \mathbf{u} = \Delta \mathbf{u}\ (\Delta \mathbf{p}_i)$$

NETZ2D (GIK)
Mechanical Analogies

Max. Change Δu : 1mm = 5% of u
Relative Change: up to 20% of u

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Static FEM Approach

System-Equations

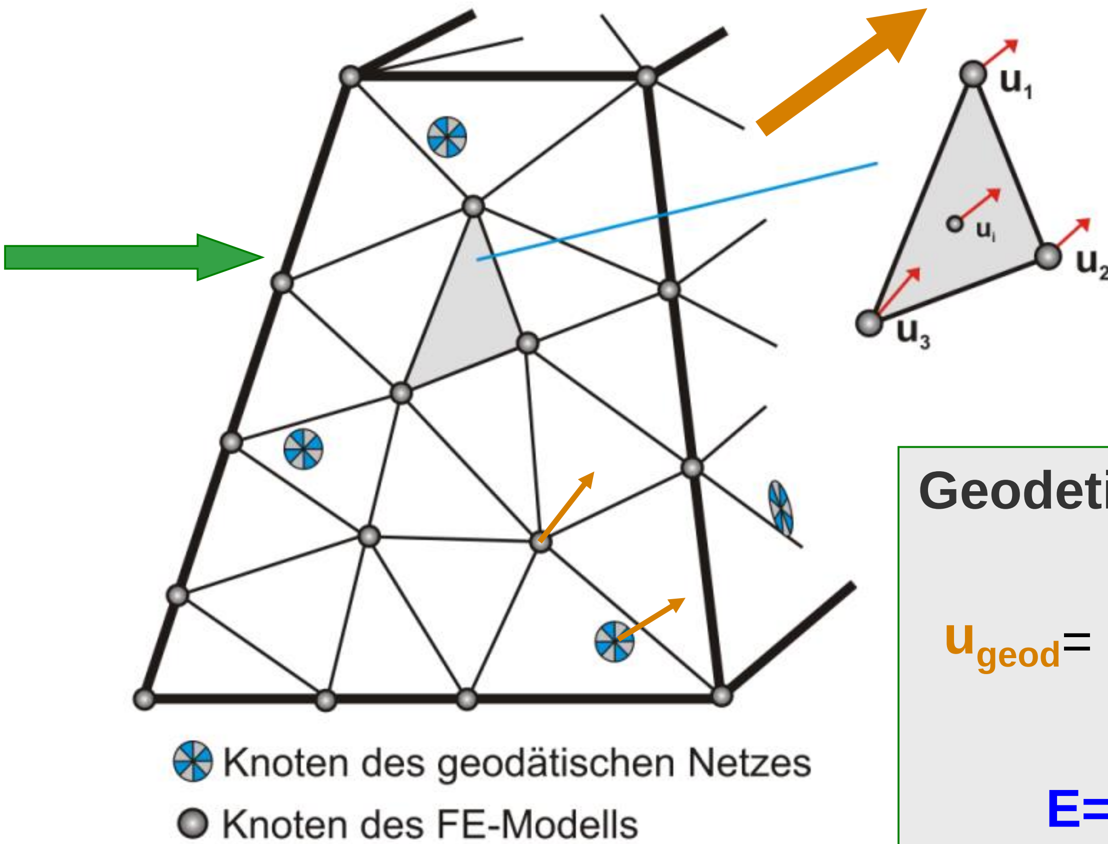
$$K \cdot u = f$$

$$K(p,\Delta p)$$

Stiffness Matrix

p = Material Parameters

Δp= Changes (Damage, Fissure)



FEM-Elements

$$\mathbf{u}_{\mathbf{i},\mathrm{E}} = \mathbf{N}_{\mathbf{E}} \cdot \begin{pmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{u}_3 \end{pmatrix} = \mathbf{N}_{\mathbf{E}} \cdot \mathbf{u}_{\mathrm{E-Nodes}}$$

N_E=Shape-Functions

Geodetic Displacements u_{geod}

$$u_{geod} = \mathbf{N}_{\mathbf{E}}(\mathbf{x}_{\mathrm{geod}}) \cdot \begin{pmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{u}_3 \end{pmatrix} = \mathbf{N}_{\mathbf{E}}(\mathbf{x}_{\mathrm{geod}}) \cdot \mathbf{E} \cdot \mathbf{u}$$

E= (0,1)-Matrix => Geod. Design (FOD)

GOCA = GNSS/LPS based Online Control and Alarm System

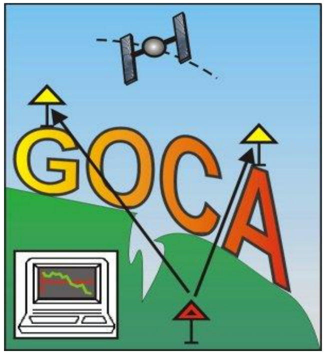
Integrated Deformation-Analysis – Static FEM Approach

