Measuring with Cameras

Dr. Kevin Köser

GEOMAR

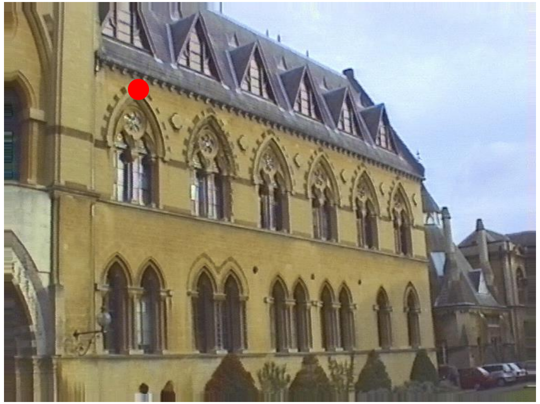
OCEANS
FROM THE DEEP SEA
TO THE ATMOSPHERE

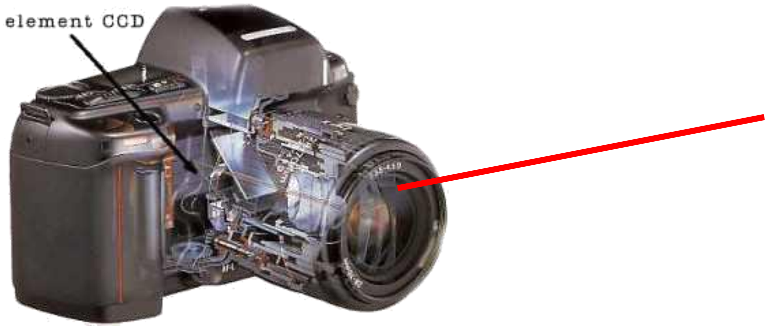
Outline

- Cameras and mathematical models
- Image correspondences and 3D reasoning
- Photometric underwater effects
- Geometric underwater effects
- Applications

Cameras

Collect light from a „viewing ray“ in an image pixel …

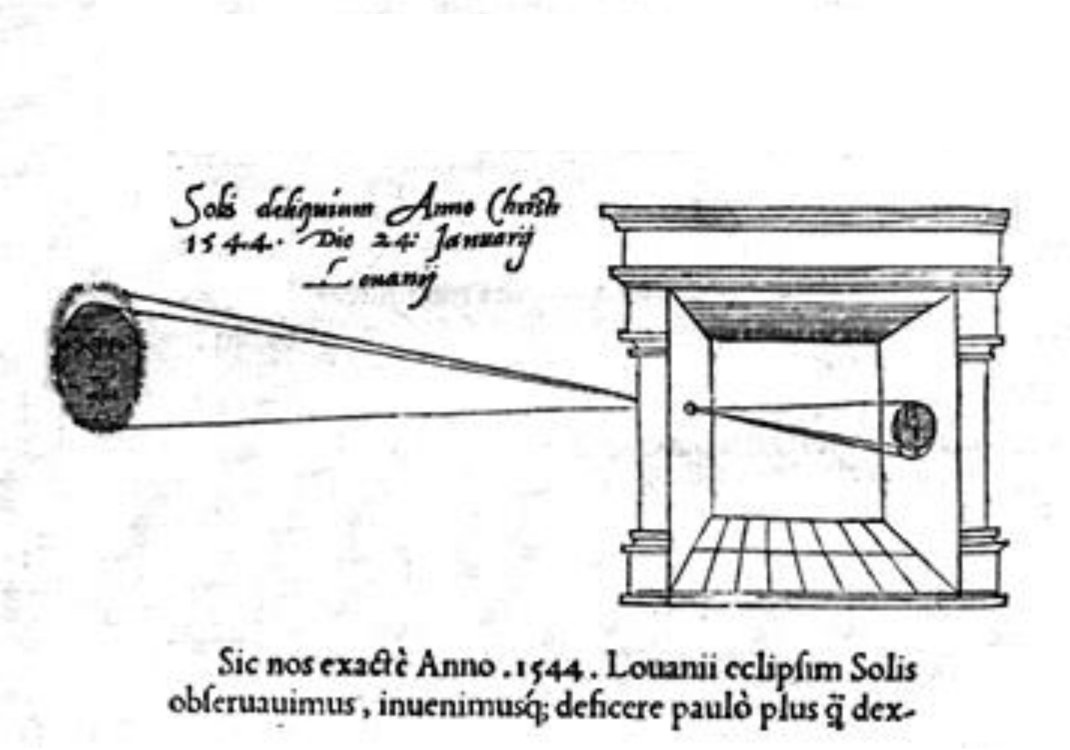




Camera Obscura

First known depiction of the pinhole camera by Dutch mathematician Frisius [1] to observe the solar eclipse in 1544.

Term „camera obscura“ introduced by Johannes Kepler.



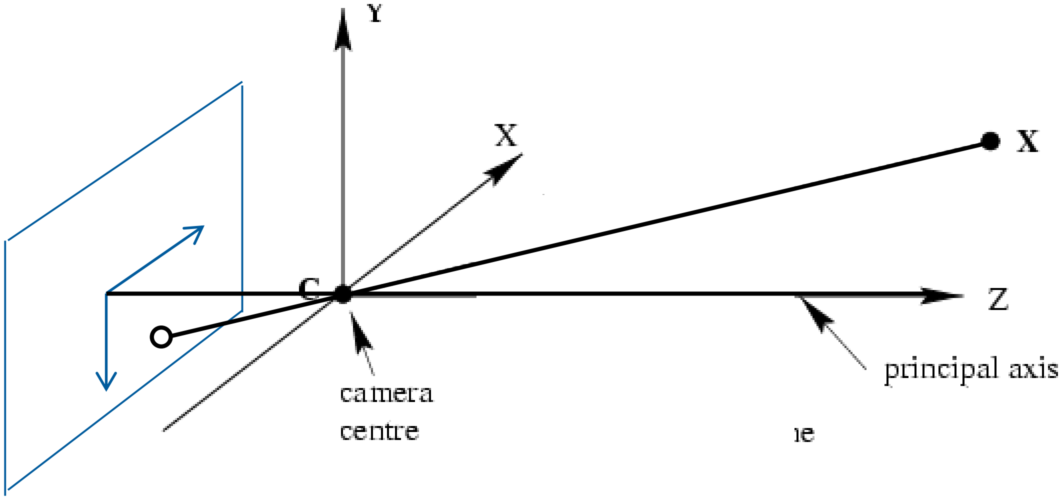
[1] Rainer Gemma Frisius: *De radio astronomico et geometrico liber*. Greg. Bontius, 1545

Pinhole Camera Model

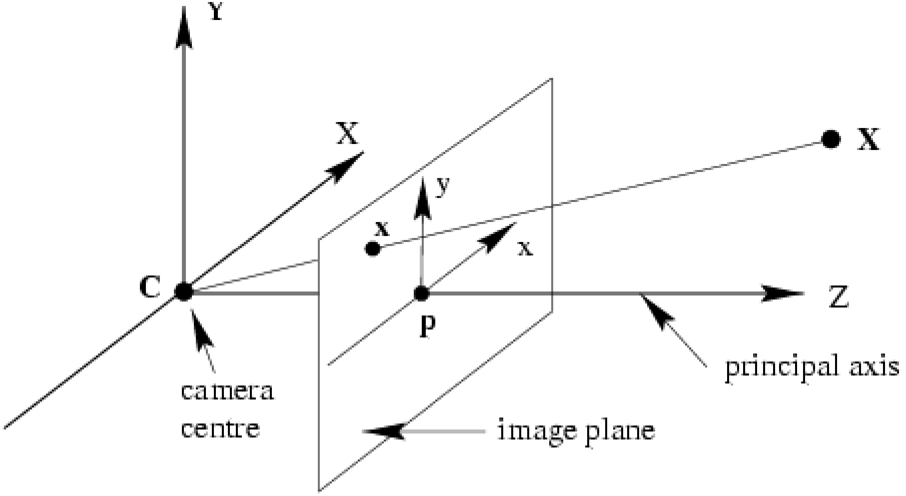
Camera obscura produces „upside down“ image of the object !

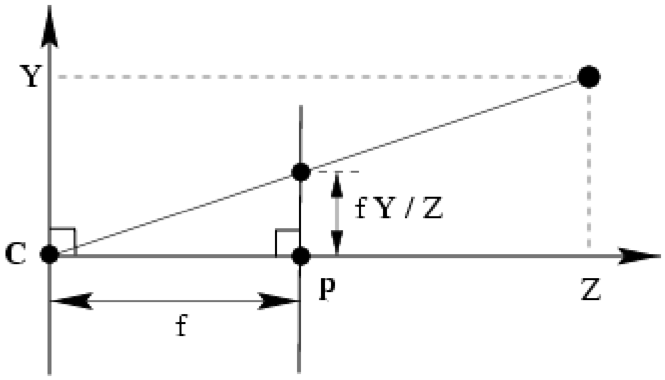
Mathematically equivalent:

Position image plane in front of camera !



