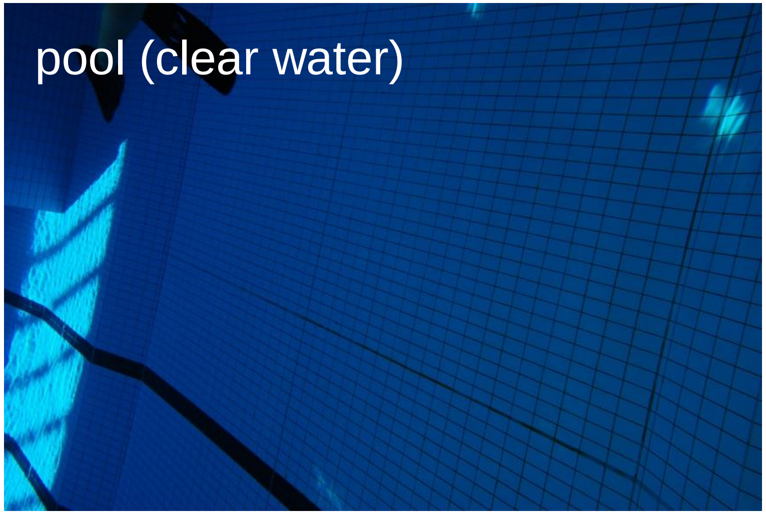
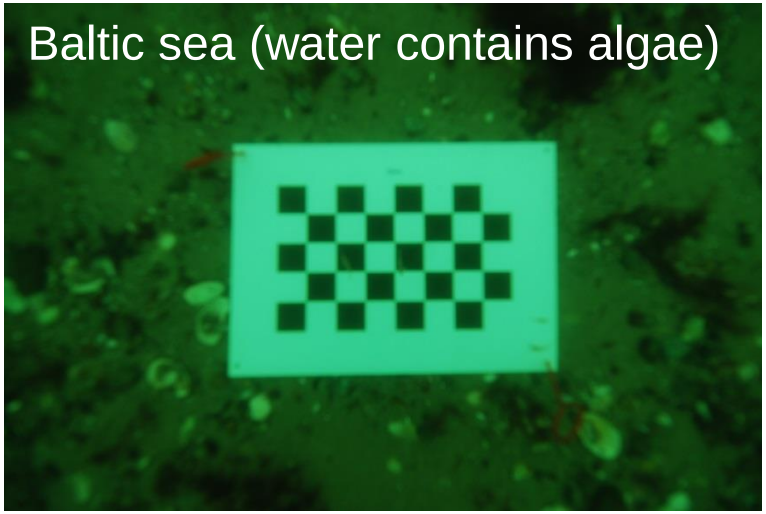
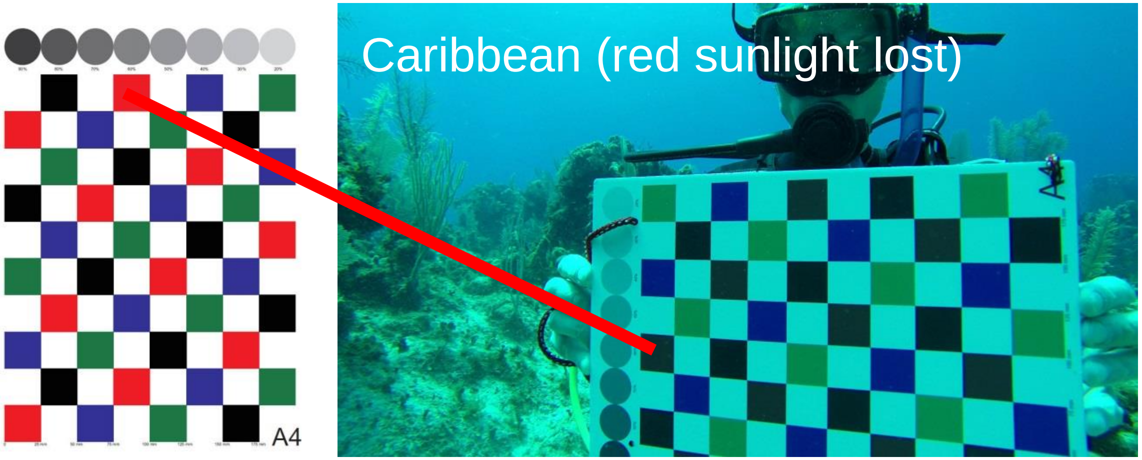
Outline