FEM- / System- Parts (Static) & *Parameter-Integration*

$$\mathbf{0}_{sys} + \mathbf{v}_{sys} = \hat{\mathbf{u}} - \mathbf{K}(\hat{\mathbf{p}}_k, \Delta\hat{\mathbf{p}})^{-1} \cdot \hat{\mathbf{f}} \quad \text{and} \quad \mathbf{C}_{sys} \Rightarrow \mathbf{0}$$

$$\mathbf{p}_k + \mathbf{v}_p = \hat{\mathbf{p}}_k \quad \text{und} \quad \mathbf{C}_{p_k}$$

$$\mathbf{f} + \mathbf{v}_f = \hat{\mathbf{f}} \quad \text{und} \quad \mathbf{C}_f$$



Geod. Monitoring & Network Adjustment

$$\mathbf{u}_{geod} + \mathbf{v}_{geod} = \mathbf{N}_E \cdot \mathbf{E}_{geod}\, \hat{\mathbf{u}} \quad \text{and} \quad \mathbf{C}_{u,geod}$$

Sensor-Integration

$$\mathbf{l}_{geom} + \mathbf{v}_{geom} = \mathbf{l}_{geom}(\mathbf{N}_E, \mathbf{E}_{geom}, \hat{\mathbf{u}}) \quad \text{and} \quad \mathbf{C}_{geom}$$

Local Extensiometers, Strain

$$\boldsymbol{\varepsilon} = \mathbf{L} \cdot \mathbf{N}_E \cdot \mathbf{E}_{geom} \cdot \hat{\mathbf{u}}$$

$$\mathbf{l}_{phys} + \mathbf{v}_{phys} = \mathbf{l}_{phys}(\mathbf{N}_E, \mathbf{E}_{phys}, \hat{\mathbf{u}}, \hat{\mathbf{p}}_k, \Delta\hat{\mathbf{p}}) \quad \text{and} \quad \mathbf{C}_{phys}$$

Local pressure, stress

$$\boldsymbol{\sigma} = \mathbf{D}(\mathbf{p}_k) \cdot \mathbf{L} \cdot \mathbf{N}_E \cdot \mathbf{E}_{phys} \cdot \hat{\mathbf{u}}$$

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Dynamics FEM Approach

General Vibration of a Structure in FEM Dynamics

$$\mathbf{K}(\mathbf{p}_K)\cdot\mathbf{u}(t)+\mathbf{C}(\mathbf{p}_C)\cdot\dot{\mathbf{u}}(t)+\mathbf{M}(\mathbf{p}_M)\cdot\ddot{\mathbf{u}}(t)=\mathbf{f}(t)$$

Eigenvibration of Structures in FEM Dynamics

$$\mathbf{K}(\mathbf{p}_K)\cdot\mathbf{u}(t)+\mathbf{C}(\mathbf{p}_C)\cdot\dot{\mathbf{u}}(t)+\mathbf{M}(\mathbf{p}_M)\cdot\ddot{\mathbf{u}}(t)=\mathbf{0}$$

$K(p_K)$ = Parametrized Stiffnessmatrix
$C(p_C)$ = Parametrized Damping-Matrix
$M(p_M)$ = Parametrized Mass-Matrix
$f(t)$ = External Nodal Point Force

Research Topic in „System Analysis“ or „Integrated Deformation Analysis“

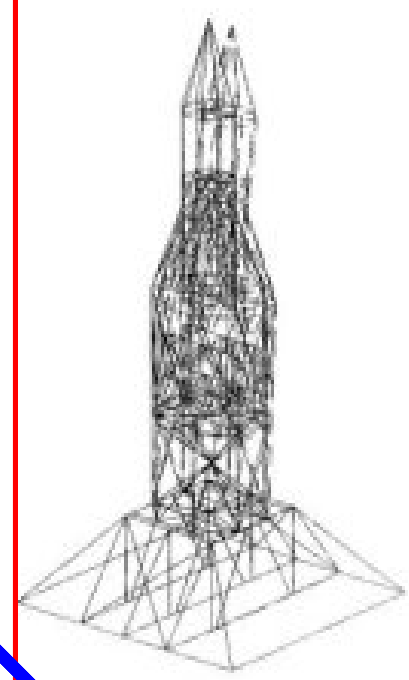
GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Dynamics FEM Approach

<u>State Vector:</u> ***Displacements + Velocities + Accelerations***

Descriptive Modelling – Simple Kalman-Filter

$$\begin{bmatrix} u_O(t+\Delta t)\\ \dot{u}_O(t+\Delta t)\\ \ddot{u}_O(t+\Delta t)\end{bmatrix} = \begin{bmatrix} I & [\Delta t] & \left[\frac{1}{2}\Delta t^2\right] \\ 0 & I & [\Delta t] \\ 0 & 0 & I\end{bmatrix}\cdot \begin{bmatrix} u_O(t)\\ \dot{u}_O(t) \\ \ddot{u}_O(t)\end{bmatrix}$$



Systemanalysis-Modell – Extended Kalman- Filter

for Eigenvibrations:

$$\begin{bmatrix} u_O(t+\Delta t)\\ \dot{u}_O(t+\Delta t)\\ \ddot{u}_O(t+\Delta t)\end{bmatrix} = \begin{bmatrix} I & [\Delta t] & \left[\frac{1}{2}\Delta t^2\right] \\ 0 & I & [\Delta t] \\ 0 & [-M(p_M)^{-1}\cdot K(p_K)\cdot\Delta t] & [I - M(p_M)^{-1}\cdot C(p_C)\cdot\Delta t]\end{bmatrix}\cdot \begin{bmatrix} u_O(k)\\ \dot{u}_O(k) \\ \ddot{u}_O(k)\end{bmatrix}$$

