

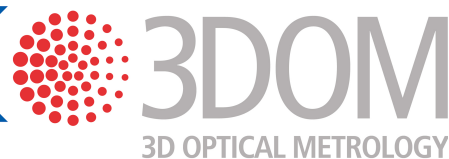
Off-the-shelf videogrammetry - a success story

EuroCOW 2014
Castelldefels, Barcelona

E. Rupnik^a and J. Jansa^b

^a 3D Optical Metrology (3DOM) Unit, Bruno Kessler Foundation (FBK),
Trento, Italy - rupnik@fbk.eu

^b Research Group of Photogrammetry and Remote Sensing,
Department of Geodesy and Geoinformation, Vienna University of Technology -
josef.jansa@geo.tuwien.ac.at



Introduction

Close-range photogrammetry trends

- ▶ UAV
- ▶ mobile mapping
- ▶ cultural heritage
- ▶ human motion analyses
- ▶ industrial applications

→ task-specific

Introduction

Close-range photogrammetry trends

- ▶ UAV
- ▶ mobile mapping
- ▶ cultural heritage → task-specific
- ▶ human motion analyses
- ▶ industrial applications

Dynamic applications: *Online or offline system?*

- ▶ dynamic or (quasi-) static? → Smart/machine-vision or dSLR camera
- ▶ how expert are you? → Immediate results or data processing
- ▶ what is the budget? → Adequate or low

Introduction

Close-range photogrammetry trends

- ▶ UAV
- ▶ mobile mapping
- ▶ cultural heritage → task-specific
- ▶ human motion analyses
- ▶ industrial applications

Dynamic applications: *Online or offline system?*

- ▶ dynamic or (quasi-) static? → Smart/machine-vision or dSLR camera
- ▶ how expert are you? → Immediate results or data processing
- ▶ what is the budget? → Adequate or low

dSLR's can record video!

Still, in dynamic applications

- ▶ multiexposures prevail, $f < 1Hz$
- ▶ much lesser interest for higher frame rates, $f \approx 30Hz$

Research objective

HelioFLOAT

- ▶ pre-industrialize a novel concept of a **floating solar power plant**
- ▶ design \iff simulate \iff experiment
- ▶ **photogrammetry** as the experimental method



Task characteristics

- ▶ motion
- ▶ instantaneous water state

→ **Dynamic event**

and

- ▶ in-plane/out-of-plane motion
- ▶ reconstruction compliant with FEM element definition
- ▶ testing in different environments (scalability)

→ **Passive imaging**

Project planning

Imaging setup

Low-cost

- ▶ 3x Canon 60D
- ▶ 30Hz, 1920x1080 pix
- ▶ 20mm Sigma lens
- ▶ 3x 1200W halogen lamps

≈ 5.000€

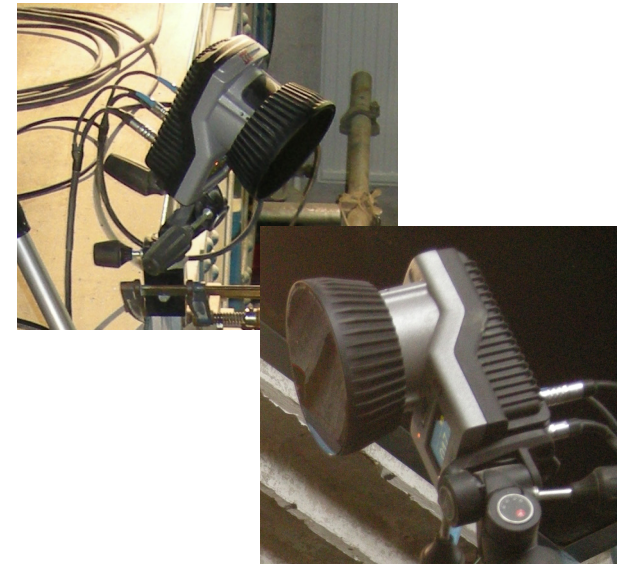


validated with

Motion capture system

- ▶ 3x Qualisys Oqus
- ▶ 60Hz
- ▶ XYZ coordinates as output
- ▶ infrared strobe inside the housing