- Introduction
- Features and Feature Matching
- Geometry of Image Formation
- Calibration
- Structure from Motion
- Dense Stereo
- **Radiometry of Underwater Image Formation**
- Conclusion

Radiometry of Underwater Image Formation







Underwater Light Propagation

- water virtually blocks electromagnetic radiation but …
- visible light is **absorbed** and **scattered** depending on its wavelength

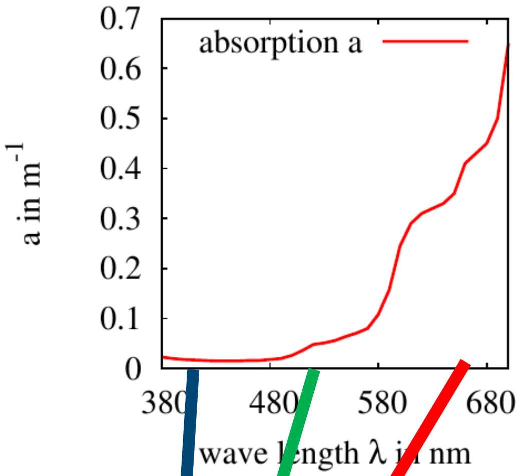
loss of flux out of light beam after photons are absorbed by particles -> main influence on image color

photons change their direction after collision with particle -> degraded visibility

- overall loss of flux depends on distance traveled
- different visibilities in different water bodies (from centimeters to over a hundred meters, usually less than 10 m)

Hecht 05, Mobley 1994

Absorption

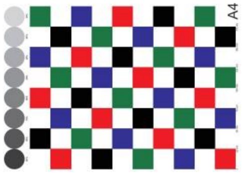


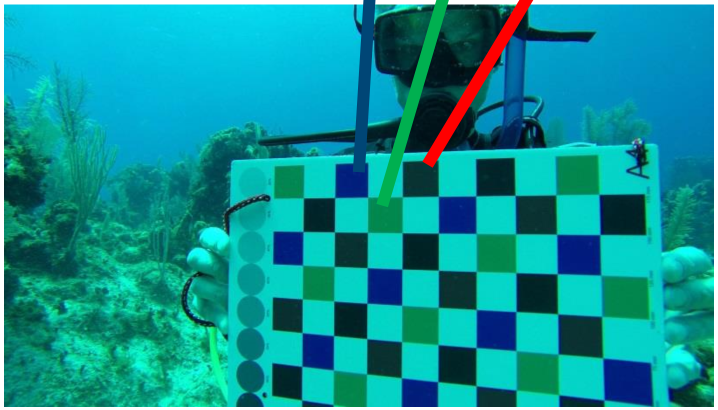
absorption in clear water

different particles have different absorption characteristics:

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

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





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

κ distance traveled

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

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

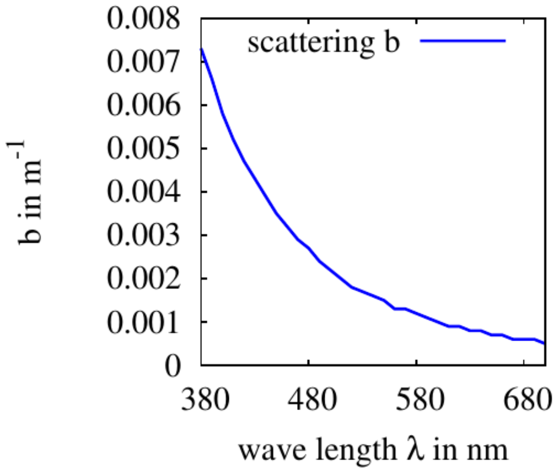
Mobley 1994

Scattering

- complicated phenomenon – here random change of direction after collision

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

b(λ) 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

Mobley 1994

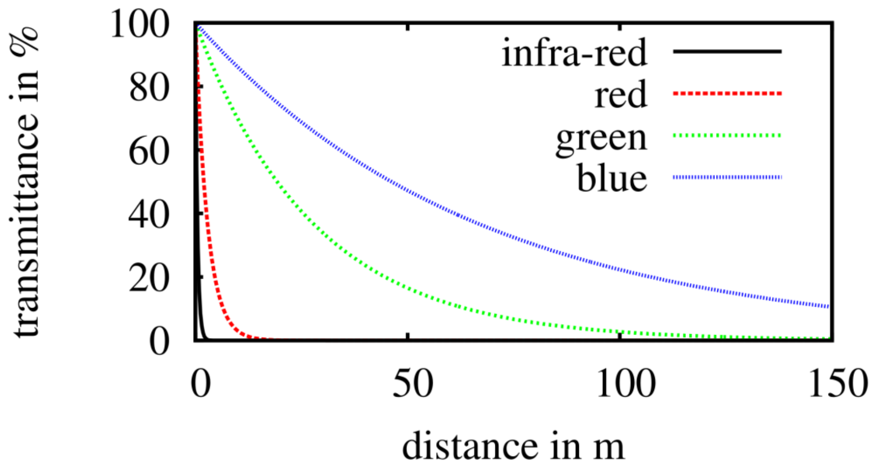
Attenuation

loss of flux due to absorption and scattering

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

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

$\eta(\lambda)$ 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

Mobley 1994

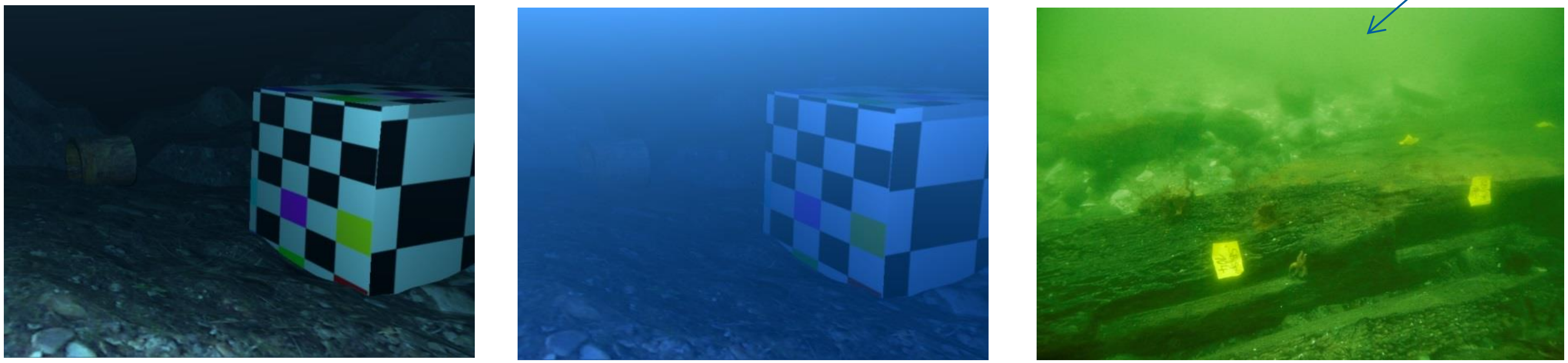
Transmittance for Clear Water

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

Mobley 1994

Backscattering

- photons can be scattered multiple times resulting in a background or **veiling light**
- degraded visibility
- in case of artificial light, backscattering can make objects invisible



Left: clear water, middle: strong scattering (note the light source to the upper left). Right: ship wreck in Baltic Sea with strong veiling light (sun light illumination).

Color Correction

Jaffe McGlamery model works well for simulating underwater light propagation, but is too complicated for color correction (i.e. cannot be easily inverted)

Methods for color correction are classified into physical model based methods (**restoration**) and others (**enhancement**) (state-of-the-art paper: *Schettini and Corchs 2010)*

Restoration:

- simplification of underlying physical principles
- often concentrates on attenuation or backscatter
- For some approaches special camera hardware / optics needed