Research Topic in „System Analysis“ or „Integrated Deformation Analysis“

GOCA = GNSS/LPS based Online Control and Alarm System
Integrated Deformation-Analysis – Dynamics FEM Approach

Eigenvibration of Structure in FEM Dynamics

$$\mathbf{K}(\mathbf{p}_K)\cdot\mathbf{u}(t)+\mathbf{C}(\mathbf{p}_C)\cdot\dot{\mathbf{u}}(t)+\mathbf{M}(\mathbf{p}_M)\cdot\ddot{\mathbf{u}}(t)=\mathbf{0}$$

Undamped Eigenvibration of a Structure

$$\mathbf{K}(\mathbf{p}_K)\cdot\mathbf{u}(t)+\mathbf{M}(\mathbf{p}_M)\cdot\ddot{\mathbf{u}}(t)=\mathbf{0}$$

Spectral Domain

$$\mathbf{u}(\mathbf{x},t)=\mathbf{a}\cdot\phi(\mathbf{x})\cdot\cos(\omega\cdot t-\varphi)$$

Generalized Eigenvalue Problem (Spectral Domain)

$$[\mathbf{K}(\mathbf{p}_K)-\omega^2\cdot\mathbf{M}(\mathbf{p}_M)]\cdot\phi(\mathbf{x})=\mathbf{0}$$

Research Topic in „System Analysis“ or „Integrated Deformation Analysis“

Undamped Eigenvibration of a Structure

Generalized Eigenvalue Problem (GEWP) (Spectral Domain)

$$[\mathbf{K}(\mathbf{p}_K) - \omega^2 \cdot \mathbf{M}(\mathbf{p}_M)] \cdot \phi(\mathbf{x}) = \mathbf{0}$$

First Order Derivation of GEWP leads to 2 Inverse Eigen-Value/-Vector Problems

„Unhealthy" Structure Δp_K

1. Changes in the Eigenvalues / Eigenfrequencies

$$\Delta\omega_i^2(\Delta\mathbf{p}_K, \Delta\mathbf{p}_M) = \boldsymbol{\varphi}_i^T \cdot [d\mathbf{K}(\Delta\mathbf{p}_K) - \omega_i^2 \cdot d\mathbf{M}(\Delta\mathbf{p}_M)].\boldsymbol{\varphi}_i$$

2. Changes in the Shapes of the Eigenvectors

$$\Delta\boldsymbol{\varphi}_i(\Delta\mathbf{p}_k, \Delta\mathbf{p}_M) = -\frac{\boldsymbol{\varphi}_i^T \cdot d\mathbf{M}(\Delta\mathbf{p}_M) \cdot \boldsymbol{\varphi}_i}{2} + \sum_{\substack{j=1,\\ j\neq i}}^{n} \frac{1}{\omega_i^2 - \omega_j^2} \boldsymbol{\varphi}_i^T \cdot [d\mathbf{K}(\Delta\mathbf{p}_K) - d\mathbf{M}(\Delta\mathbf{p}_M)] \cdot \boldsymbol{\varphi}_j$$

New Research Topic in „System Analysis" or „Integrated Deformation Analysis"

„Structural Health Monitoring“ => Parameter-Integration

1.) Integrated Time Domain Model (State Transition,Kalman-Filtering)

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T \quad \Longrightarrow \quad \mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t) \,|\, \mathbf{p}_K, \mathbf{p}_C, \mathbf{p}_M]^T$$

2.) Integrated Spectral Approach and Inverse Eigenvalue-Problem

$$\mathbf{y}(t) = [\mathbf{u}(t), \dot{\mathbf{u}}(t), \ddot{\mathbf{u}}(t)]^T \quad \Longrightarrow \quad [\Delta\omega_i^2, \Delta\boldsymbol{\varphi}_i] \quad \Longrightarrow \quad y(t) = [\Delta\mathbf{p}_K, \Delta\mathbf{p}_C, \Delta\mathbf{p}_M]$$

New Research Topic in „System Analysis“ or „Integrated Deformation Analysis“

Integrated Deformation-Analysis

System Analysis

Structural Health Monitoring

Sensors

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Sensors & Algorithms

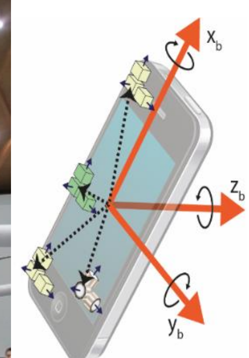
GNSS
- *Code*
- *Phase*
- *Doppler*

+

Tight Coupling
- *Position &*
- *Velocity*

MEMS
- *Gyroskope*
- *Accelerometer*
- *Magnetometer*
- *Inklinometer*
- *Barometer*
- *Camera-Coordinates*

$$y(t) = \left[x^e \; y^e \; z^e \,|\, \dot{x}^e \dot{y}^e \dot{z}^e \,|\, r^e \; p^e \; y^e \,\|\, \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \,|\, \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \,|\, \mathbf{s} \right]^T$$



www.navka.de

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Sensors & Algorithms

$$y(t) = \left[x^e \; y^e \; z^e \,|\, \dot{x}^e \dot{y}^e \dot{z}^e \;|\, r^e \; p^e \; y^e \,\|\, \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \,|\, \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \,|\, \mathbf{s} \right]^T$$