≈ 15.000€+



Project planning

Imaging setup

Workplace



Project planning

Imaging setup

Workplace



Vienna Model Basin

▶ Length: 180m

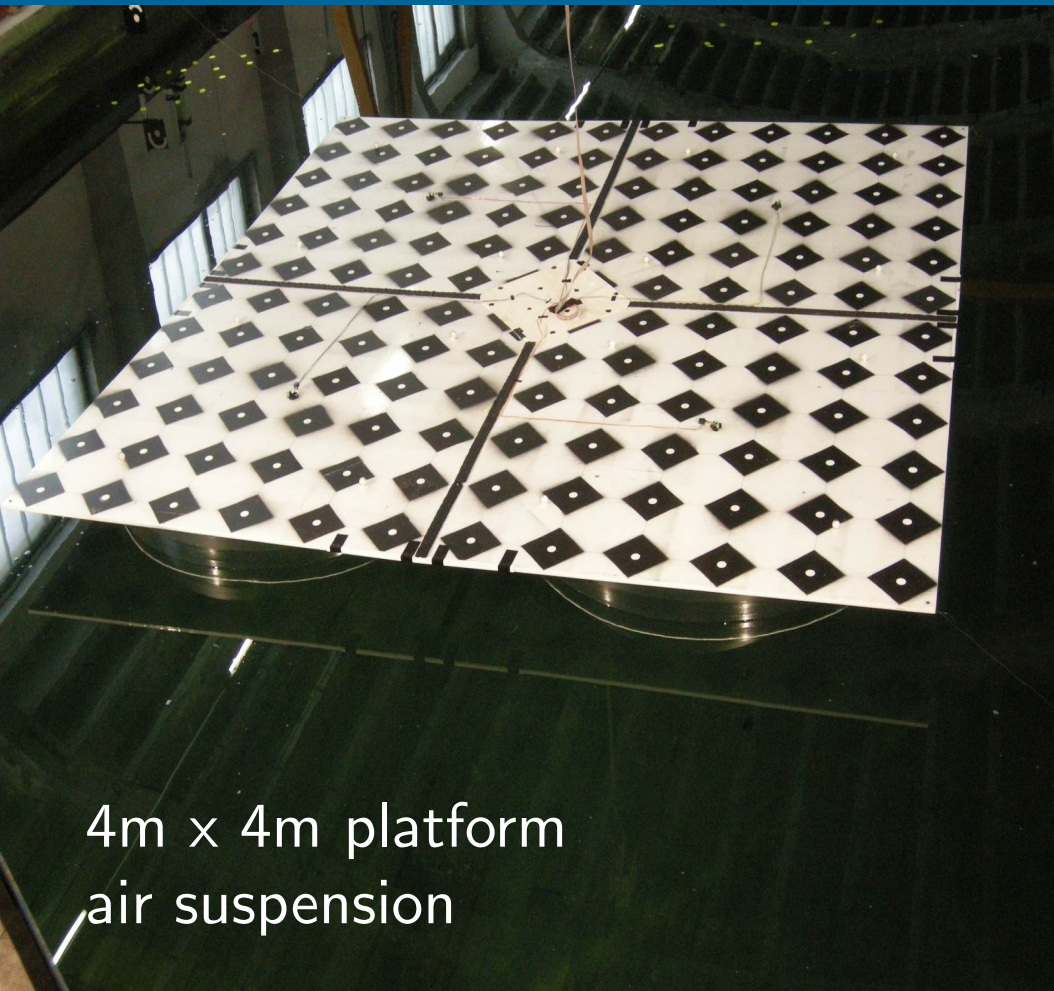
▶ Width: 10m

Project planning

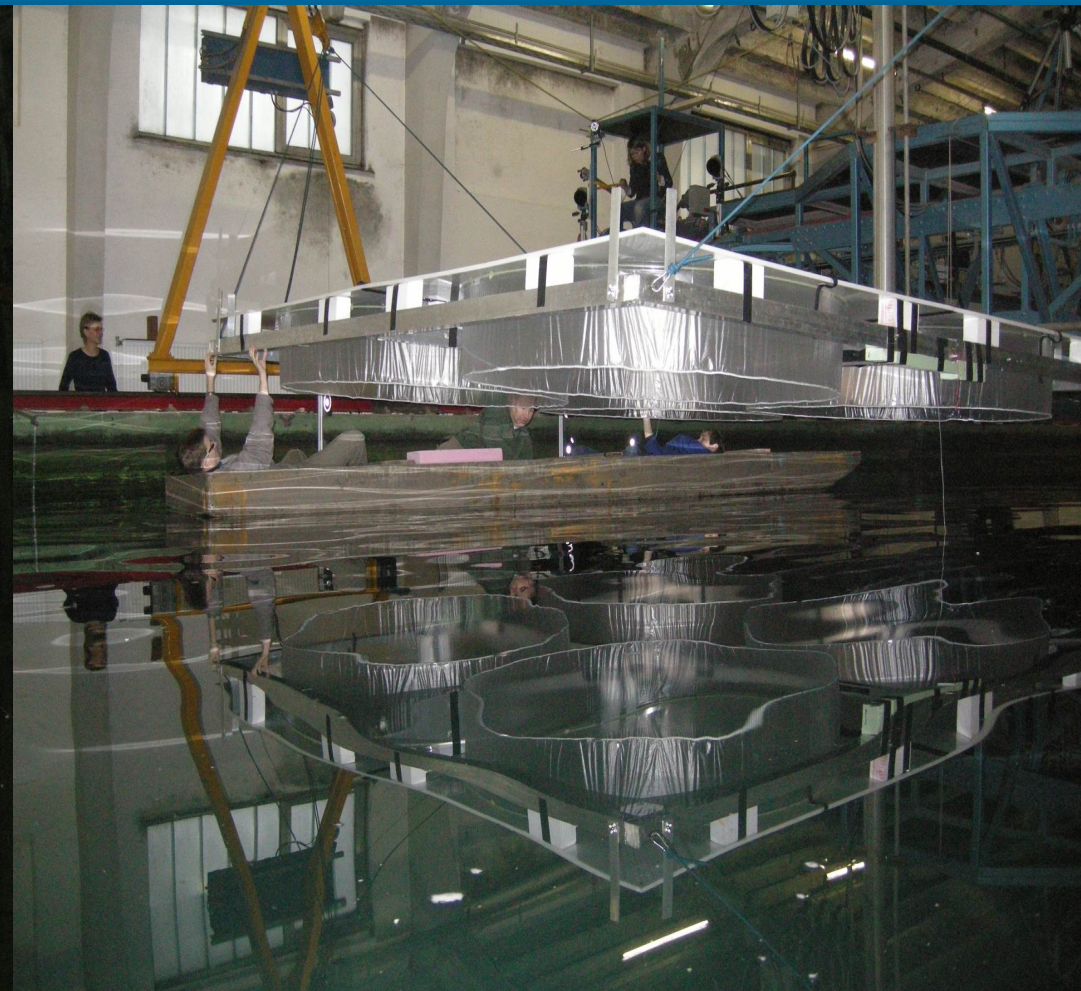
Imaging setup

Workplace

Object of interest

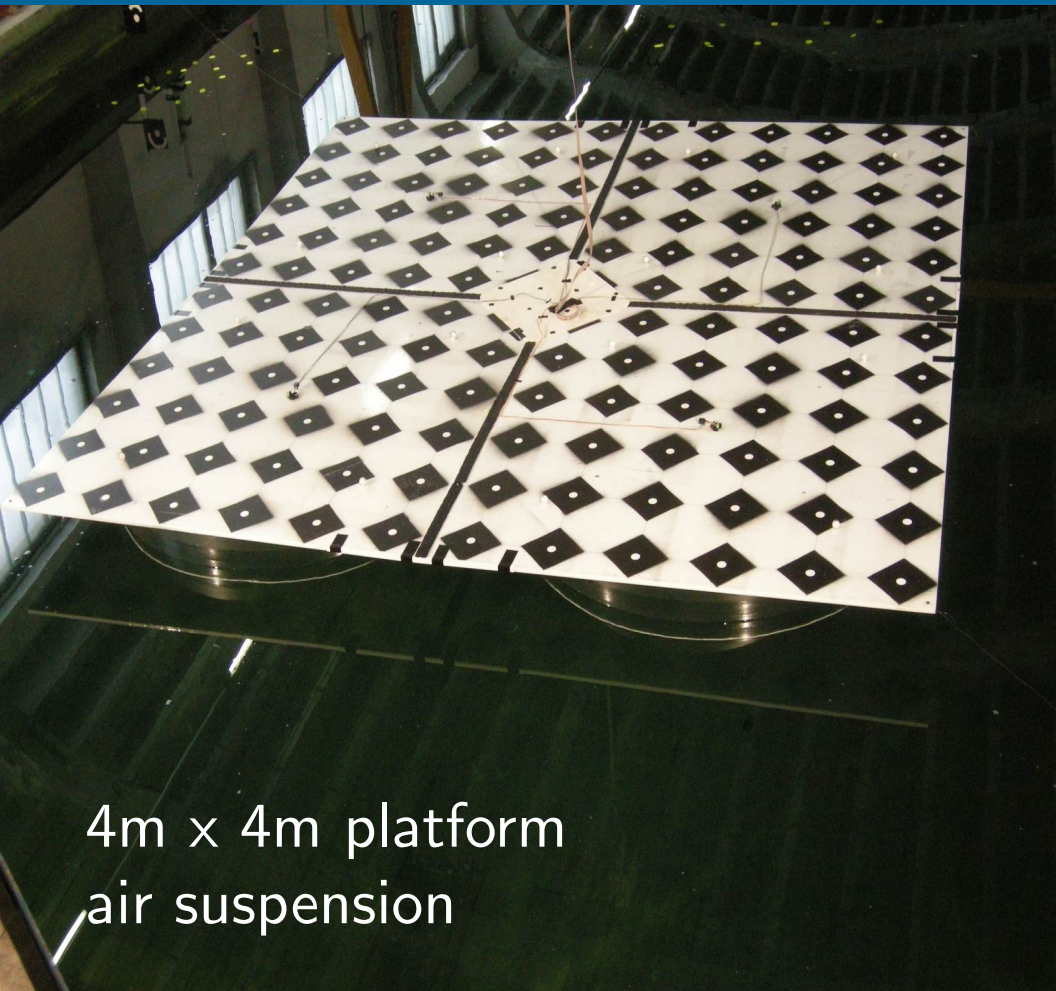


4m x 4m platform
air suspension

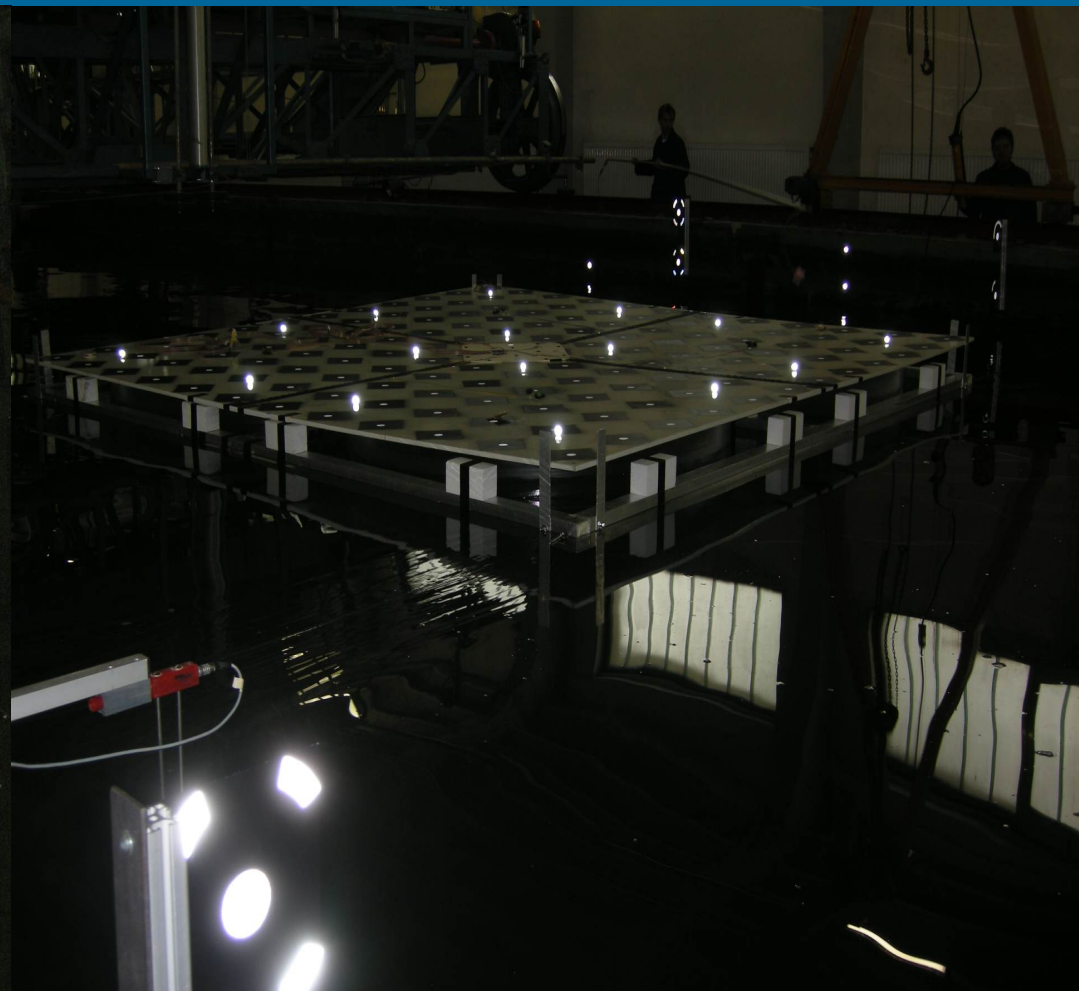


Low-cost system

- ▶ 144 retro targets (planar)



4m x 4m platform
air suspension

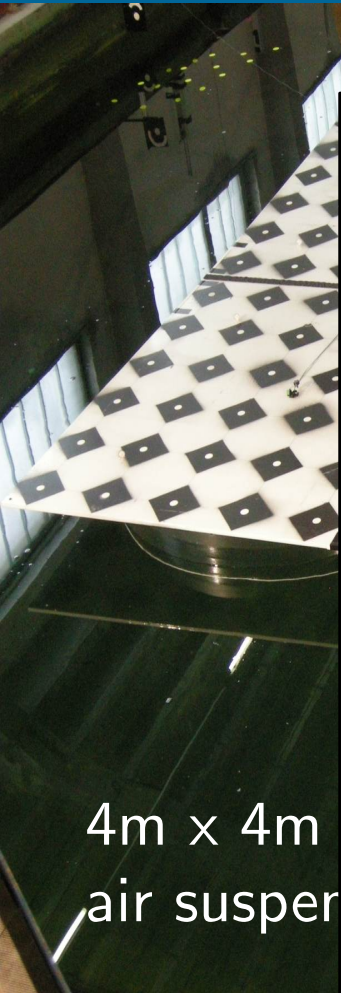


Low-cost system

- ▶ 144 retro targets (planar)

Qualisys Oqus

- ▶ 16 retro targets (spheres)
- ▶ offset wrt to real surface



4m x 4m
air susper

Outline of the talk

- ▶ Network design
- ▶ System calibration
- ▶ Target motion modelling
- ▶ Dynamic referencing
- ▶ Evaluation
- ▶ Summary