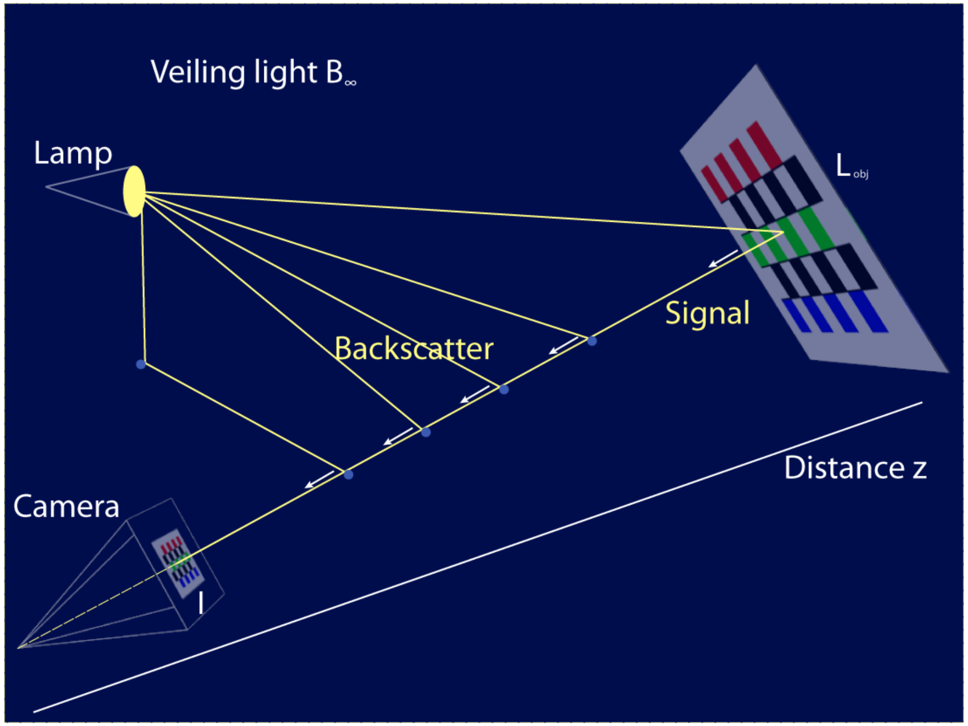
Enhancement:

- different filters, histogram stretching, etc.
- often unclear why method works
- parameters can be very difficult to tune
- often works only on certain water bodies

GEOMAR

Color Restoration

- physical model for underwater light propagation
- simplified Jaffe-McGlamery model used in many computer vision papers
- signal: part of light traveling from lamp to object to camera, distance dependent attenuation
- backscatter: veiling light scattered into the camera, increases with increasing distance
- B_∞ veiling light color
- simple inversion
- correct color for known κ