Use of Additional State Information

Parallel Processing Algorithms

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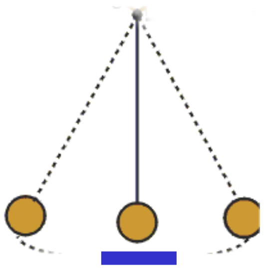
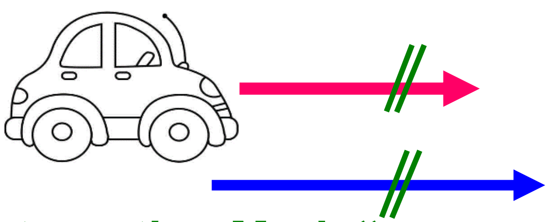
Zero-Updates („ZUPT“)



$$\mathbf{F}(\mathbf{x}) = \mathbf{0}$$



Roll

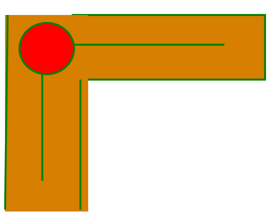
Velocity

„Automotive Mode“

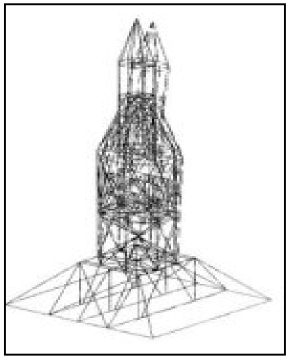
Unequations

$$\mathbf{u} \leq \mathbf{F}(\mathbf{x}) \leq \mathbf{o}$$

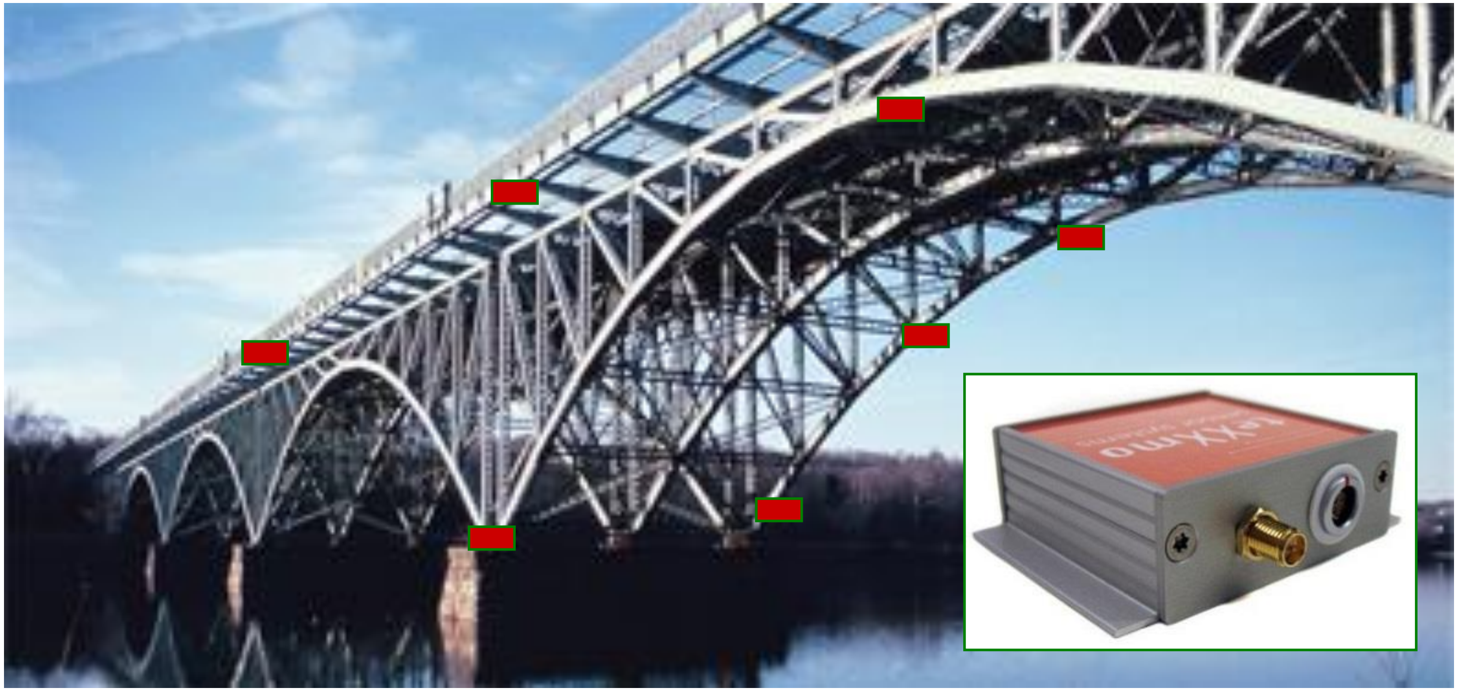
„Indoor-Map-Matching“



„System-Analysis“



„Structural Health Monitoring“ via Structual Eigenvibrations