Low-cost

- ▶ 144 re

Network design

Criteria

- ▶ economy
- ▶ precision, accuracy
- ▶ reliability



Lower cost ↓
Lower quality

- ▶ deteriorated image
measurement accuracy
 - ▶ impeded tracking
- Sensor deficiency**

Imaging geometry

- ▶ intersection angles
- ▶ scale
- ▶ redundancy

- ▶ far distances & low ceiling
 - ▶ conflict with Qualisys
- Workplace constraints**

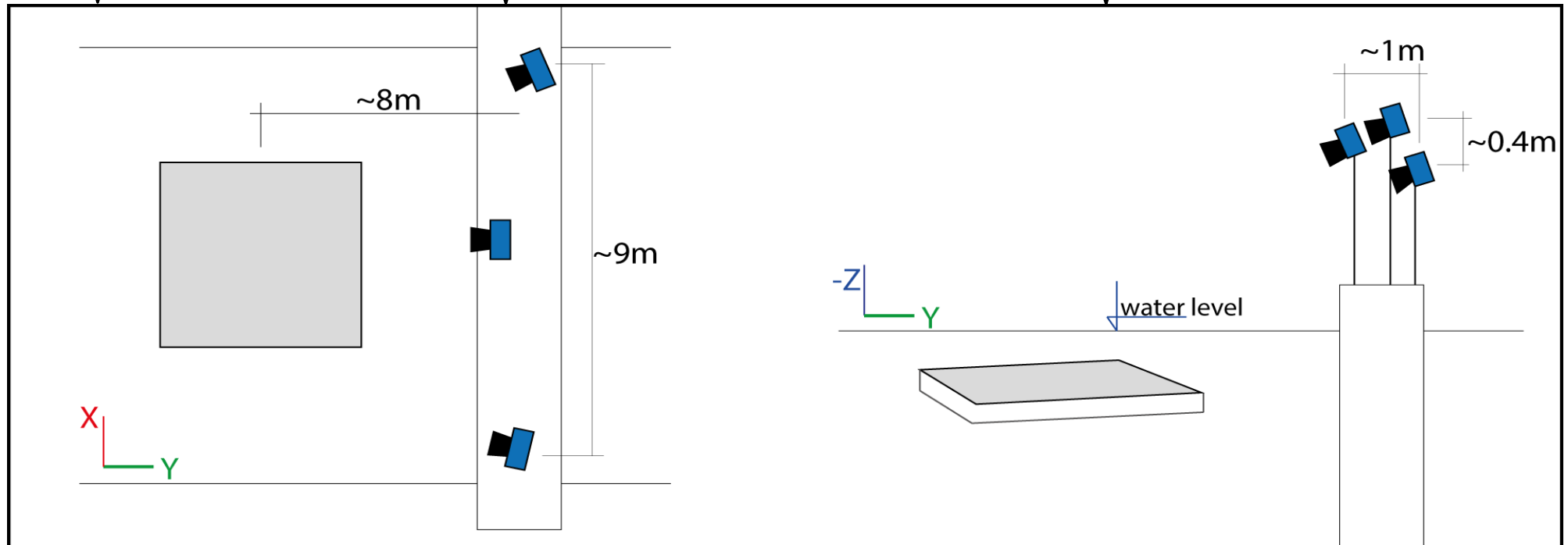
Datum definition
Estimation techniques

- ▶ free network/minimum constraint
- ▶ up-to-date system calibration

Network design

Criteria

- ▶ economy
- ▶ precision, accuracy
- ▶ reliability



System calibration

- A. Interior orientation
- B. Lens distortion
- C. Camera orientation

$$\begin{pmatrix} x - x_p + \Delta x \\ y - y_p + \Delta y \\ -c \end{pmatrix} = \lambda R^T \begin{pmatrix} X - X^0 \\ Y - Y^0 \\ Z - Z^0 \end{pmatrix}$$

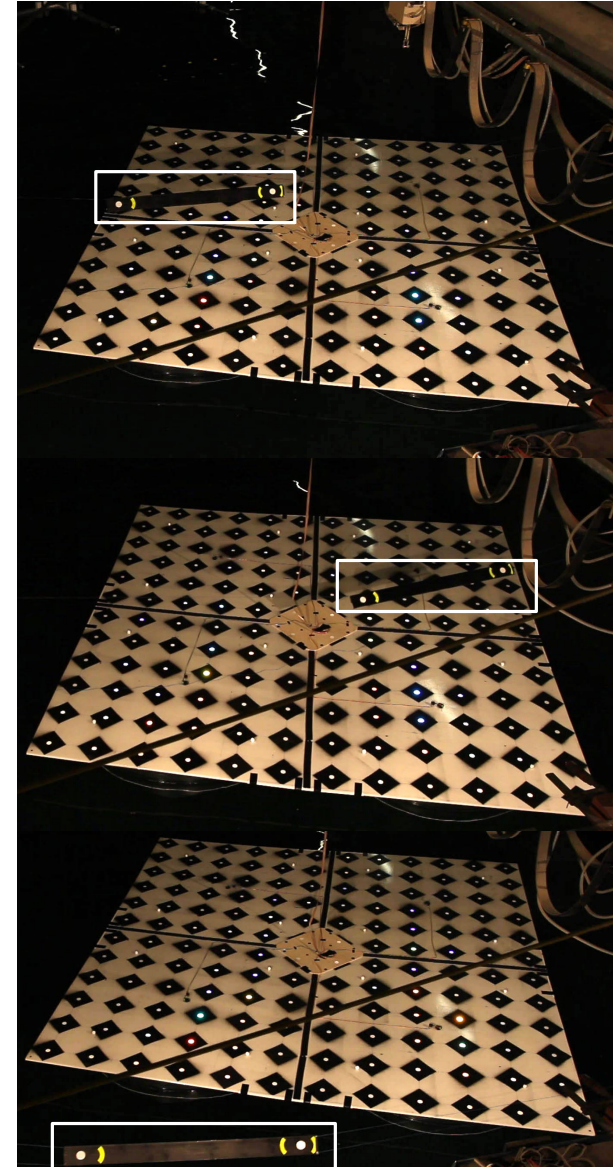
System calibration

- A. Interior orientation
- B. Lens distortion
- C. Camera orientation

$$\begin{pmatrix} x - x_p + \Delta x \\ y - y_p + \Delta y \\ -c \end{pmatrix} = \lambda R^T \begin{pmatrix} X - X^0 \\ Y - Y^0 \\ Z - Z^0 \end{pmatrix}$$

Moving reference bar

- ▶ A, B, C restored in a single procedure
- ▶ calibrated bar signalised with points
 $1.5m \pm 0.1mm$
- ▶ random motion around the volume



System calibration

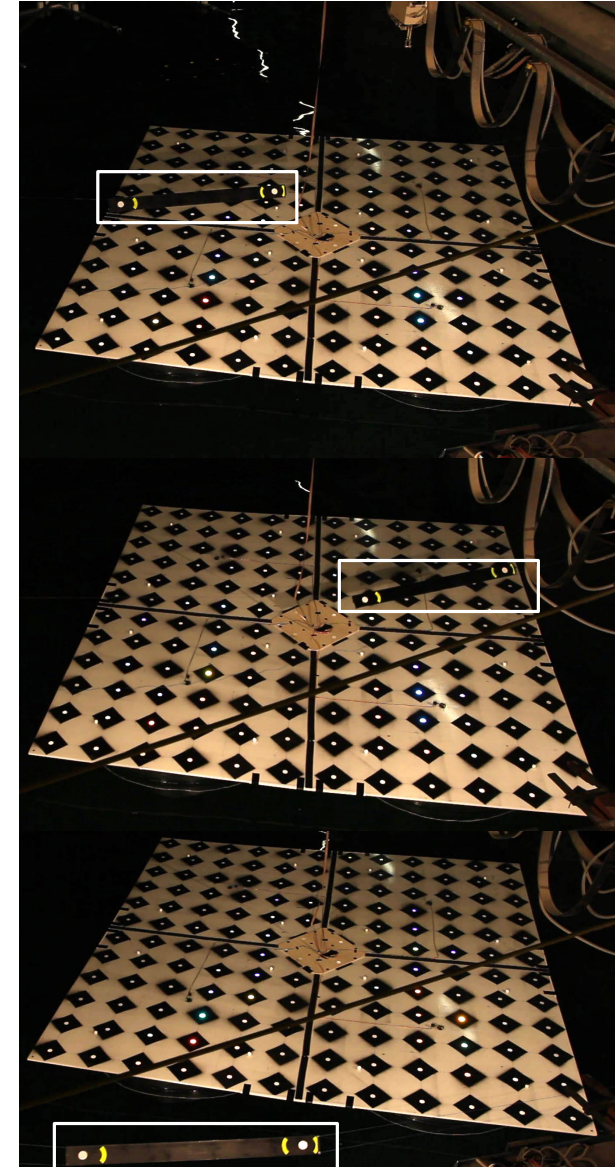
- A. Interior orientation
- B. Lens distortion
- C. Camera orientation

$$\begin{pmatrix} x - x_p + \Delta x \\ y - y_p + \Delta y \\ -c \end{pmatrix} = \lambda R^T \begin{pmatrix} X - X^0 \\ Y - Y^0 \\ Z - Z^0 \end{pmatrix}$$

trivial search for correspondences
no target field necessary
fast and flexible

Moving reference bar

- ▶ A, B, C restored in a single procedure
- ▶ calibrated bar signalised with points
 $1.5m \pm 0.1mm$
- ▶ random motion around the volume