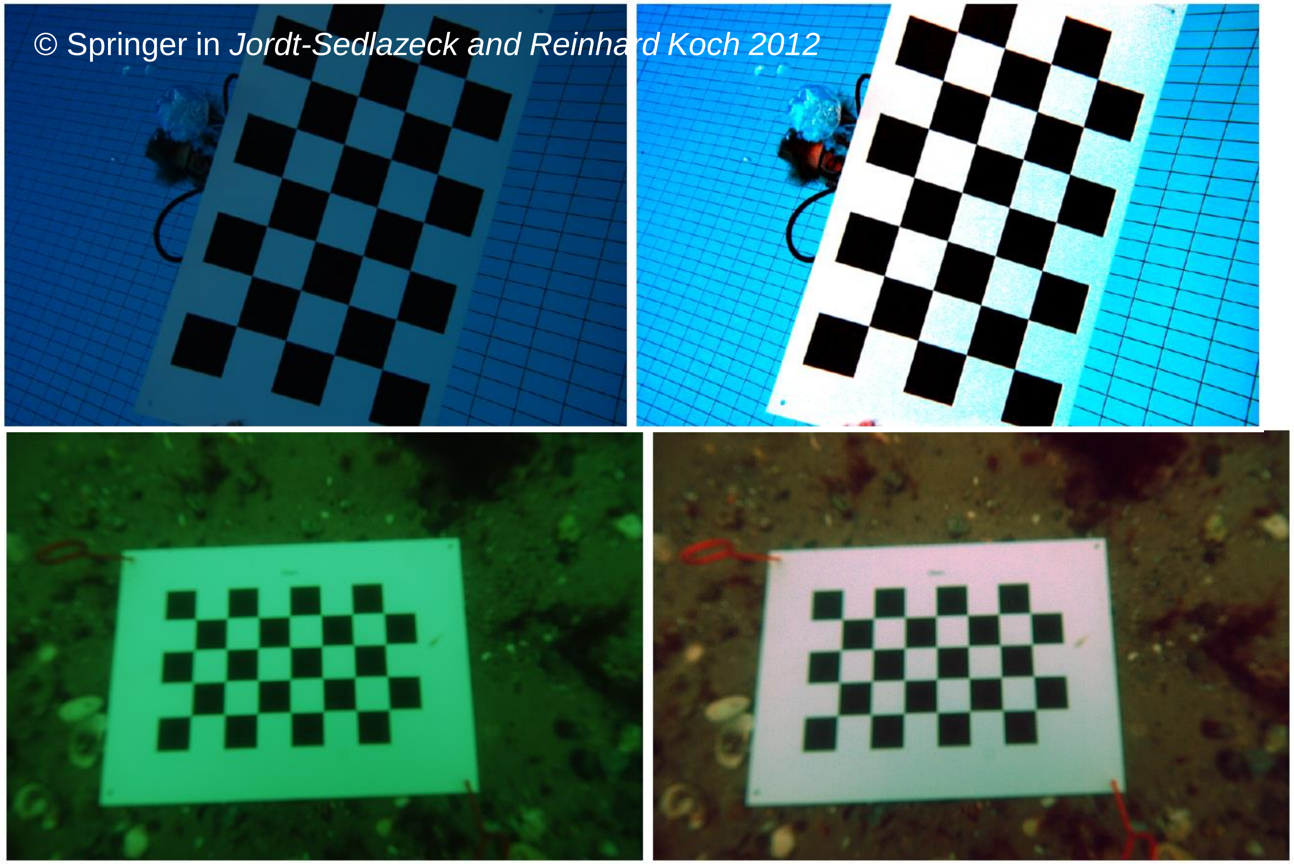


$$E_{\mathrm{cam}_\lambda} = \underbrace{E_{\mathrm{obj}_\lambda} \mathrm{e}^{-\kappa\eta(\lambda)}}_{\text{Signal}} + \underbrace{B_{\infty_\lambda}(1 - \mathrm{e}^{-\kappa\eta(\lambda)})}_{\text{Backscatter}}$$