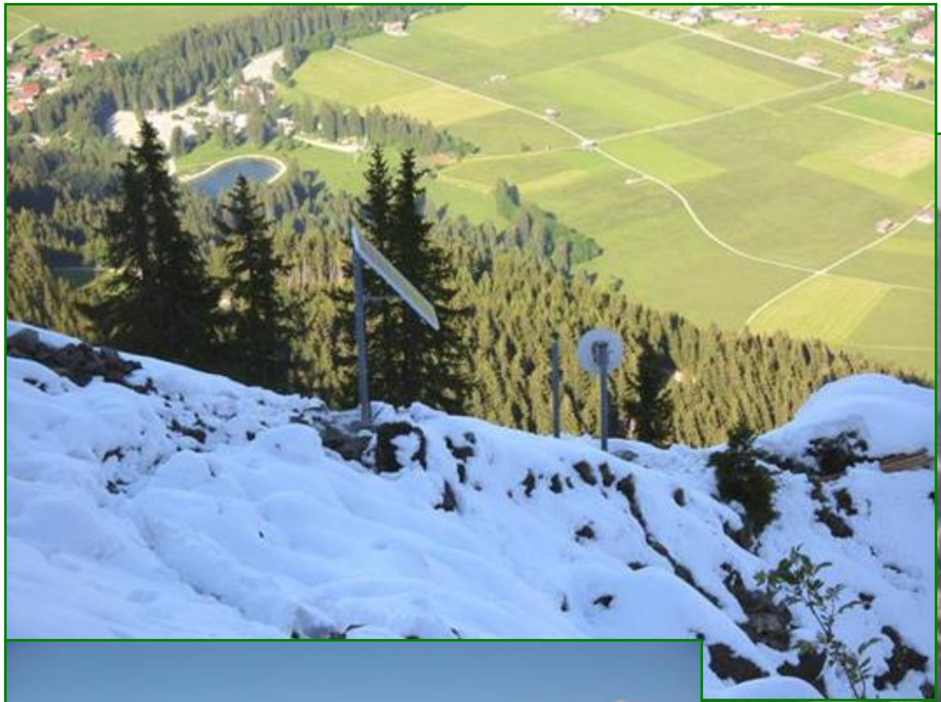


„Marriage“/Integration of Geodetic Monitoring & Navigation-Algorithms/-Sensors

$$y(t) = \left[x^e \; y^e \; z^e \,|\, \dot{x}^e \dot{y}^e \dot{z}^e \;|\, r^e \; p^e \; y^e \,\|\, \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \,|\, \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \,|\, \mathbf{s} \right]^T$$

GOCA-Examples

GOCA-based Early Warning Systems in the Alps



GOCA-Project
Hornbergl, Austria

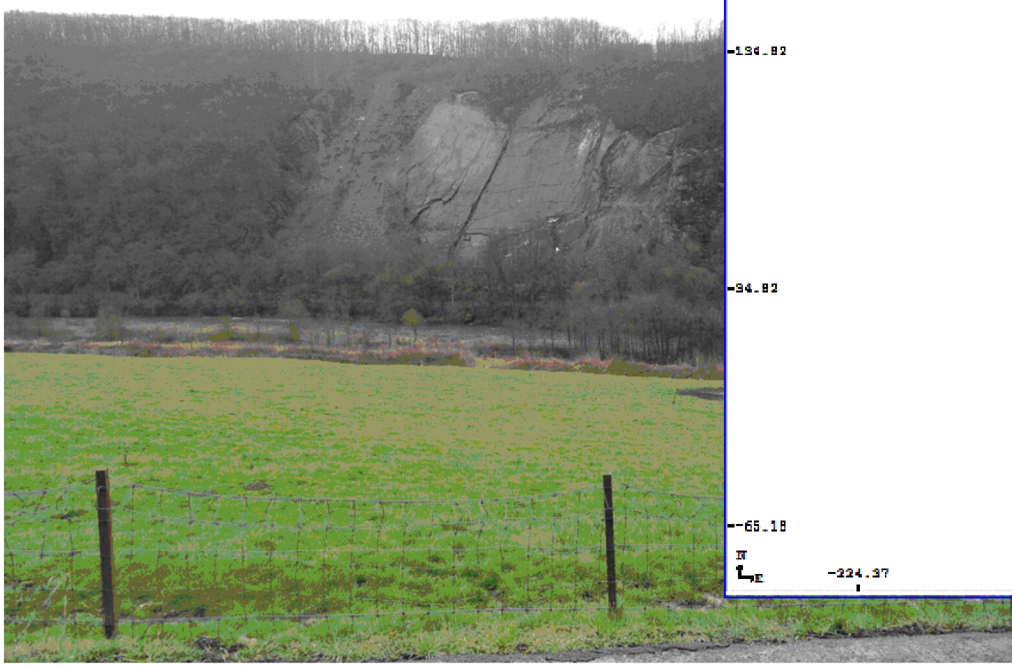
„Mining“ – Worldwide Mining / Open-Cast-Mining