Pinhole Camera Model



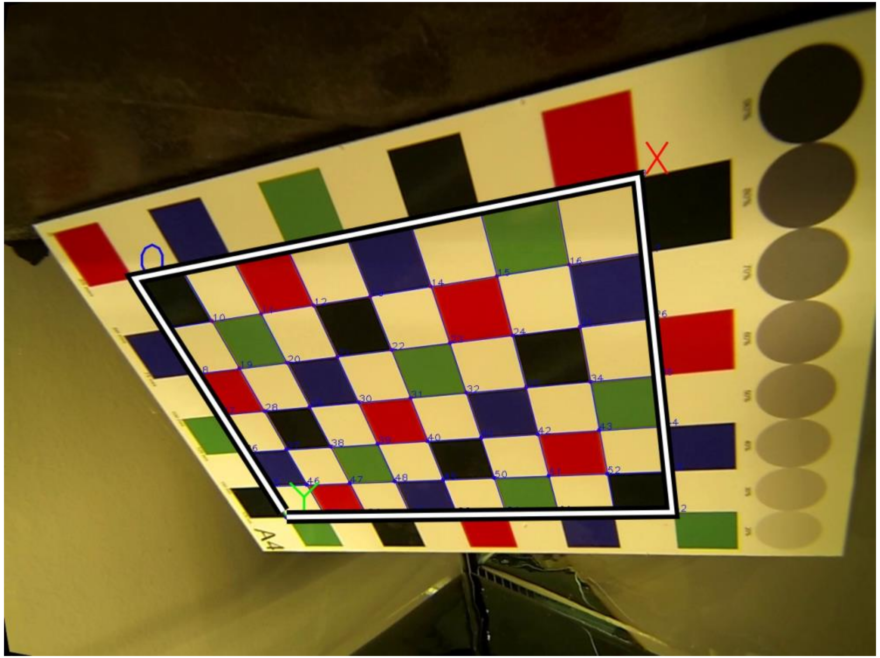


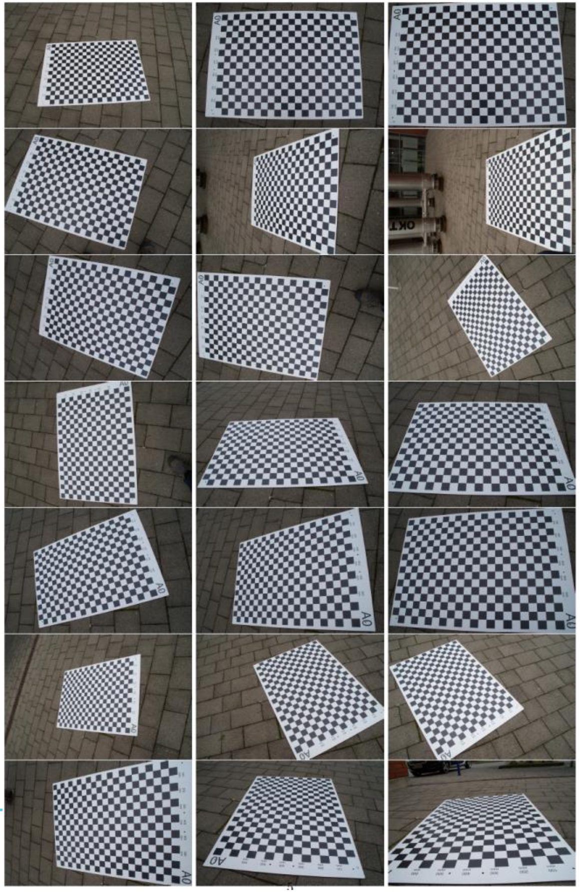
$$(X, Y, Z)^T \mapsto (fX / Z, fY / Z)^T$$

Real cameras compatible with this model ! Just more parameters like distortion, offsets, ...

Pinhole Camera Calibration

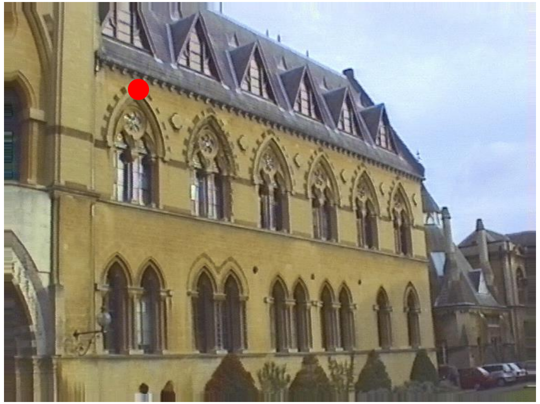
Exact focal length, distortion etc.
can be obtained by calibration.

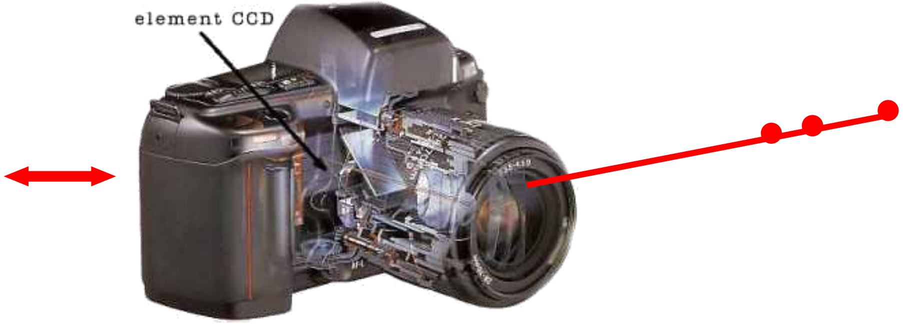




Calibrated Cameras

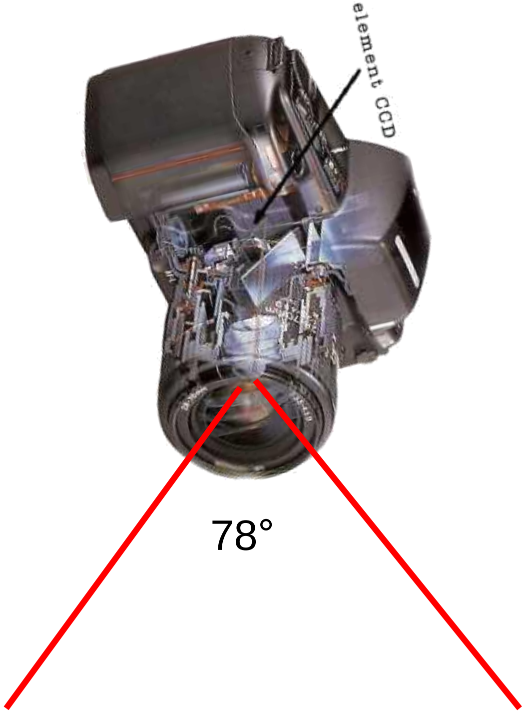
For each pixel the 3D ray direction from the camera center is known, but not the distance.





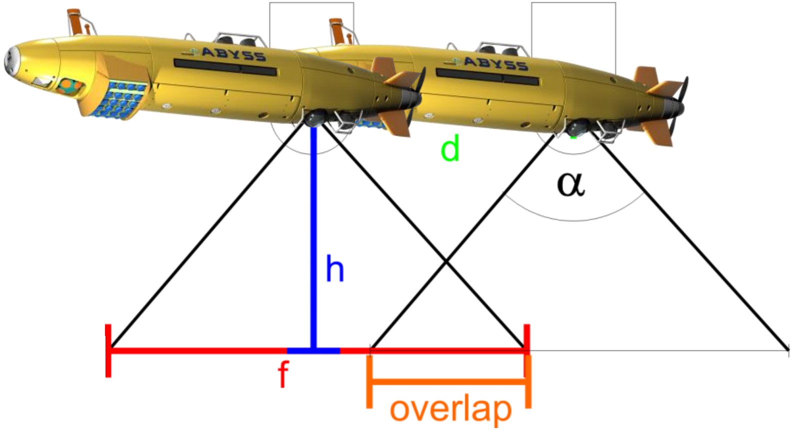
Calibrated Cameras

Also, the field-of-view is known.



Calibrated Cameras

If photographing the flat ground from known altitude,
the **footprint** can be computed



AUV-Modell: T. Kwasnitschka

and for moved cameras the image overlap can be predicted.

World Coordinates

So far, all measurements relative to camera-centric coordinate system.

If position (x,y,z) and orientation (e.g. yaw,pitch, roll) of the camera in the world is known, viewing rays can be expressed in world coordinates.

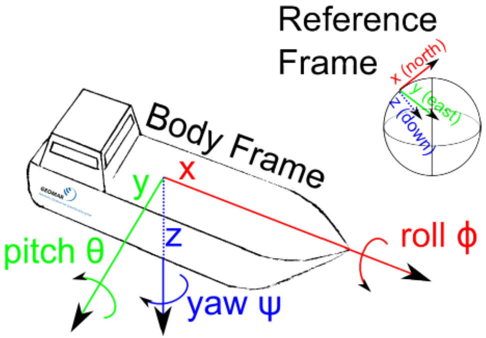
Calibrated Cameras

„extrinsic paramaters“:
latitude, longitude, depth (= 3D position)
yaw, pitch, roll (= 3D orientation)

+

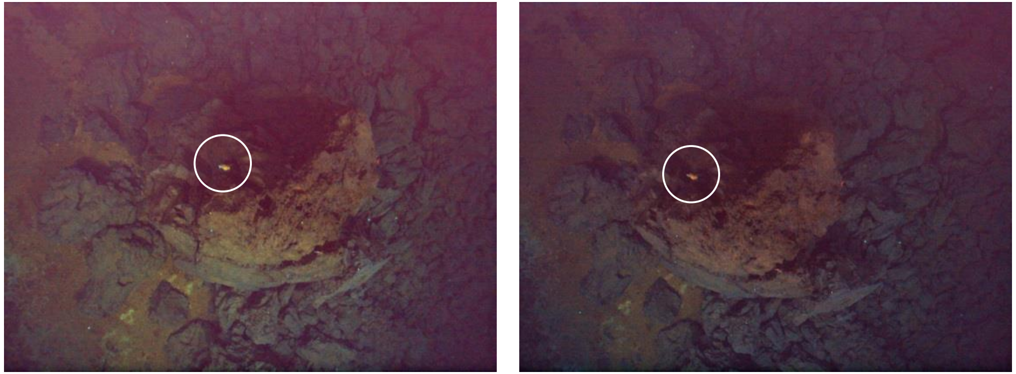
„intrinsic parameters“:
focal length, distortion

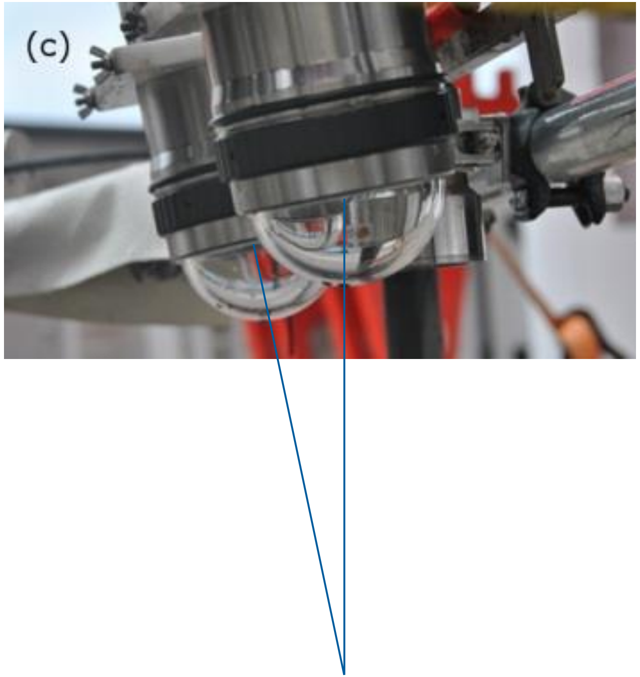
allow **geo-referencing** a photo (=draw it on map).



Measuring Distances

Two images of the same object allow measuring distances.