System calibration

- A. Interior orientation
- B. Lens distortion
- C. Camera orientation

$$\begin{pmatrix} x - x_p + \Delta x \\ y - y_p + \Delta y \\ -c \end{pmatrix} = \lambda R^T \begin{pmatrix} X - X^0 \\ Y - Y^0 \\ Z - Z^0 \end{pmatrix}$$

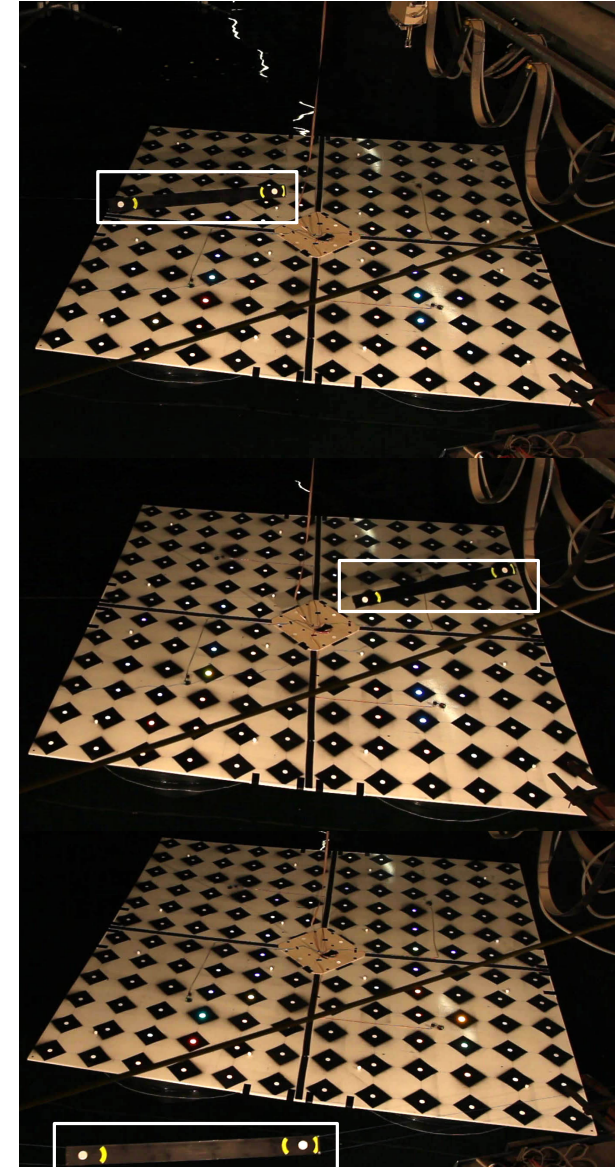
trivial search for correspondences
no target field necessary
fast and flexible

Moving reference bar

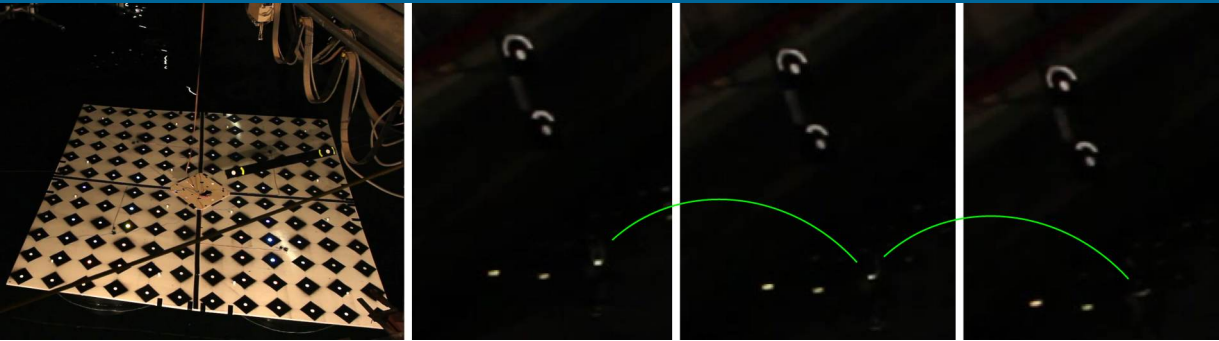
- ▶ A, B, C restored in a single procedure
- ▶ calibrated bar signalised with points
 $1.5m \pm 0.1mm$
- ▶ random motion around the volume

Estimation technique

- ▶ datum parallel to water surface
fixed with **minimal constraints**
- ▶ final adjustment in self-calibrating **free network**
 - 112 distance observations
 - $\sigma_{0,obs} = 0.4pix$



Target motion model



Anomalous behaviour due to

- ▶ occlusions
- ▶ glittering effects
- ▶ disappearing signal

Spot **bad data** with Kalman filter

Target motion model



Anomalous behaviour due to

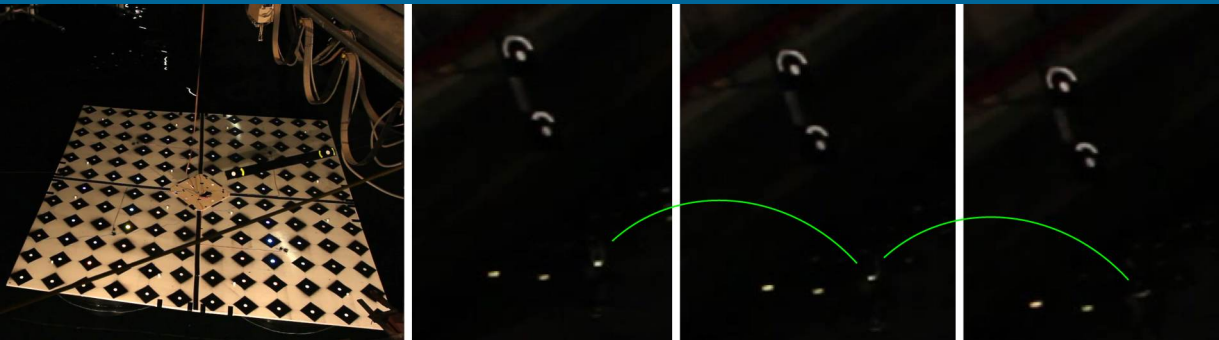
- ▶ occlusions
- ▶ glittering effects
- ▶ disappearing signal

Spot bad data with Kalman filter

$$\begin{aligned}\hat{\mathbf{X}}_k^- &= \mathbf{A}\hat{\mathbf{X}}_{(k-1)} + \mathbf{B}\mathbf{U}_{(k-1)} + \mathbf{W}_{(k-1)} & p(\mathbf{W}) &\sim N(0, \mathbf{Q}) \\ \mathbf{Z}_k^- &= \mathbf{H}\hat{\mathbf{X}}_k^- + \mathbf{V}_{(k-1)} & p(\mathbf{V}) &\sim N(0, \mathbf{R}) \\ \mathbf{P}_k^- &= \mathbf{A}\mathbf{P}_{(k-1)}\mathbf{A}^T + \mathbf{Q} & & \text{time-update}\end{aligned}$$

$$\begin{aligned}\hat{\mathbf{X}}_k &= \hat{\mathbf{X}}_k^- + \mathbf{K}_k(\mathbf{Z}_k - \mathbf{H}\hat{\mathbf{X}}_k^-) \\ \mathbf{K}_k &= \mathbf{P}_k^- \mathbf{H}^T (\mathbf{H}\mathbf{P}_k^- \mathbf{H}^T + \mathbf{R})^{-1} \\ \mathbf{P}_k &= (\mathbf{I} - \mathbf{K}_k \mathbf{H}) \mathbf{P}_k^- \\ & \text{measurement-update}\end{aligned}$$

Target motion model

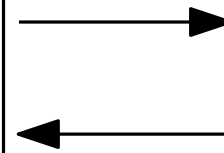


Anomalous behaviour due to

- ▶ occlusions
- ▶ glittering effects
- ▶ disappearing signal

Spot bad data with Kalman filter

$$\begin{aligned}\hat{\mathbf{X}}_k^- &= \mathbf{A}\hat{\mathbf{X}}_{(k-1)} + \mathbf{B}\mathbf{U}_{(k-1)} + \mathbf{W}_{(k-1)} & p(\mathbf{W}) &\sim N(0, \mathbf{Q}) \\ \mathbf{Z}_k^- &= \mathbf{H}\hat{\mathbf{X}}_k^- + \mathbf{V}_{(k-1)} & p(\mathbf{V}) &\sim N(0, \mathbf{R}) \\ \mathbf{P}_k^- &= \mathbf{A}\mathbf{P}_{(k-1)}\mathbf{A}^T + \mathbf{Q} & & \text{time-update}\end{aligned}$$



$$\begin{aligned}\hat{\mathbf{X}}_k &= \hat{\mathbf{X}}_k^- + \mathbf{K}_k(\mathbf{Z}_k - \mathbf{H}\hat{\mathbf{X}}_k^-) \\ \mathbf{K}_k &= \mathbf{P}_k^- \mathbf{H}^T (\mathbf{H}\mathbf{P}_k^- \mathbf{H}^T + \mathbf{R})^{-1} \\ \mathbf{P}_k &= (\mathbf{I} - \mathbf{K}_k \mathbf{H}) \mathbf{P}_k^- & \text{measurement-update}\end{aligned}$$