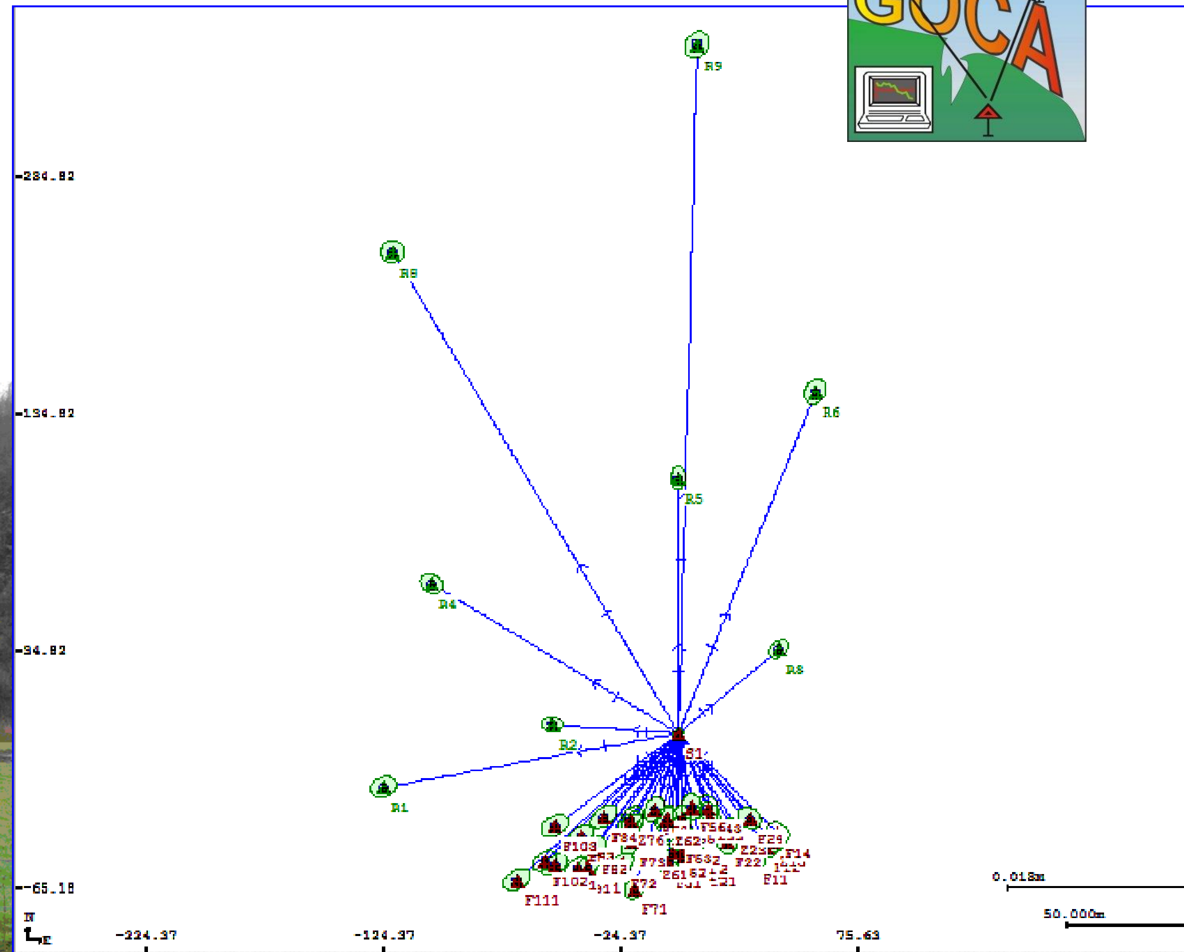
Vattenfall, Europe

GOCA-Centre with GOCA-Software =>

Landslide – Monitoring 2014

www goca.info



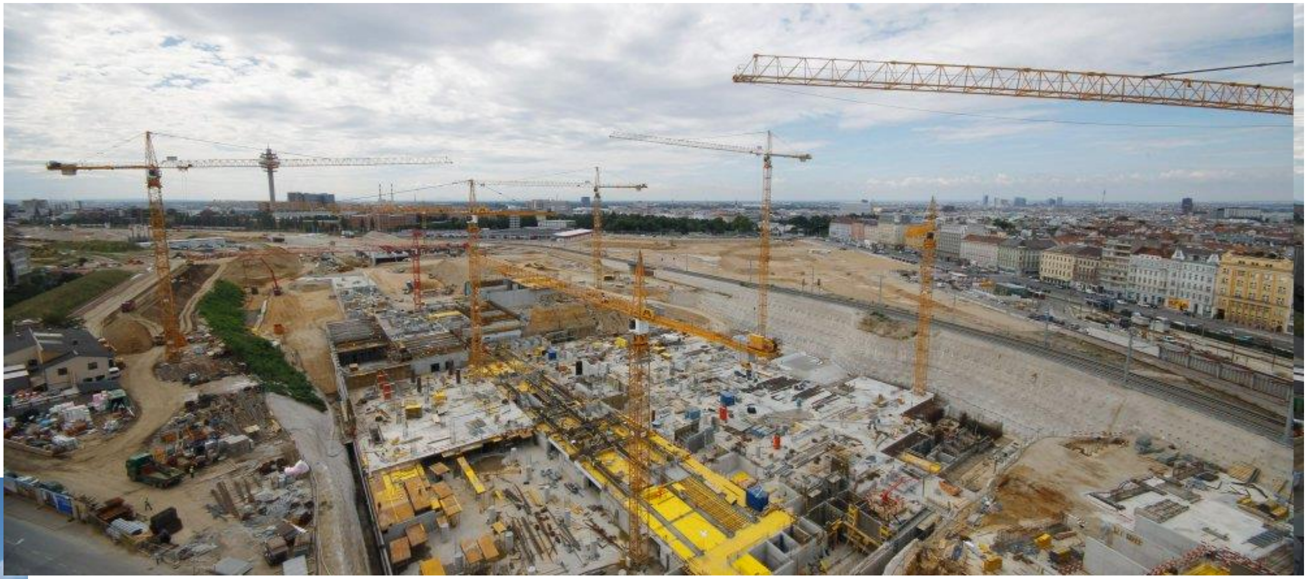


Movements of Rock Wall along a street

Administration des Ponts et Chaussées, Luxembourg

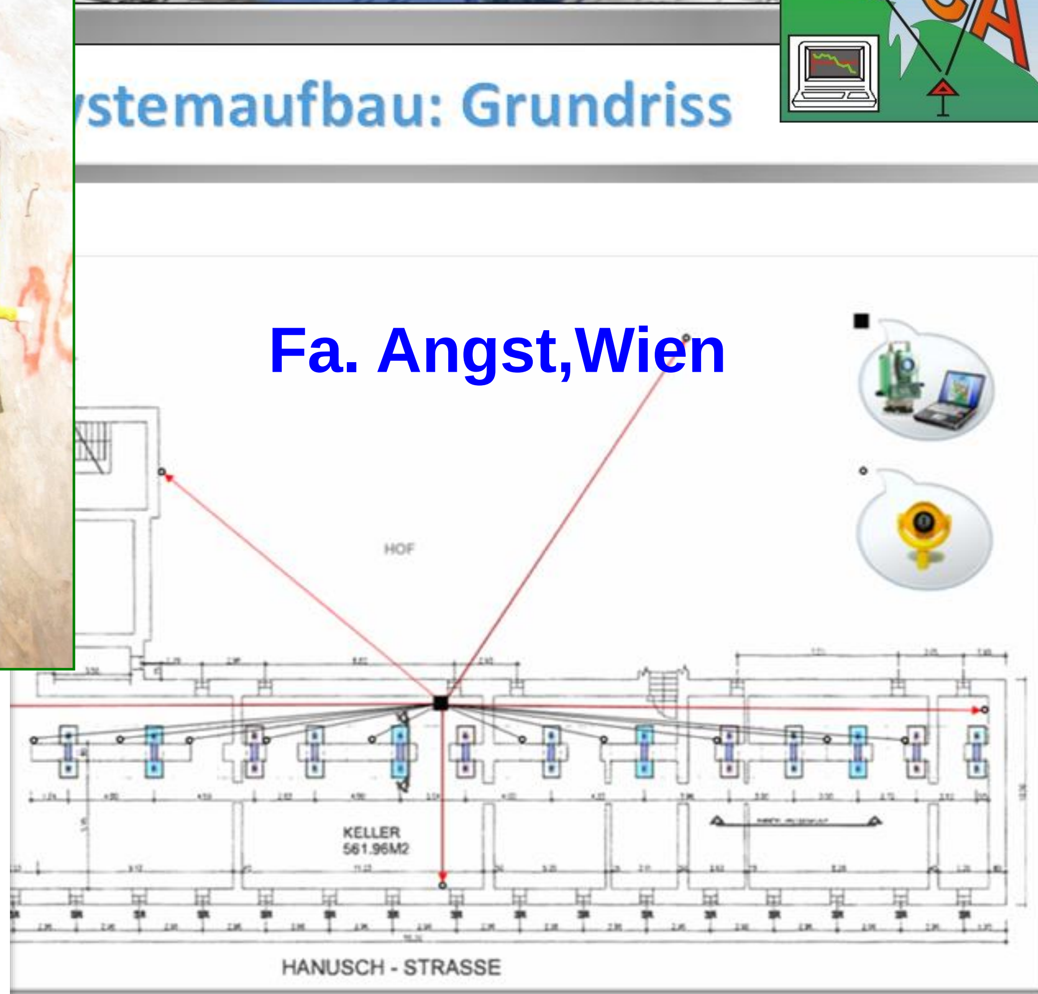
Construction-Area Monitoring

New Construction South MainTrain Station, Vienna Fa. Angst ZT GmbH



Building - Monitoring

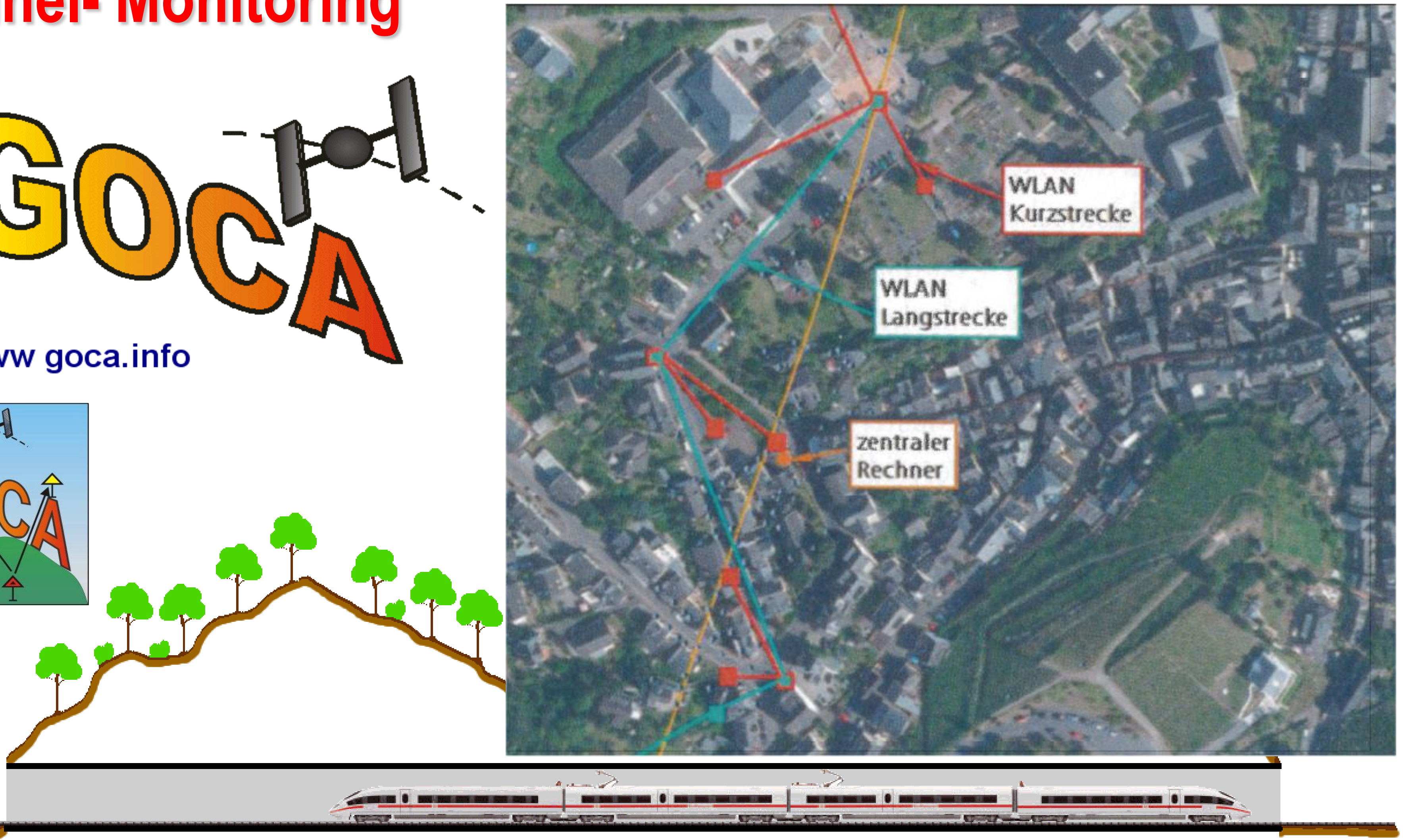
Fa. Angst,Wien



„Jäger-Kaserne“
Bruck an der Leitha /Austria

Tunnel- Monitoring

www goca.info



2011/2012 „Kaiser-Wilhelm“Tunnel, Cochem

Diameter: 10 m, Ground-Cover: > 3 m

Dam, Building etc. Monitoring in Russia, GNSSPlus

GOCA
Уникальный программный продукт для мониторинга

ROSCOSMOS


GOCA
(GNSS/LPS/LS-based Online Control and Alarm Systems) - on-line система непрерывного наблюдения за деформациями, основанная на точных спутниковых (ГНСС) и наземных геодезических наблюдениях (LPS).