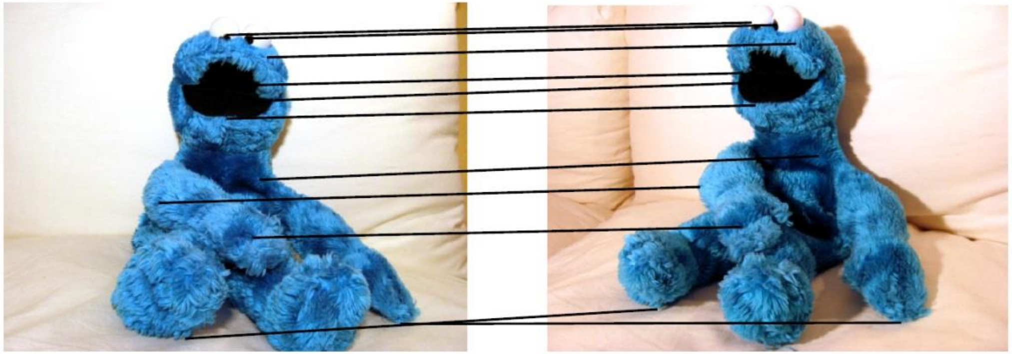




Requires stereo camera system
(or, for static scenes, moving camera)

3D Reconstruction

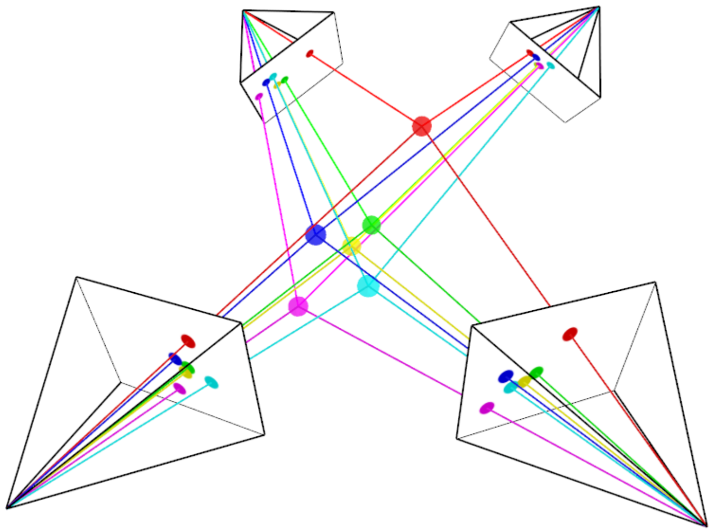
Basic principle:
Identify salient features through images

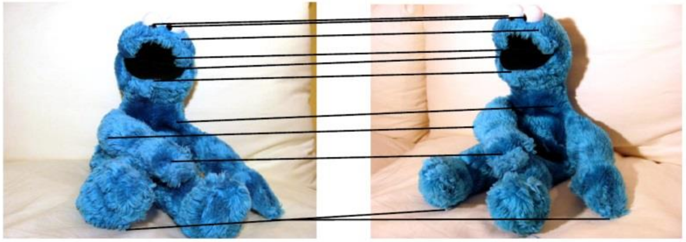


Images / sketches courtesy Anne Jordt

GEOMAR OCEANS FROM THE DEEP SEA TO THE ATMOSPHERE

Compute camera motion and 3D coordinates from positions of features in images.



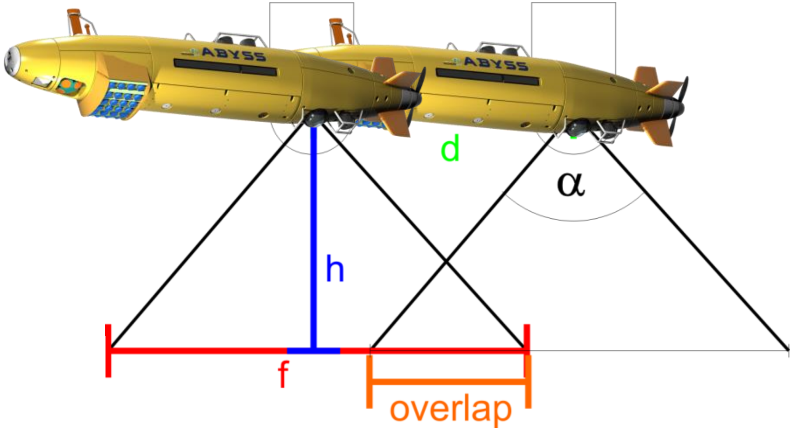


Images / sketches courtesy Anne Jordt

Systematic Seafloor Survey

Finding corresponding points in images requires **overlap**.

AUV-Modell: T. Kwasnitschka



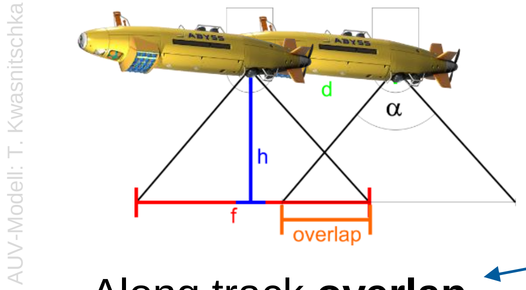
To refine vehicle navigation, points must be seen at least 3 times, better 4-5 times.
(helps also to distinguish rigid seafloor and floating particles/fish).

Systematic Seafloor Survey

Finding corresponding points in images requires **overlap**.

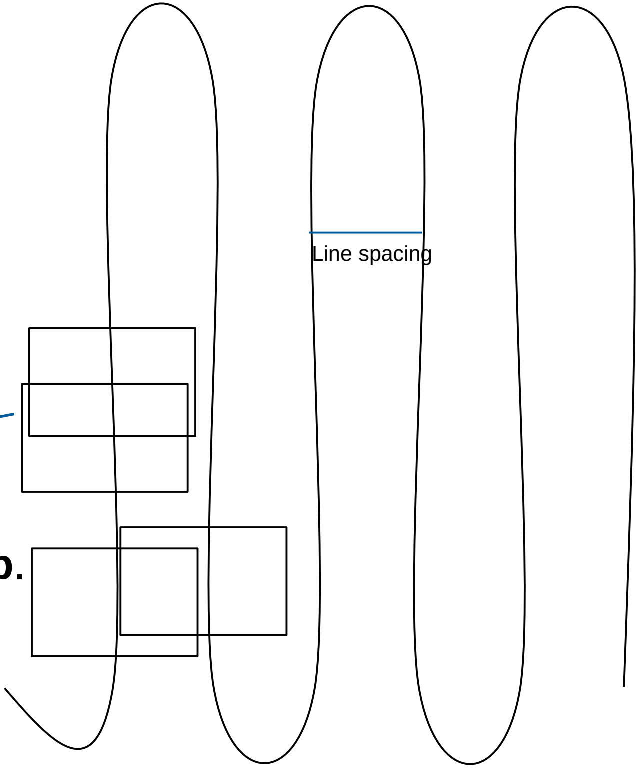
Foto capture rate, line spacing and vehicle speed must consider altitude and image footprint (along track resp. across track) + uncertainty buffer !

Otherwise: holes + drift



Along track **overlap**.

Across track **overlap**.



Over time, estimated position will drift. Can be corrected when seeing „old“ points.

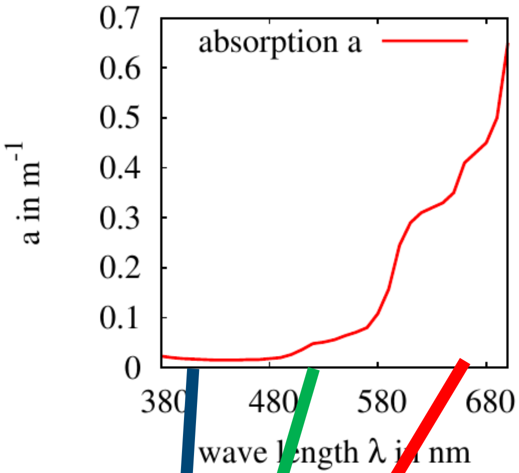
Underwater Imaging

Underwater, all this is complicated by several challenges:
- absorption
- scattering
- refraction
- floating particles
- dynamic illumination
- No GPS / challenging localization
- often difficult/no human intervention (deep sea)

Absorption

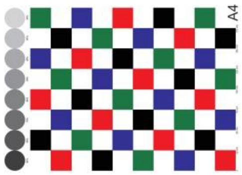
different particles have different absorption characteristics:

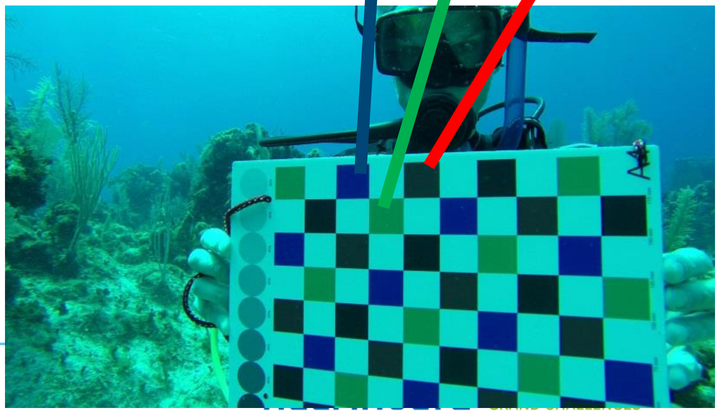
- water molecules
- organic substances
- yellow matter (dissolved remains of animals and plants)
- anorganic matter



absorption in clear water

$$E(\kappa,\lambda) = E(0,\lambda)e^{-a(\lambda)\kappa} \quad [\mathrm{Wm}^{-2}]$$