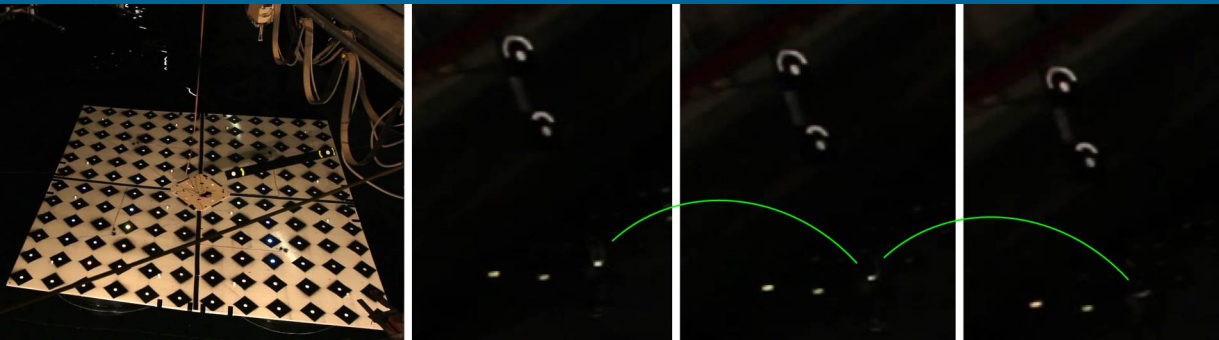
Motion characteristics

- ▶ manoeuvre freely
- ▶ accelerate/decelerate

Jerk model →

2D position, velocity,
acceleration, jerk

Target motion model



Anomalous behaviour due to

- ▶ occlusions
- ▶ glittering effects
- ▶ disappearing signal

Spot bad data with Kalman filter

$$\begin{aligned} \hat{\mathbf{X}}_k^- &= \mathbf{A}\hat{\mathbf{X}}_{(k-1)} + \mathbf{B}\mathbf{U}_{(k-1)} + \mathbf{W}_{(k-1)} & p(\mathbf{W}) &\sim N(0, \mathbf{Q}) \\ \mathbf{Z}_k^- &= \mathbf{H}\hat{\mathbf{X}}_k^- + \mathbf{V}_{(k-1)} & p(\mathbf{V}) &\sim N(0, \mathbf{R}) \\ \mathbf{P}_k^- &= \mathbf{A}\mathbf{P}_{(k-1)}\mathbf{A}^T + \mathbf{Q} & & \end{aligned}$$

time-update

$$\begin{aligned} \hat{\mathbf{X}}_k &= \hat{\mathbf{X}}_k^- + \mathbf{K}_k(\mathbf{Z}_k - \mathbf{H}\hat{\mathbf{X}}_k^-) \\ \mathbf{K}_k &= \mathbf{P}_k^- \mathbf{H}^T (\mathbf{H}\mathbf{P}_k^- \mathbf{H}^T + \mathbf{R})^{-1} \\ \mathbf{P}_k &= (\mathbf{I} - \mathbf{K}_k \mathbf{H}) \mathbf{P}_k^- \end{aligned}$$

measurement-update

Motion characteristics

- ▶ manoeuvre freely
- ▶ accelerate/decelerate

$$x_k = x_{k-1} + v_{k-1}T + a_{k-1}\frac{1}{2}T^2 + j_{k-1}\frac{1}{6}T^3$$

Jerk model →

2D position, velocity, acceleration, jerk

$$\mathbf{x} = \begin{bmatrix} x \\ \dot{x} \\ \ddot{x} \\ \dddot{x} \\ y \\ \dot{y} \\ \ddot{y} \\ \dddot{y} \end{bmatrix} \quad \mathbf{A} = \begin{bmatrix} 1 & T & \frac{1}{2}T^2 & \frac{1}{6}T^3 & \dots & & & \\ 0 & 1 & T & \frac{1}{2}T^2 & \dots & & & \\ 0 & 0 & 1 & T & \dots & & & \\ 0 & 0 & 0 & 1 & \dots & & & \\ \dots & & & & 1 & T & \frac{1}{2}T^2 & \frac{1}{6}T^3 \\ \dots & & & & 0 & 1 & T & \frac{1}{2}T^2 \\ \dots & & & & 0 & 0 & 1 & T \\ \dots & & & & 0 & 0 & 0 & 1 \end{bmatrix}$$

Dynamic referencing

Continuous recovery of new orientation parameters

- ▶ 2D - 3D
- ▶ 3D - 3D + control information
- ▶ 2D - 2D - 2D - 3D

Dynamic referencing

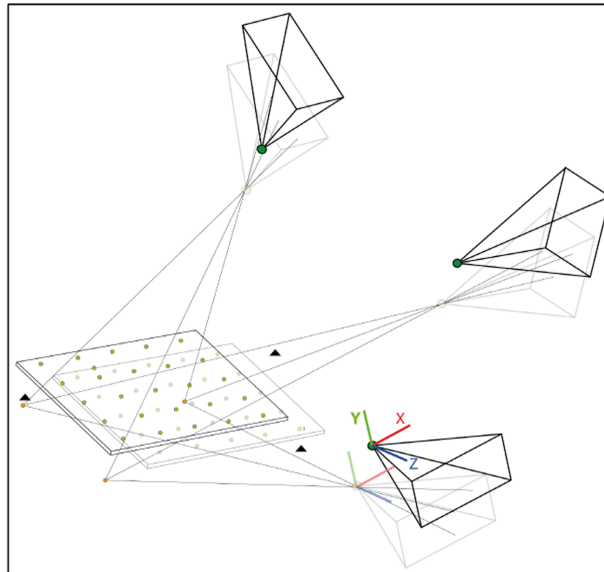
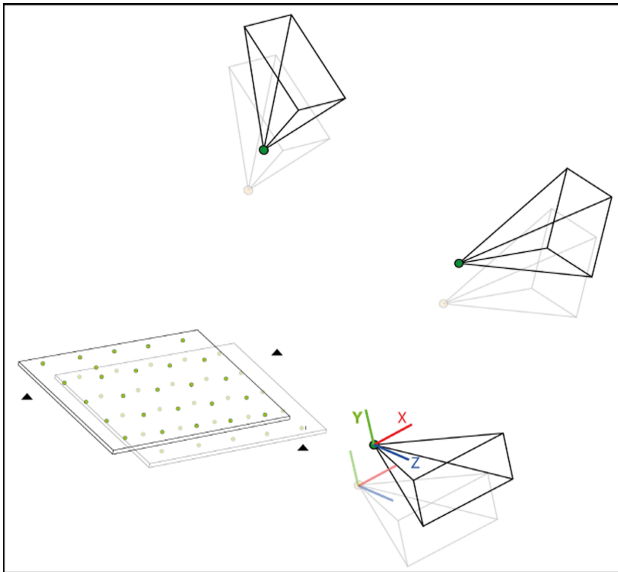
Continuous recovery of new orientation parameters

- ▶ 2D - 3D
 - ▶ 3D - 3D
 - ▶ 2D - 2D - 2D - 3D
- +control information

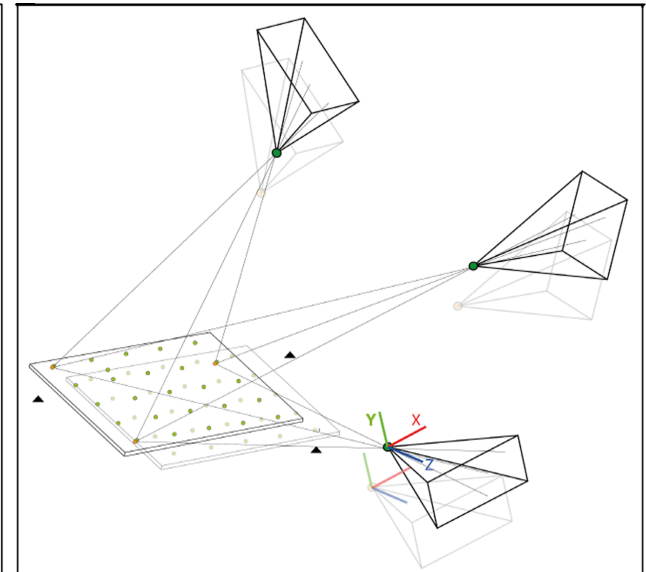
change in **object** and
'camera rig'

reconstruction in **local**
CS of the 'camera rig'