Schechner and Karpel 2005

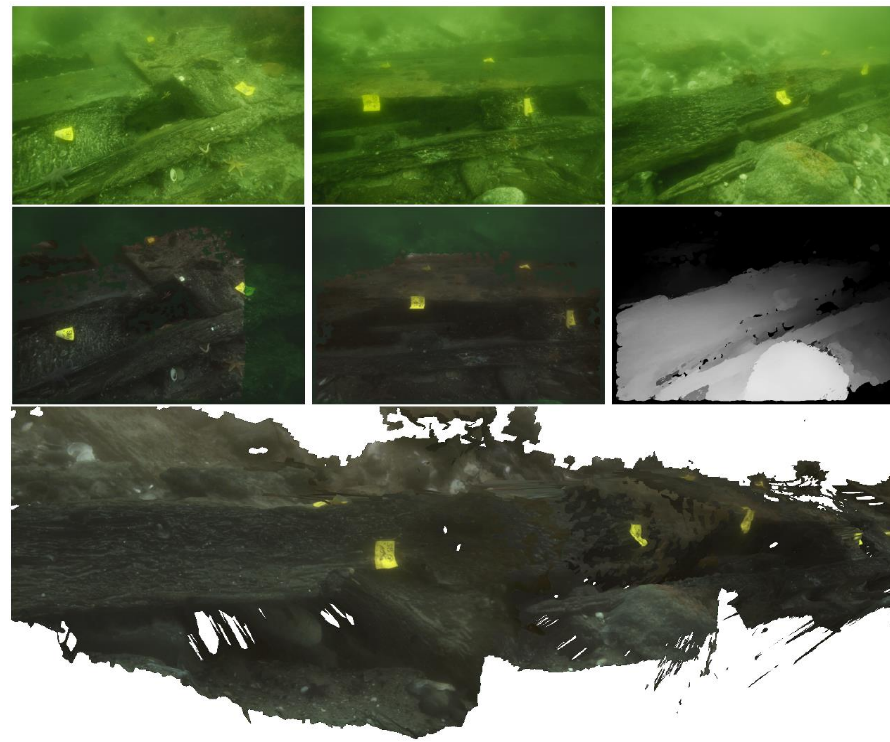
HELMHOLTZ ASSOCIATION

Color Correction



Sedlazeck et al. 2009

Hedvig Sophia Reconstruction with Depth-Based Color Correction



Sedlazeck et al. 2009

Underwater Image Enhancement Using an Integrated Color Model

RGB contrast stretching

↓

convert from RGB to HSI

↓

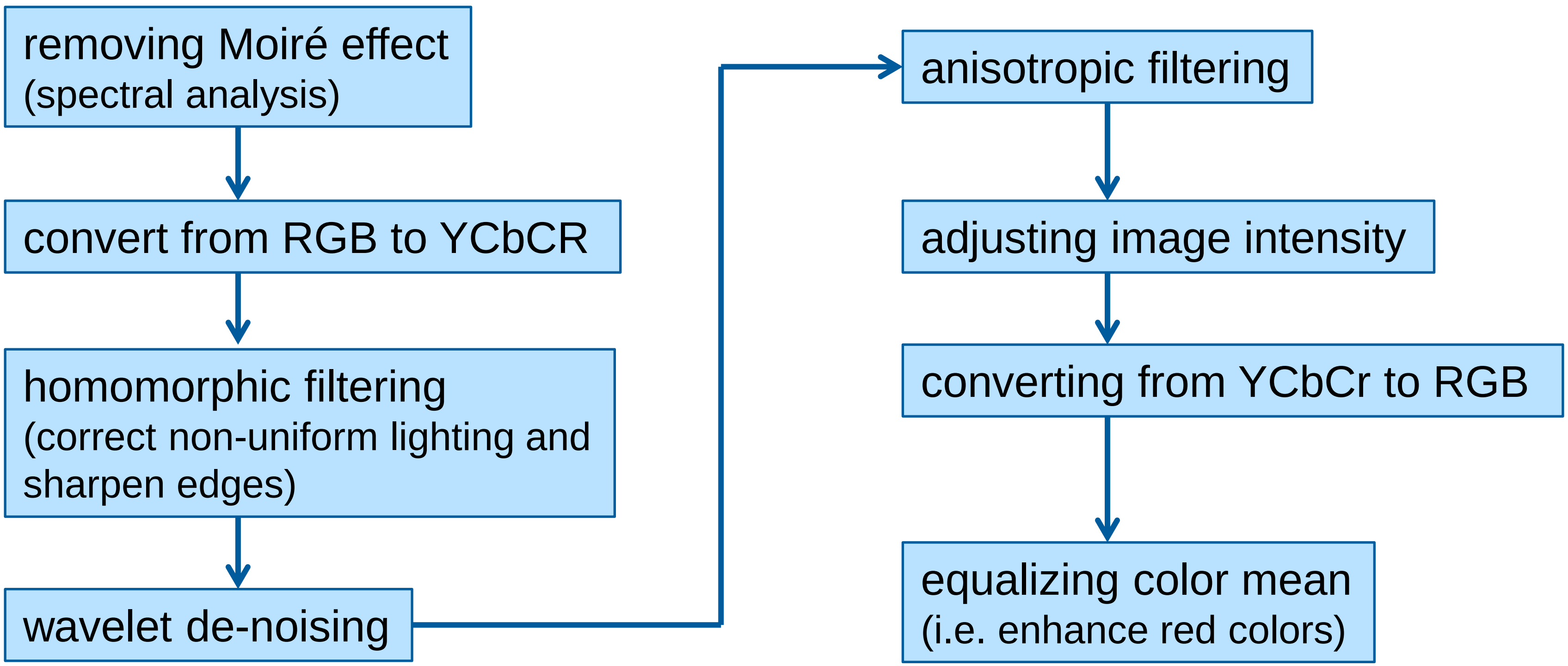
saturation and intensity stretching

↓

convert from HSI to RBG

Iqbal et al. 2007

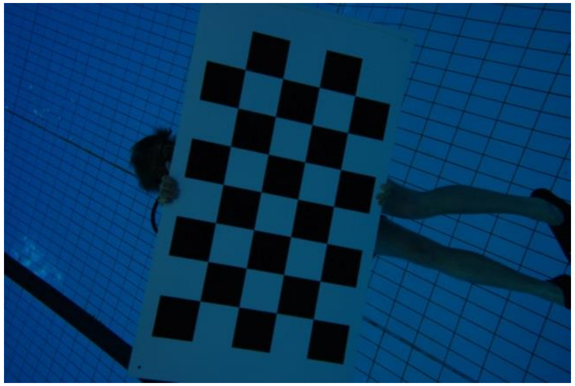