$\boldsymbol{a(\lambda)}$ **absorption coefficient**

κ distance traveled

$E(0,\lambda)$ irradiance before traveling through water

$E(\kappa,\lambda)$ irradiance after traveling through water

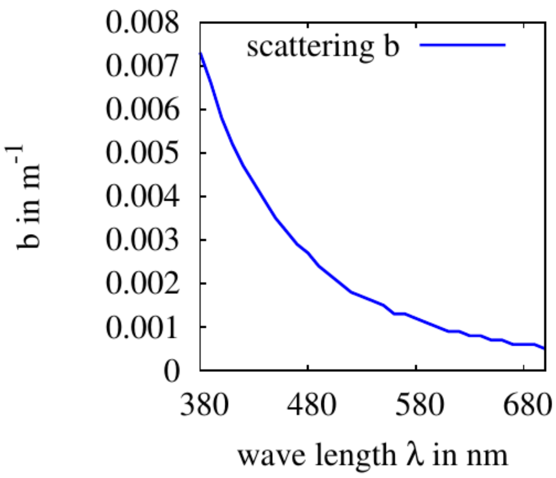
Scattering

- complicated phenomenon – here random change of direction after collision
- [angular dependency omitted for presentation]

$$E(\kappa,\lambda) = E(0,\lambda)e^{-b(\lambda)\kappa} \quad [\mathrm{Wm}^{-2}]$$

b($\boldsymbol{\lambda}$) scattering coefficient
κ distance traveled
$E(0,\lambda)$ irradiance before traveling through water
$E(\kappa,\lambda)$ irradiance after traveling through water

scattering in clear water



“foggy” appearance

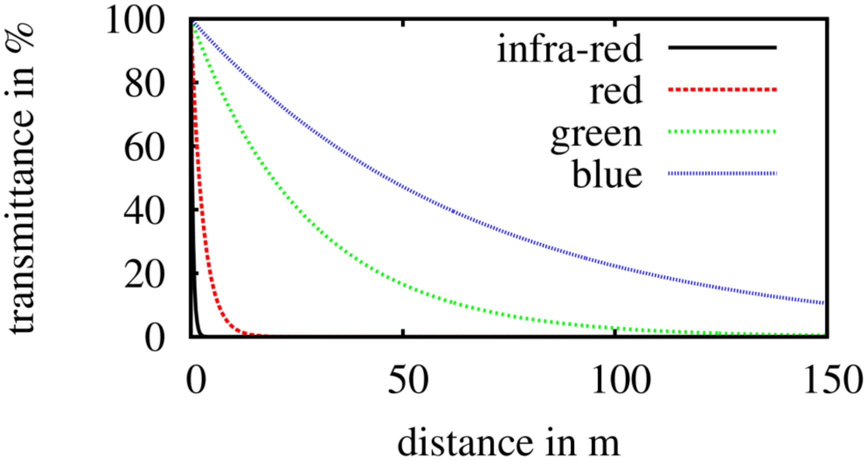
Total signal attenuation

loss of flux due to absorption and scattering

$$\eta(\lambda) = a(\lambda) + b(\lambda) \quad [\mathrm{m}^{-1}]$$

$$E(\kappa, \lambda) = E(0, \lambda) e^{-\eta(\lambda)\kappa} \quad [\mathrm{Wm}^{-2}].$$

$\boldsymbol{\eta(\lambda)}$ **attenuation coefficient**
κ distance traveled
$E(0, \lambda)$ irradiance before traveling through water
$E(\kappa, \lambda)$ irradiance after traveling through water



transmittance in clear water

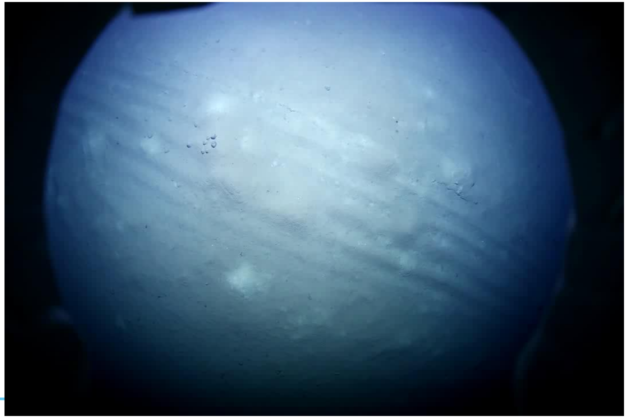
Transmittance for clear water

λ in [nm]	Attenuation η in [m^{-1}]	90% left after in [m]	50% left after in [m]	10 % left after in [m]	1% left after in [m]
440 (blue)	0.015	5.545	36.48	121.2	242.4
510 (green)	0.036	2.773	18.24	60.59	121.2
650 (red)	0.350	0.301	1.98	6.579	13.16
800 (near infra-red)	2.051	0.051	0.3381	1.123	2.246

Photometric challenges

- Absorption
- Scattering
- Floating Particles
- Little/dynamic Light

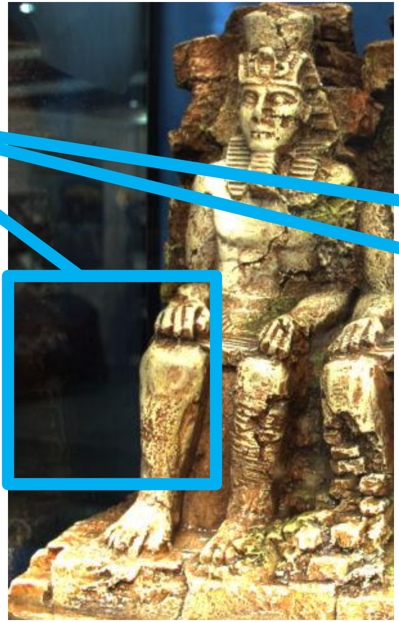
Courtesy Ocean Networks Canada / Ocean Exploration Trust, Thanks to T. Kwasnitschka



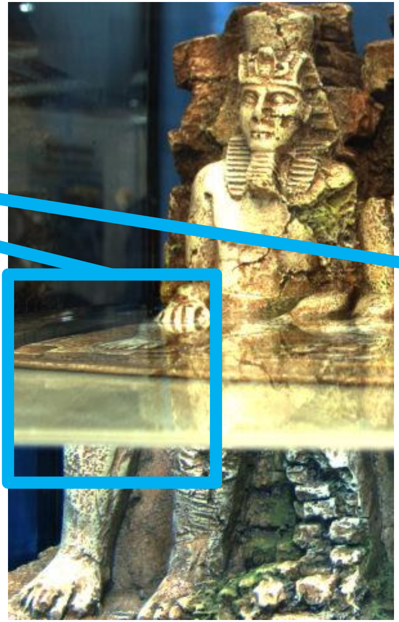
=> Measuring color is extremely difficult !

Refraction

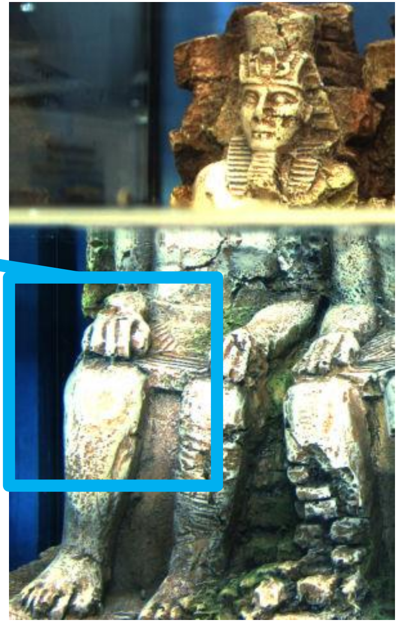
- different fields of view in air and water
- bent rays allow to "look around" objects to some extent
- changes in focus, especially for dome port cameras



No water in tank



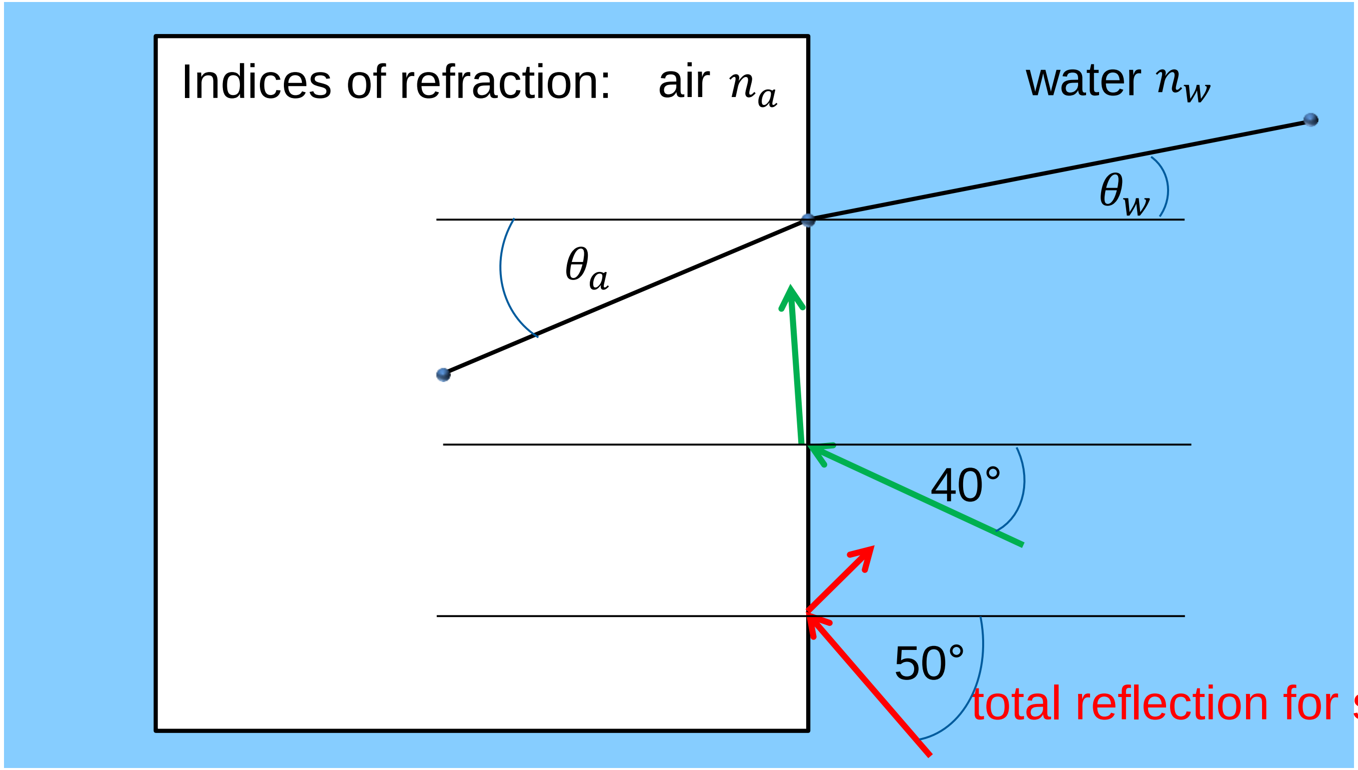
Filling tank with water…



2/3 full

=> Same happens when submerging a camera in the ocean !