3D **local** - 3D **global**
alignment

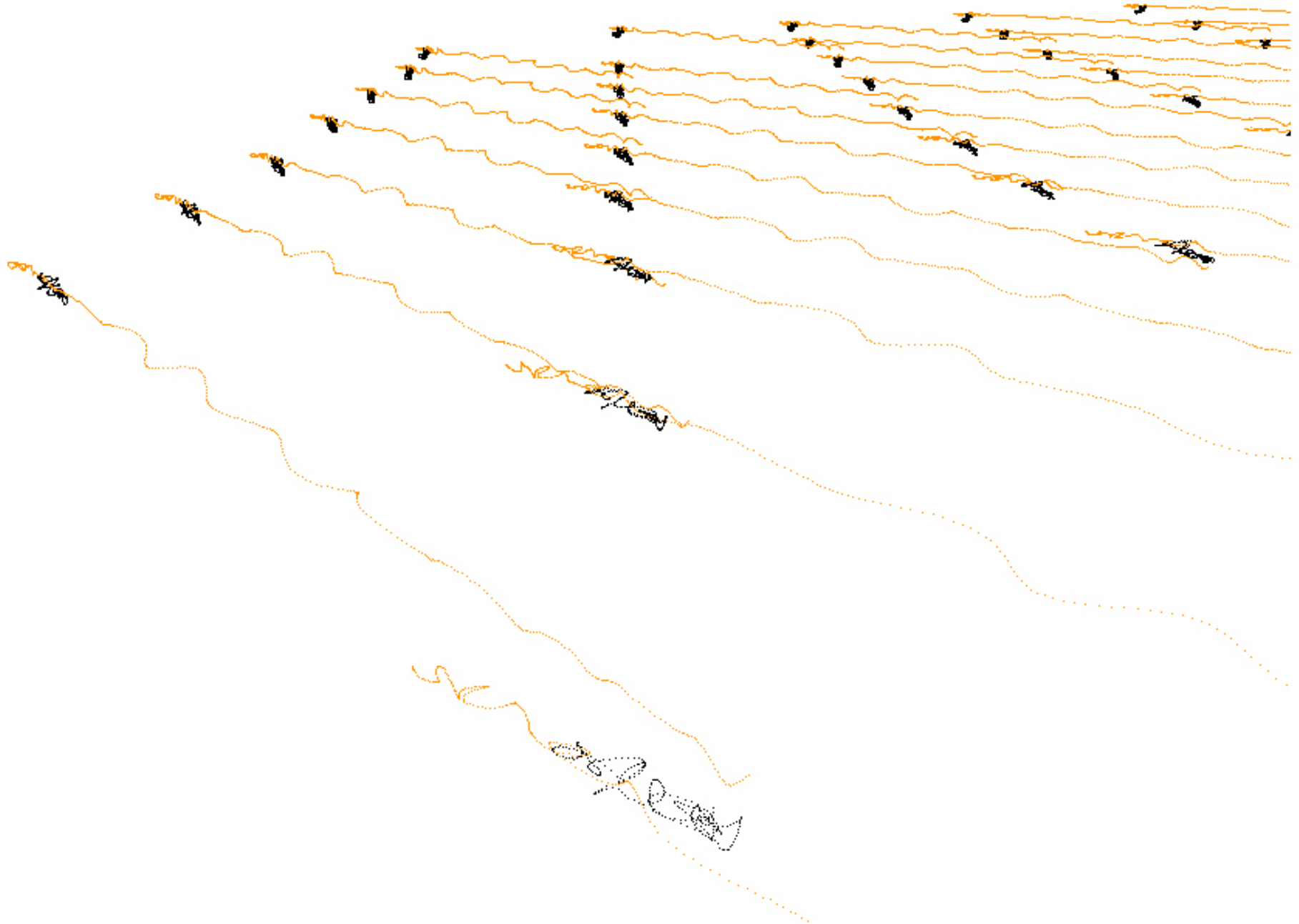


composite motion



separation into
 R, T_{RIG} + **object motion**

Dynamic referencing

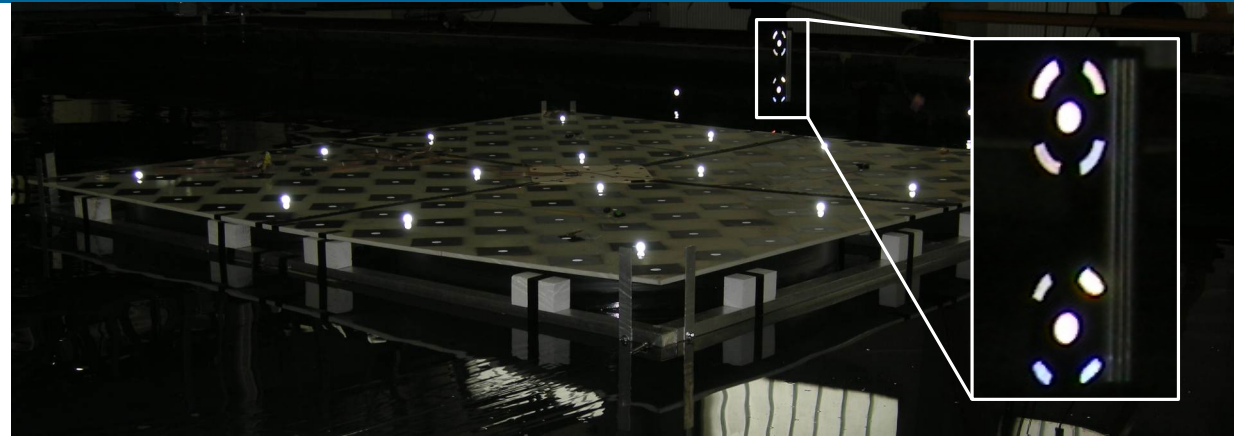


Evaluation

Low cost - Qualisys Qqus

Measurement series

- ▶ Regular waves
- ▶ Irregular waves
→ dynamic georeferencing



Precision (BA output)

- ▶ $\sigma_X \approx 1.5mm$
- ▶ $\sigma_Y \approx 3.0mm$
- ▶ $\sigma_Z \approx 4.0mm$

Image scale $\approx 1 : 500$

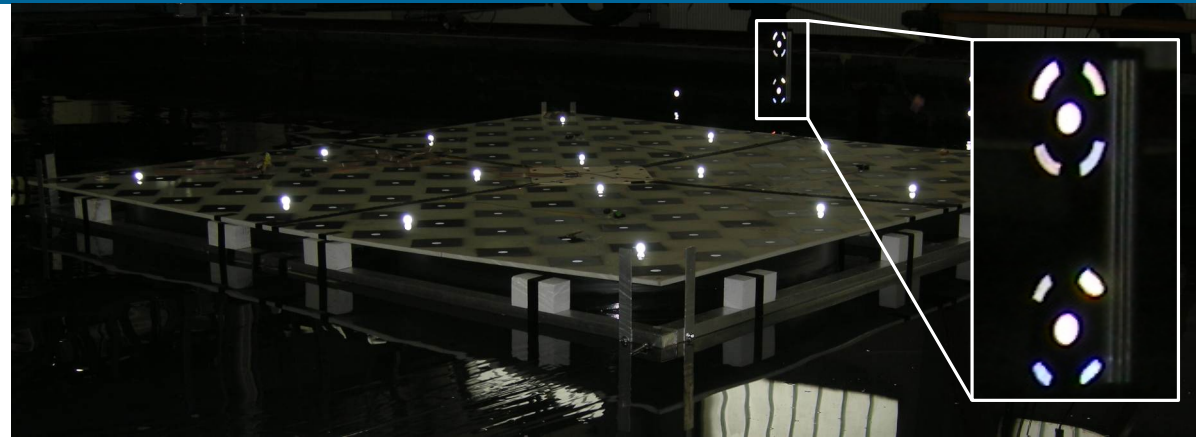
Relative accuracy $\approx 1 : 3000$

Evaluation

Low cost - Qualisys Qqus

Measurement series

- ▶ Regular waves
- ▶ Irregular waves
→ dynamic georeferencing

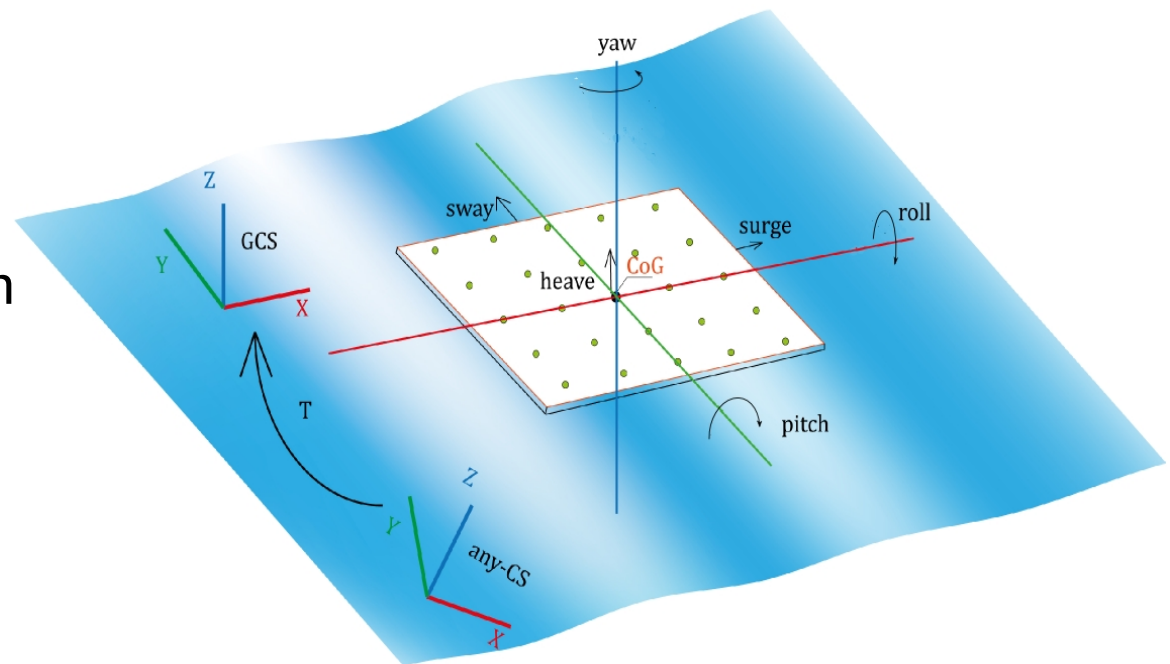


Ship motions

- ▶ surge, sway, heave
- ▶ roll, pitch, yaw

Workflow

- ▶ equalize temporal resolution
- ▶ retrieve ship motions
- ▶ align the motions in time by cross-correlation
- ▶ compare results visually and RMSE