Универсальная система мониторинга

Программное обеспечение GOCA было разработано в Институте прикладных научных исследований (IaF) города Карлсруэ (Германия) под руководством профессора Р. Ягера.

Данный программный комплекс используется для геодинамического мониторинга сооружений и природных процессов. На основание ГНСС данных, а также другого геодезического оборудования производится анализ стабильности объекта, производится обнаружение и прогноз деформаций, а также оповещение при критических состояниях.

Области применения: мониторинг
- зон влияния природных факторов (оползни, вулканы, сейсмоактивные зоны и т.д.),
- зоны влияния антропогенных факторов (дамбы, плотины, открытые карьеры, различные здания и инженерные сооружения и т.д.).

Bridge - Monitoring

GOCA Monitoring

New „Rethe-Brücke“
Hamburger Harbour

2011 - 2014

Hamburg Port Authority

Old Rethe-Hub-Brücke

Dam-Monitoring - 3 Dams in Bosnia-Herzegowina

From Classical to Online-Monitoring

GOCA = GNSS/LPS based Online Control and Alarm System

Integrated Deformation-Analysis – Sensors & Algorithms

Engineered in Germany
Powered by NAVKA

www.robinette.de
www.navka.de

www goca.info

Futher Developments

- Robustification of Adjustment-Step 2 (L1-Norm)
- Introduction of Geopotential Models (Reduction of Zenith-Angles => 1 Identical Point between GNSS/TPS)
- 3D Integrated Geodesy (GNSS,TPS,LS,Kamera,..., Schwerewerte)
- Prediction Models

- RaD on Integrated Deformationsanalysis
- GNSS/MEMS Algorithms for Lowcost Sensors
- GNSS-Algorithms
- Structural Health Monitoring (Physical Parameters)

GOCA-WebSite: www.goca.info

MONIKA-WebSite: www.monika.ag


THANK
YOU
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