Refraction at flat interfaces



Snell's law:

$$\frac{\sin\theta_w}{\sin\theta_a} = \frac{n_a}{n_w}$$

For $\theta_a \rightarrow 90°$
in air/water we have

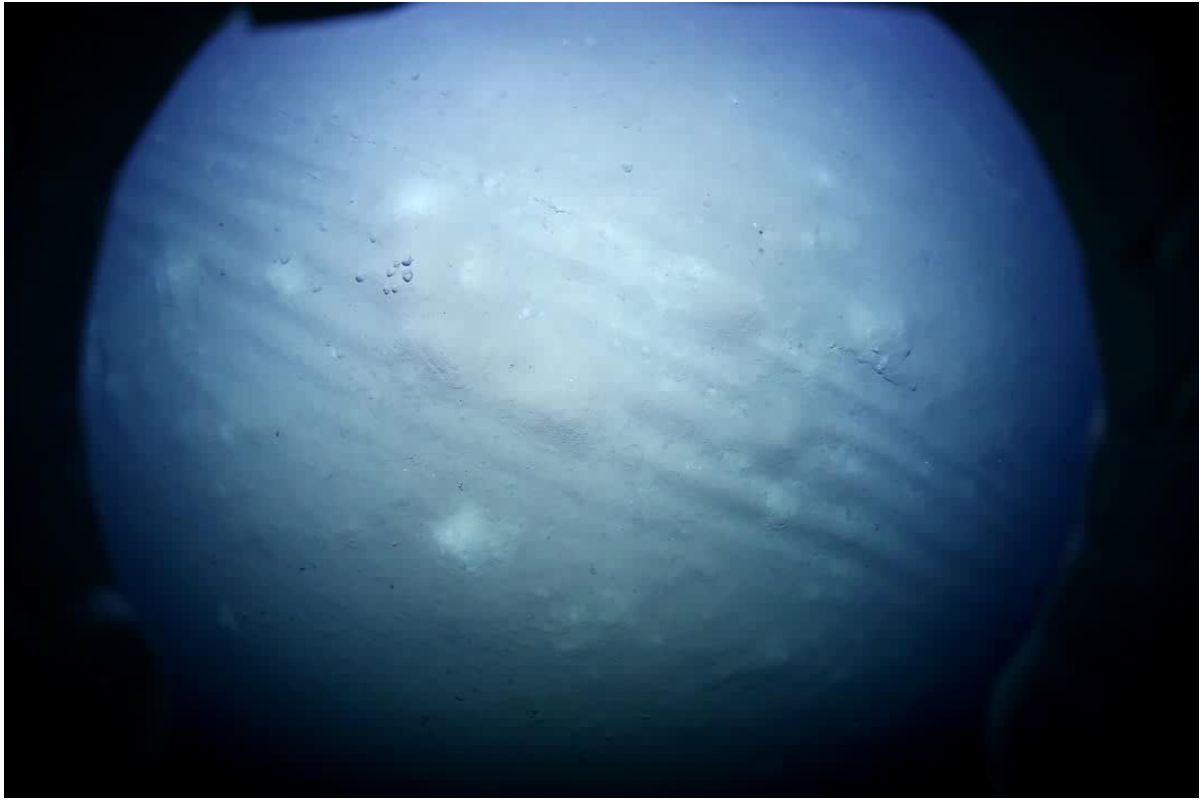
$$\frac{\sin\theta_w}{1} = \frac{1}{1.33}$$

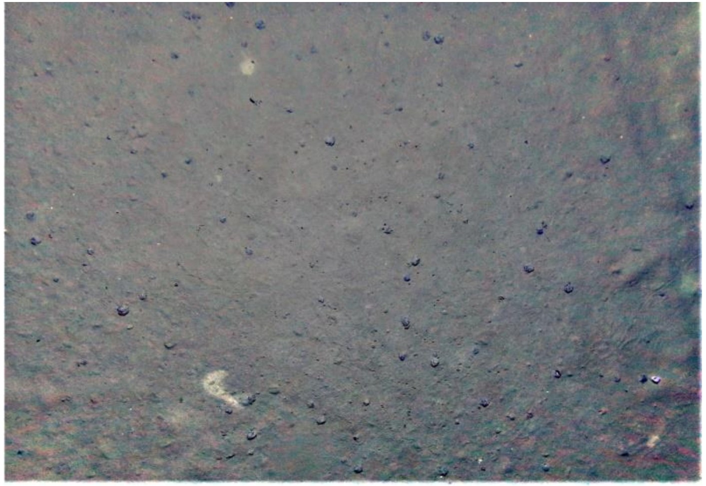
=> θ_w = 48.8°

total reflection for shallow incoming light

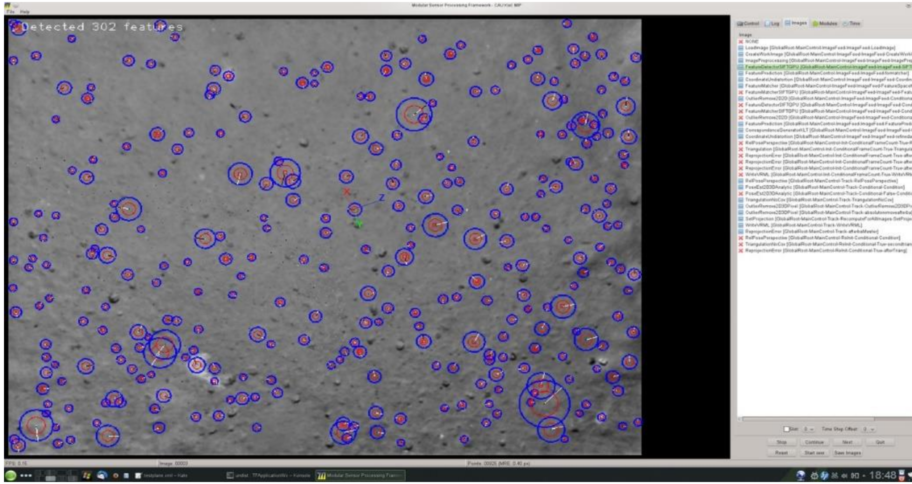
=> Field of view much different "on deck" and "underwater" !