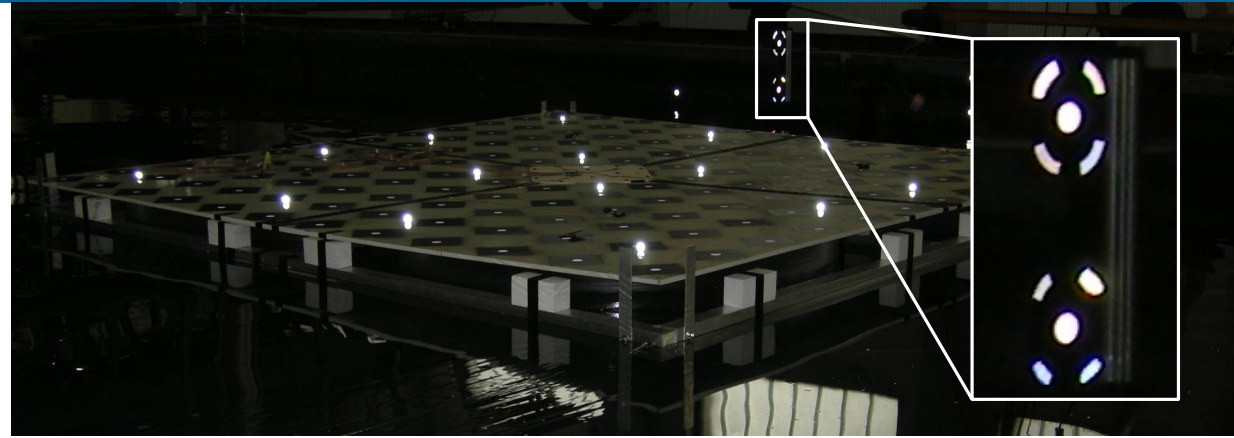


Evaluation

Low cost - Qualisys Qqus

Measurement series

- ▶ Regular waves
- ▶ Irregular waves
→ dynamic georeferencing

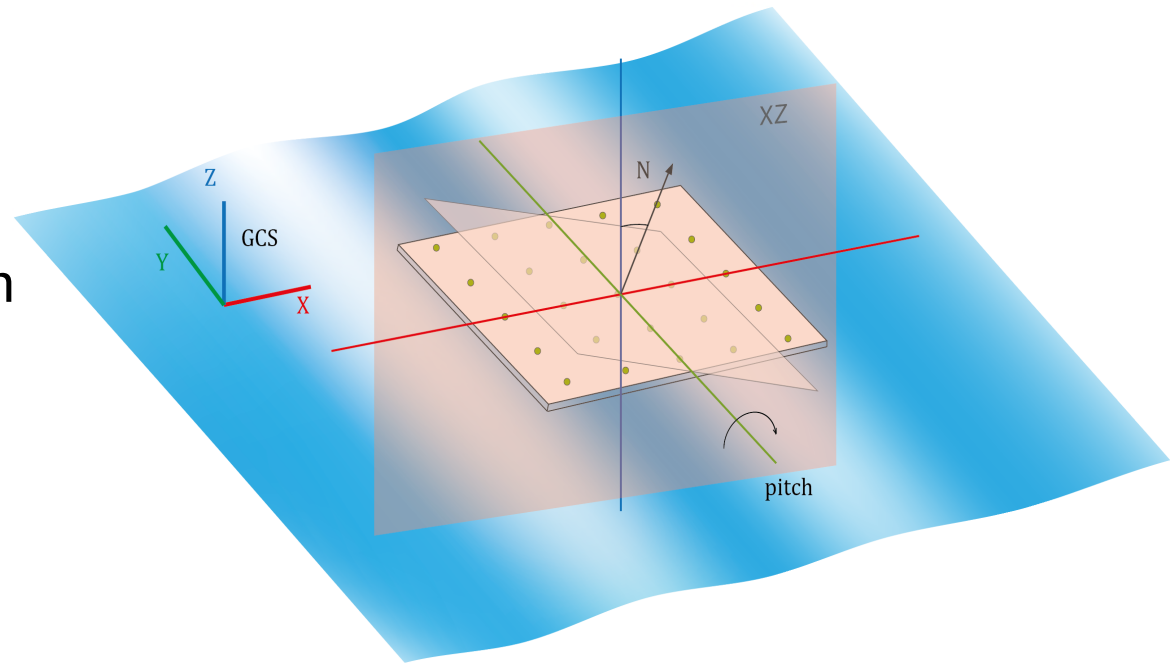


Ship motions

- ▶ surge, sway, heave
- ▶ roll, pitch, yaw

Workflow

- ▶ equalize temporal resolution
- ▶ retrieve ship motions
- ▶ align the motions in time by cross-correlation
- ▶ compare results visually and RMSE

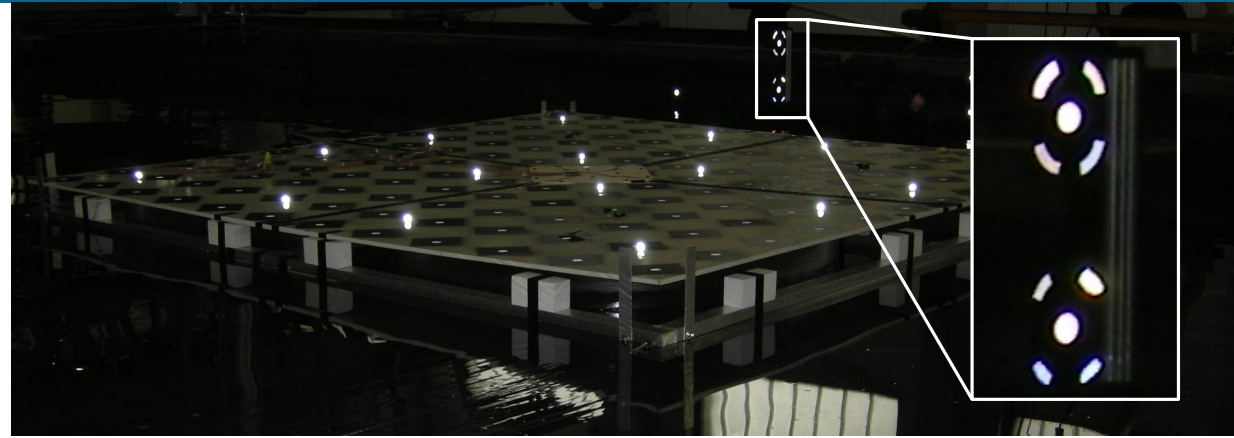


Evaluation

Low cost - Qualisys Qqus

Measurement series

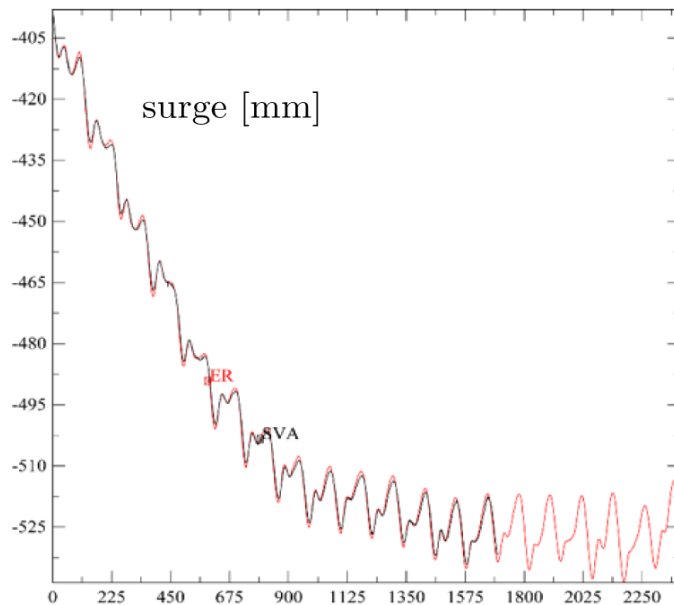
- ▶ Regular waves
- ▶ Irregular waves
→ dynamic georeferencing



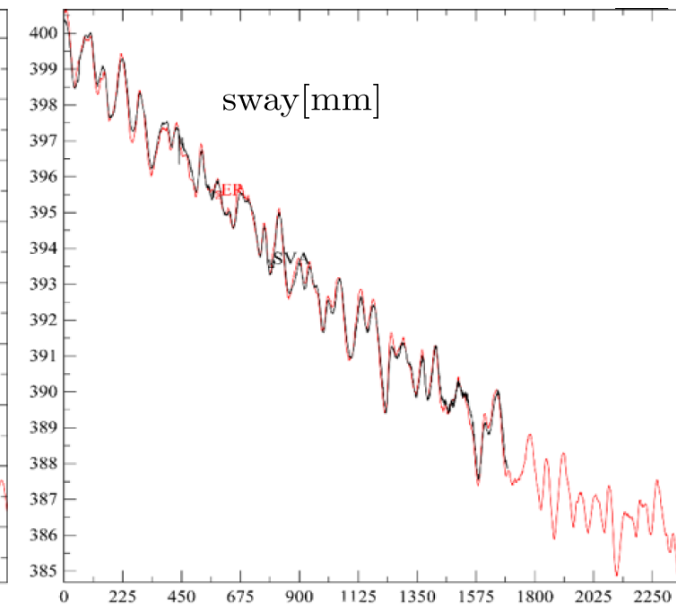
Ship motions

- ▶ surge, sway, heave

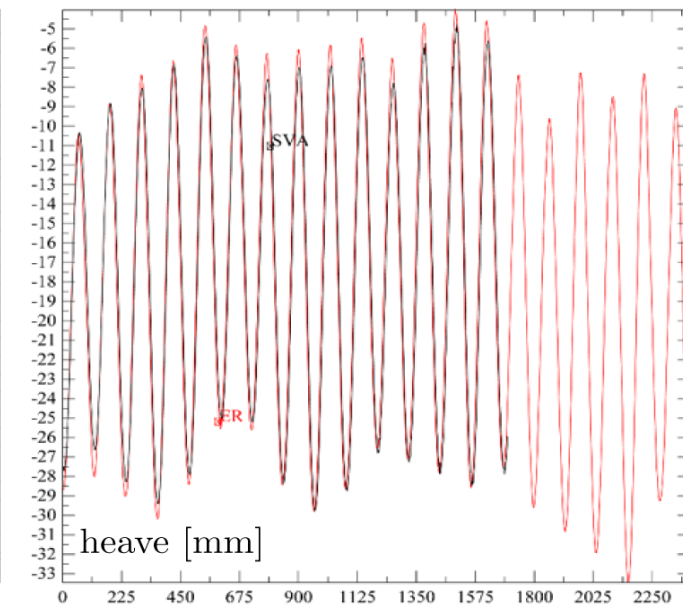
$$RMSE = \sqrt{\frac{(X_{SVA} - X_{ER})^2}{n_{samples}}}$$