Applications (I): Mapping



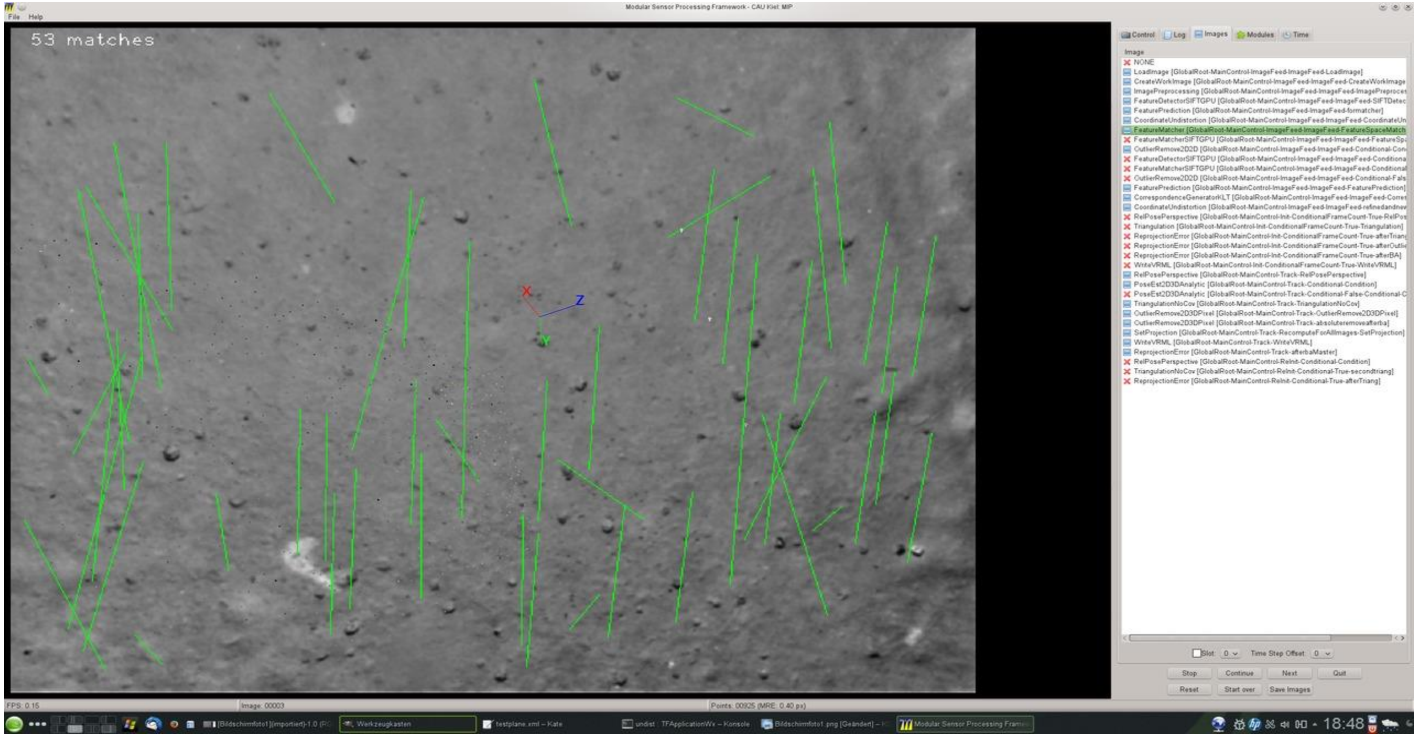


Input image

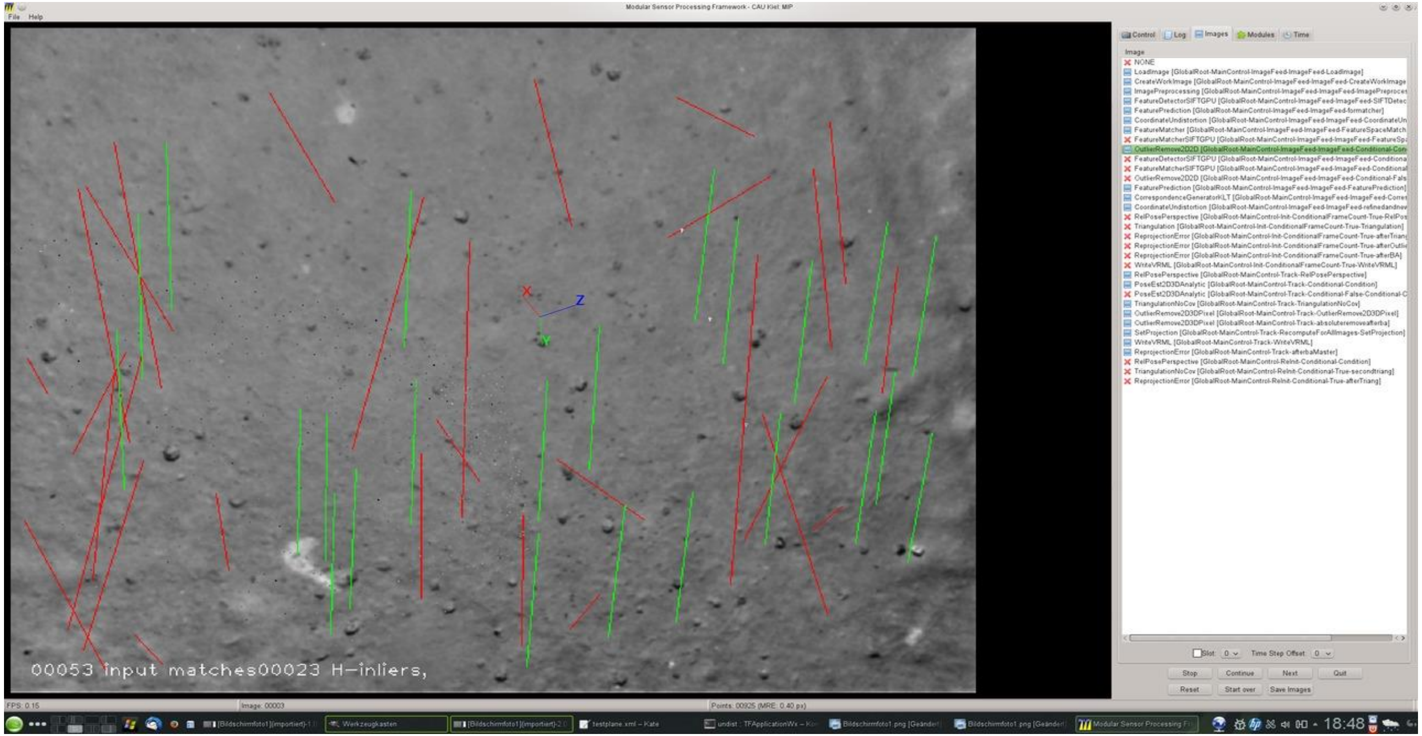


Detected Features

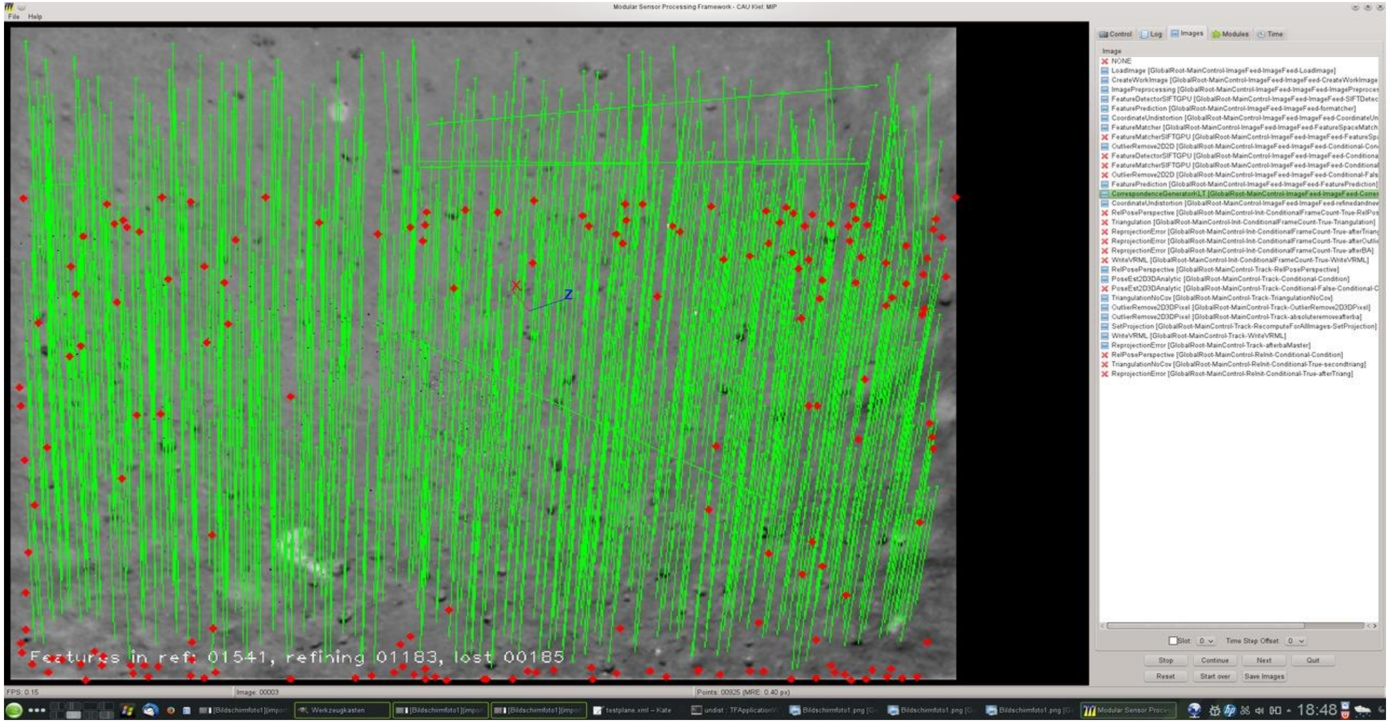
Feature Matcher



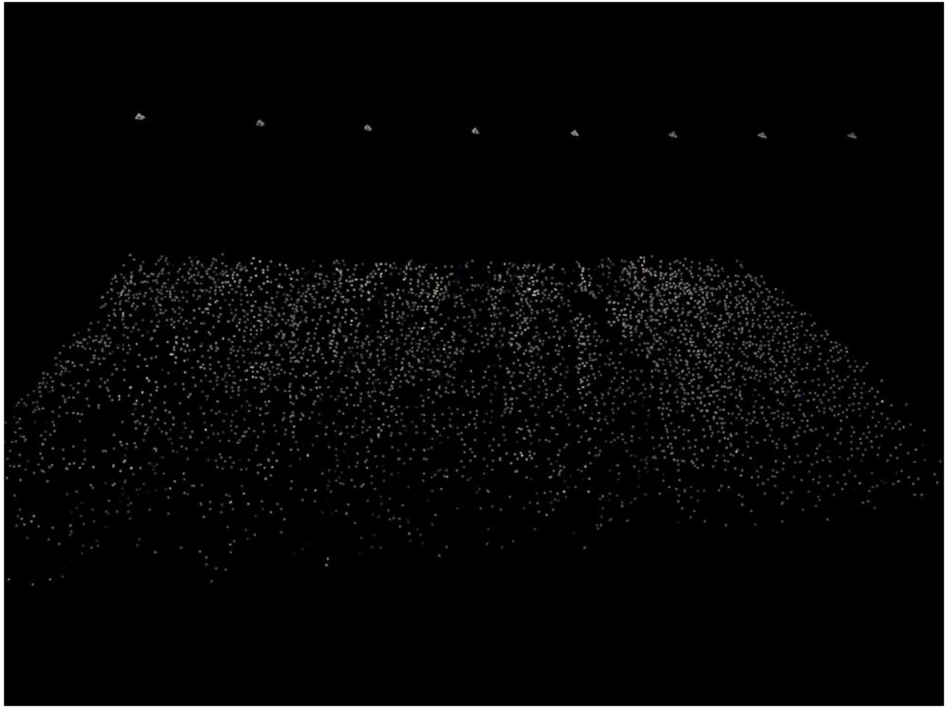
Geometric consensus set



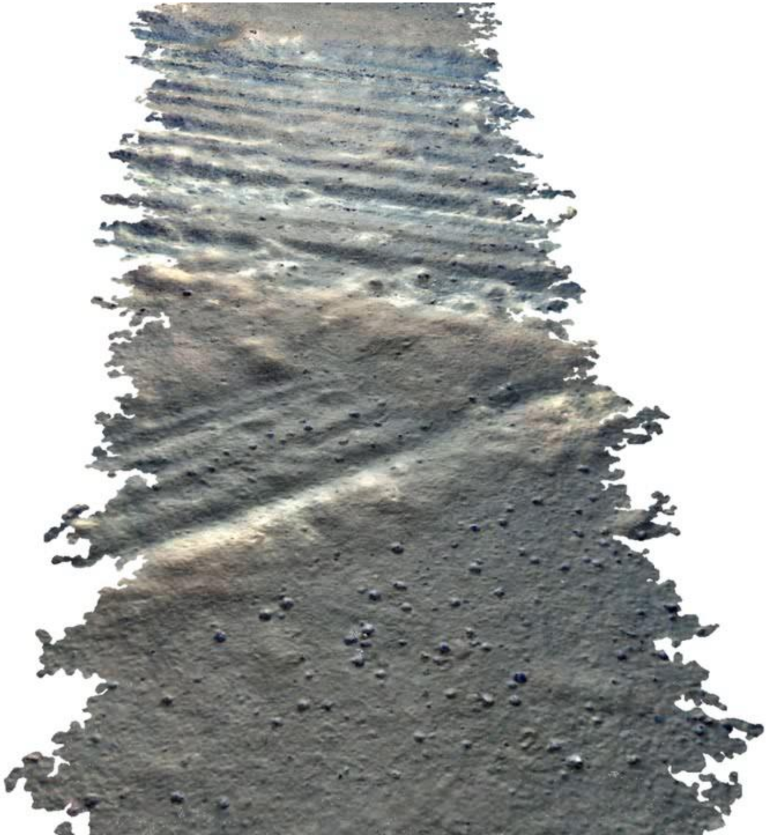
Guided Search, using RANSAC inliers



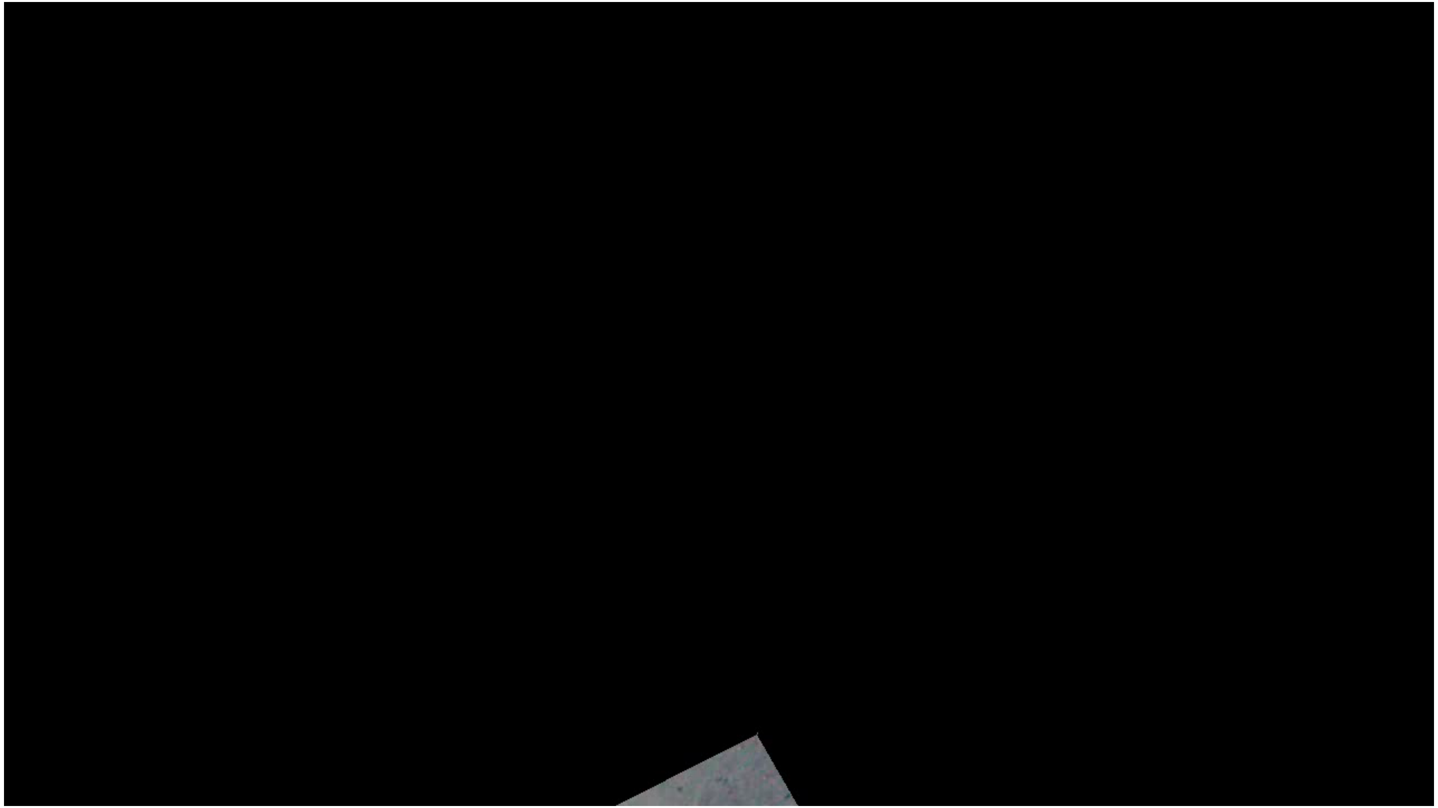
Triangulated Features and Estimated Poses



Digital Seafloor Models
(need correspondence for every pixel, „dense motion stereo“)

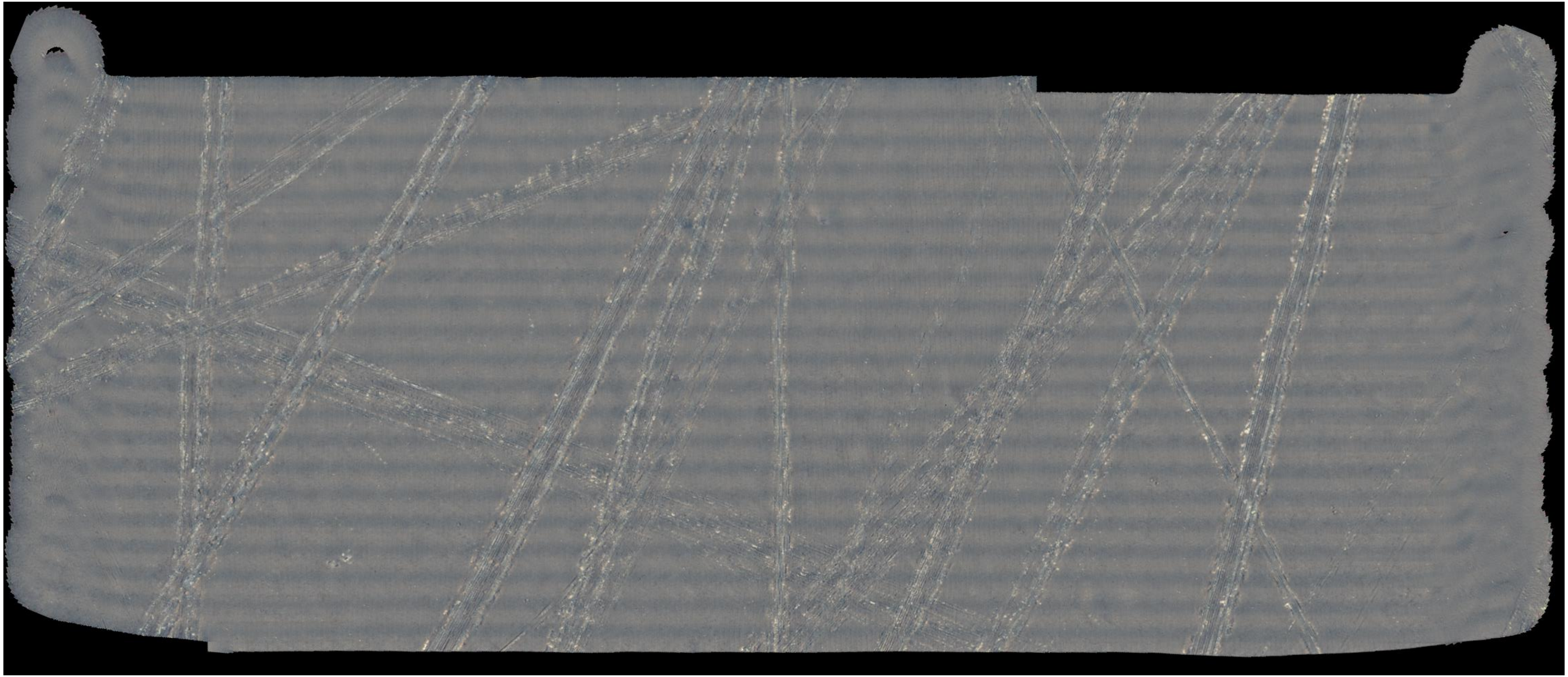


Applications (I): Mapping



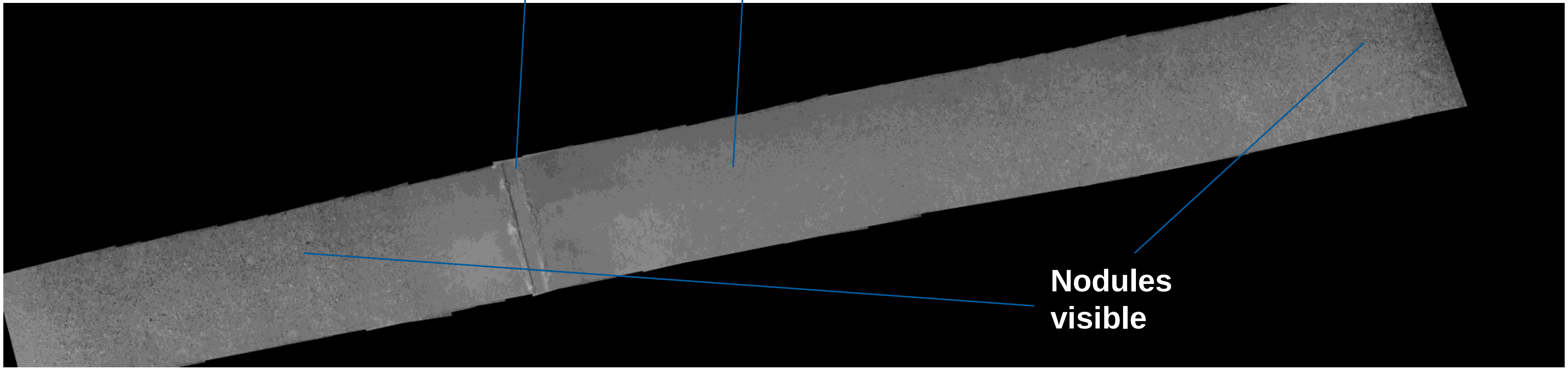
Applications (I): Mapping

450m



>10000 photos, >70000 m^2 (7 football fields), ca. 4,5m altitude. Pattern from 1989 experiment visible in 2015 !