$RMSE = 0.95mm$



$RMSE = 0.19mm$



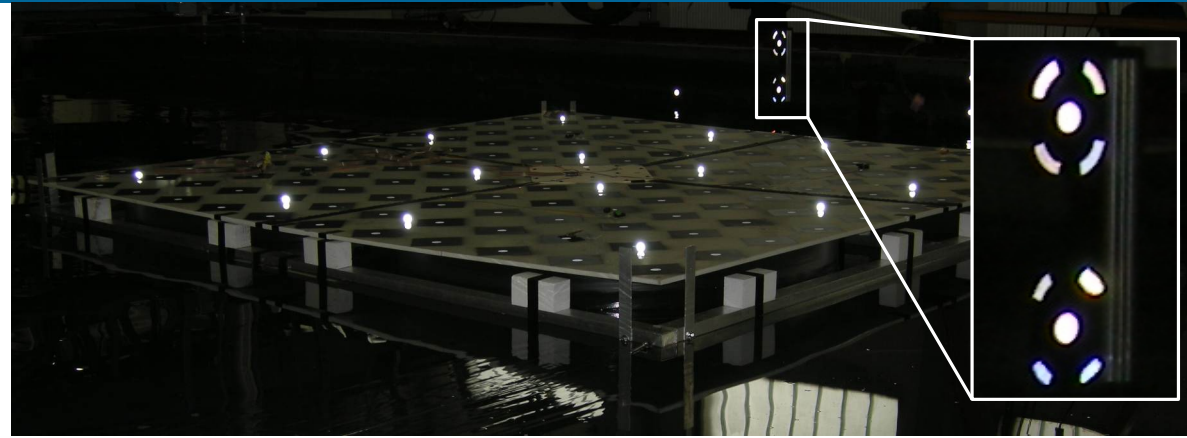
$RMSE = 1.42mm$

Evaluation

Low cost - Qualisys Qqus

Measurement series

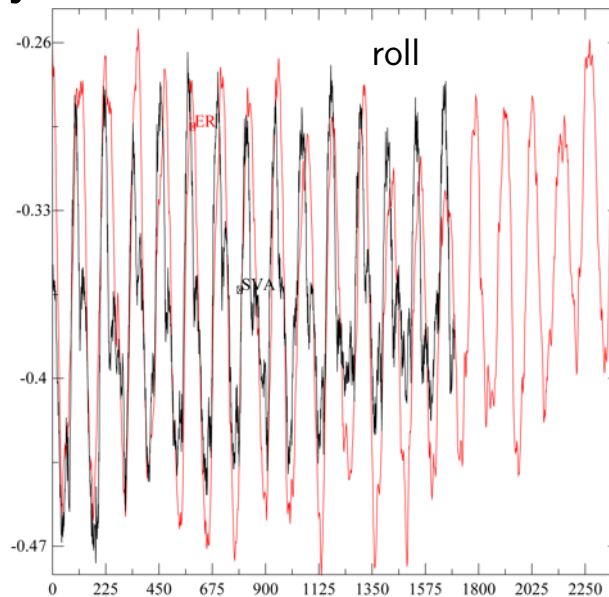
- ▶ Regular waves
- ▶ Irregular waves
→ dynamic georeferencing



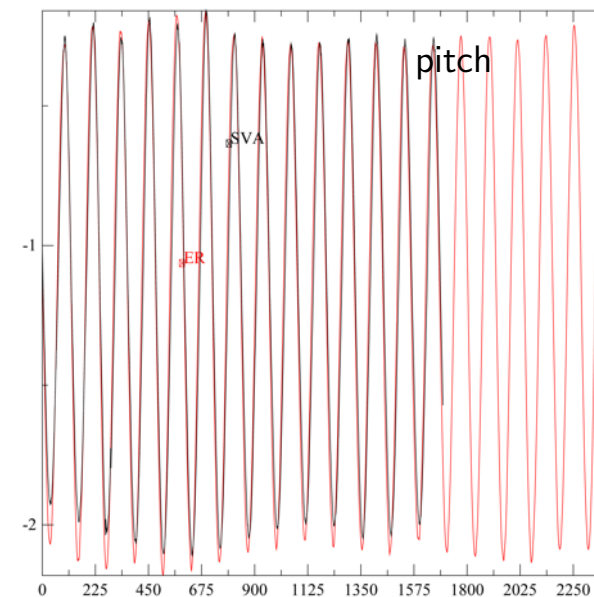
Ship motions

- ▶ surge, sway, heave
- ▶ roll, pitch, yaw

$$RMSE = \sqrt{\frac{(X_{SVA} - X_{ER})^2}{n_{samples}}}$$



$RMSE = 0.04^\circ$
 $\approx 18\%$ max amplitude



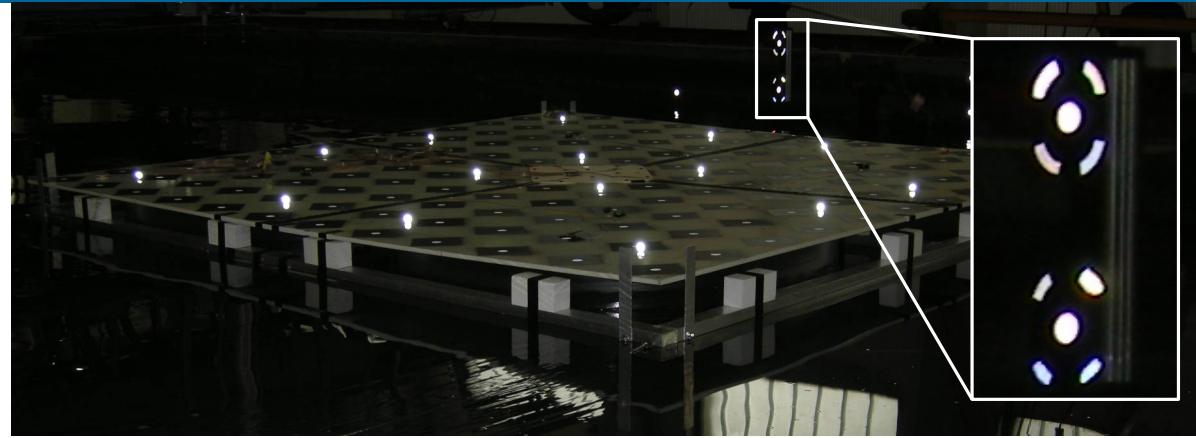
$RMSE = 0.12^\circ$
 $\approx 6\%$ max amplitude

Evaluation

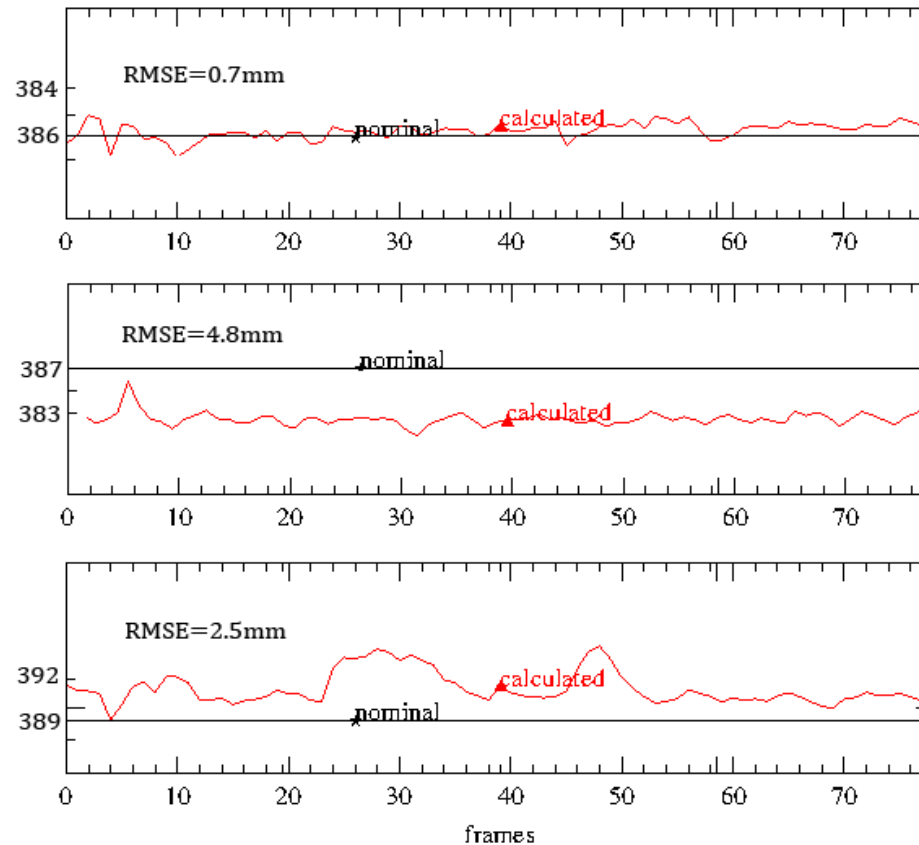
Low cost - Qualisys Qqus

Measurement series

- ▶ Regular waves
 - ▶ Irregular waves
- dynamic georeferencing



Measured distances



Conclusion

- ▶ dSLR cameras are flexible *offline* tools
 - capture of static object, in high resolution (20MPix+), at **high accuracy** levels
 - serve as video cameras, lower resolution, at **moderate accuracy** levels
- ▶ Expert knowledge necessary for full exploitation
- ▶ **Sensor deficiencies**
 - image quality is deteriorated due to compression artefacts
 - interfacing with the camera is limited
 - exact synchronization is impossible
- ▶ **Workplace constraints**
 - importance of network design
 - importance of lighting