Applications (I): Mapping



Applications (II): 3D Reconstruction

Applications (II): 3D Reconstruction

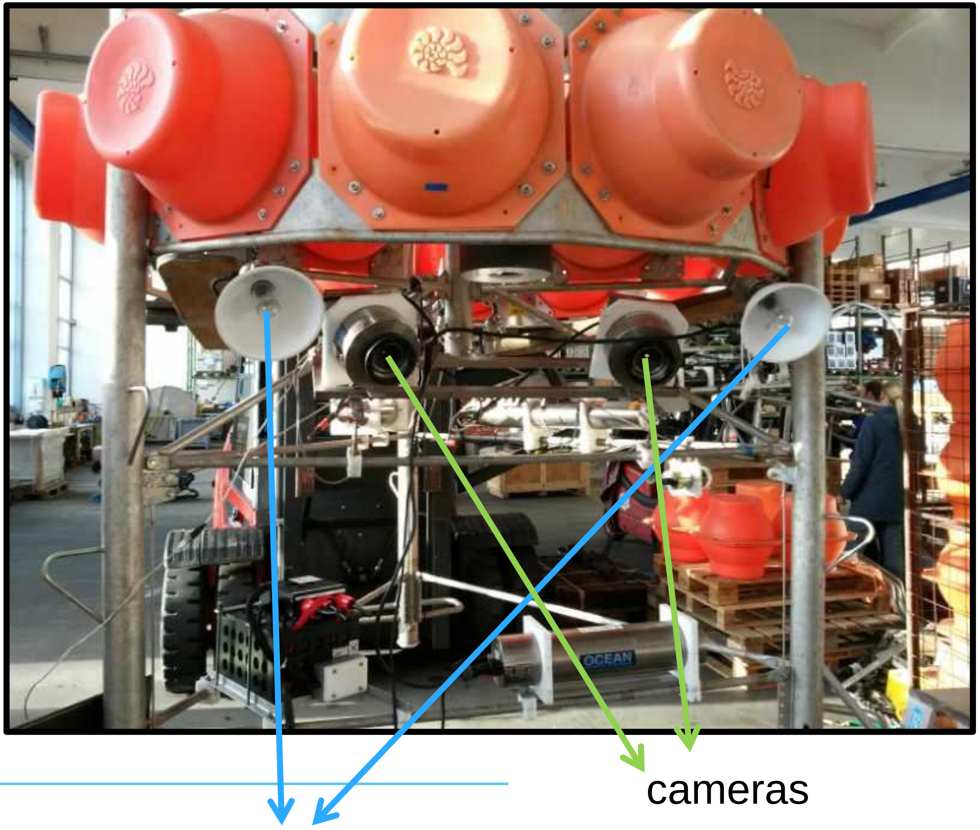
Applications (II): 3D Reconstruction

Applications (III): Time-lapse photography

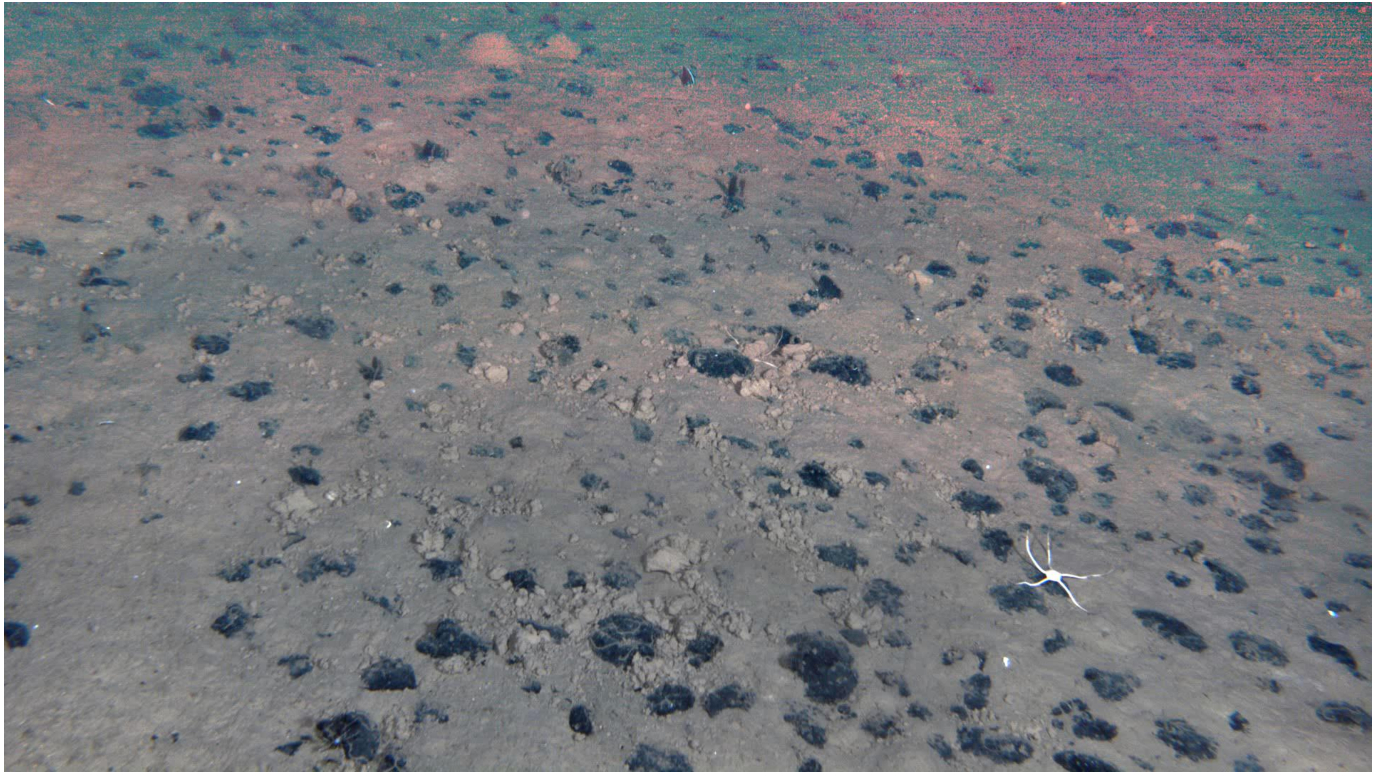
Deployed: 26.03.2015 07:16
during SO239 (station 44) at
11° 51,44' N 117° 0,18' W rwK: 270°
(German license area)
Depth: 4.1 km

Stereo camera takes
photo pair every 15min

After 3 weeks (April 16th) probably
battery (Enitec) has given up.

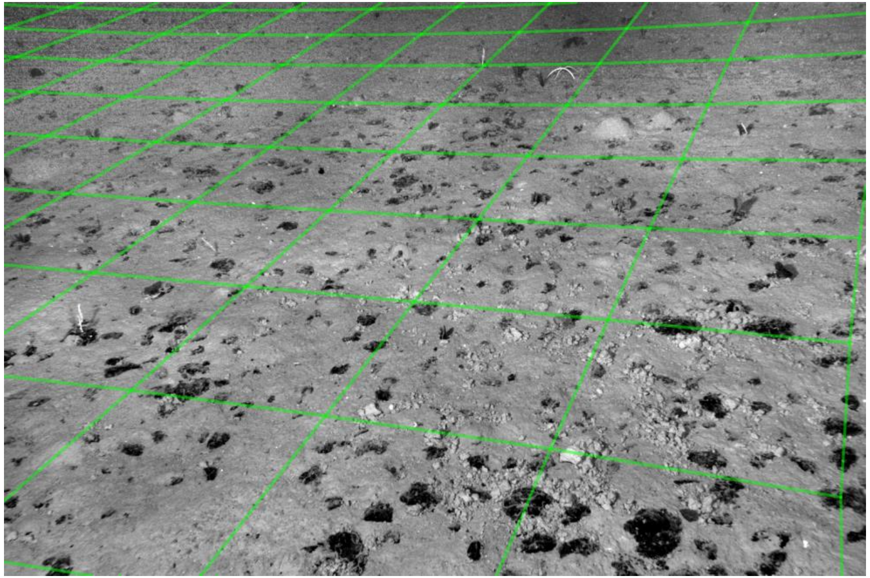


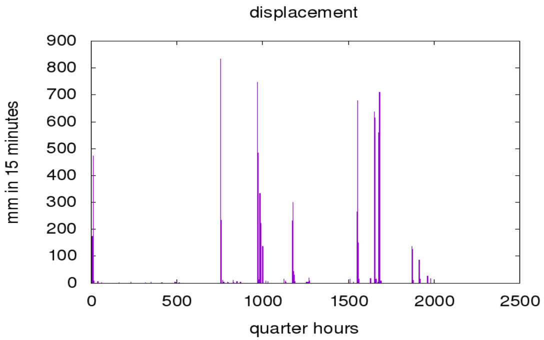
Applications (III): Time-lapse photography



Playback: 1000x faster

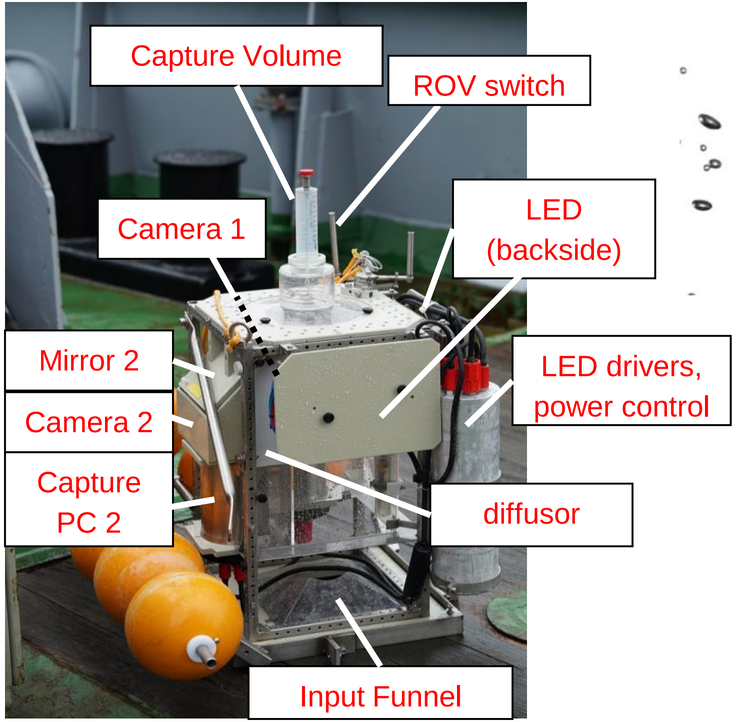
Applications (III): Time lapse photography

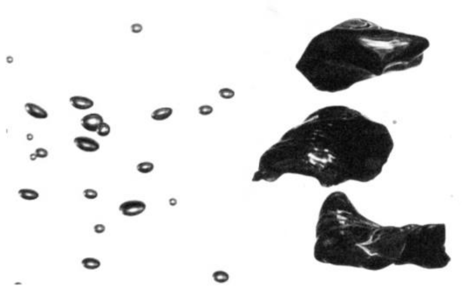


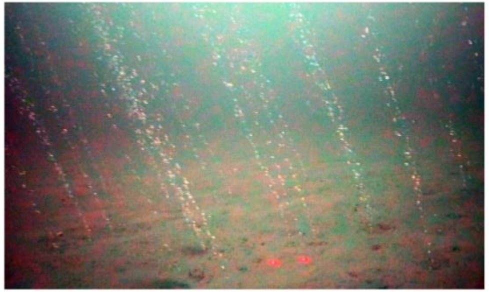


Orphiuroid motion pattern

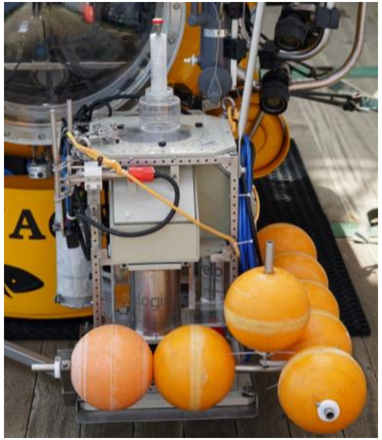
Applications (IV): Bubble stream stereo

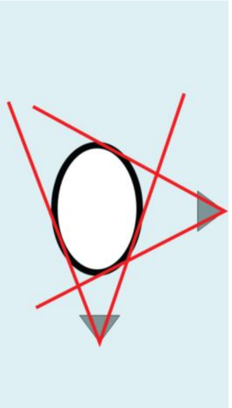




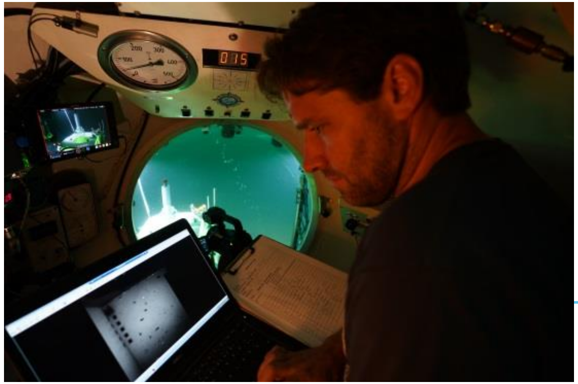


Applications (IV): Bubble stream stereo





(c) wide baseline stereo



Playback: 10x slower

Summary

Calibration + systematic image capture
enables visual measuring and quantitative science !

Underwater effects to consider:
- absorption + scattering degrade image quality
- refraction changes ray directions and field of view
- dynamic lighting + floating particles

Automated methods from machine vision help to create
- maps
- 3D models (for measuring volumes, surfaces, etc.)
- geo-referenced photos
- motion patterns (e.g. bubbles, fauna)