Automatic Underwater Image Pre-Processing



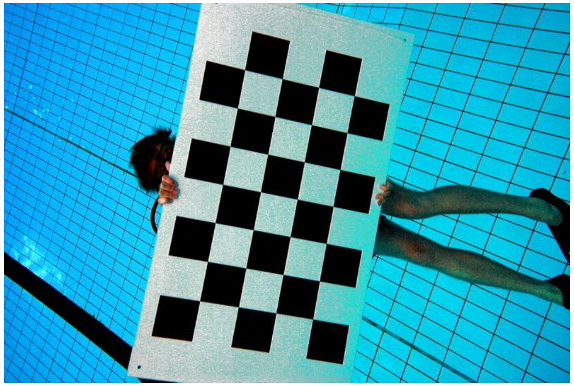
Bazeille et al. 2006

Color Enhancement

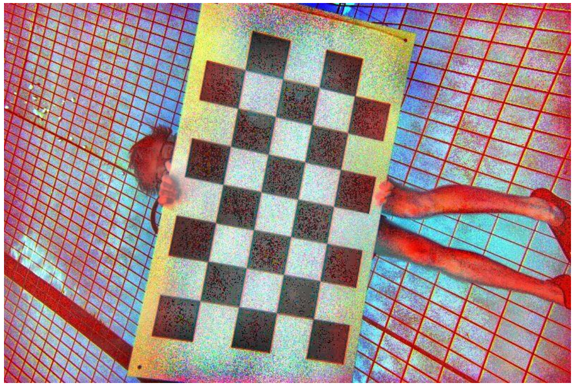
input image



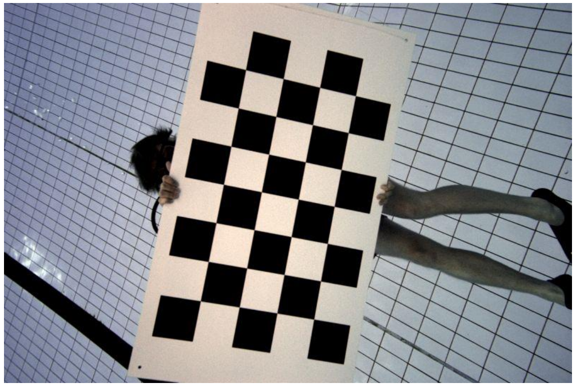
contrast stretching Iqbal et al. 2007



adaptive histogram equalization



Bazeille et al. 2006



Color Enhancement

input image

contrast stretching Iqbal et al. 2007

adaptive histogram equalization

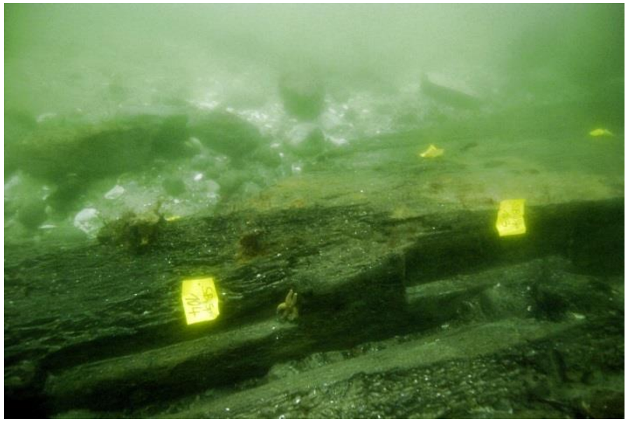
Bazeille et al. 2006

Radiometry of Underwater Image Formation

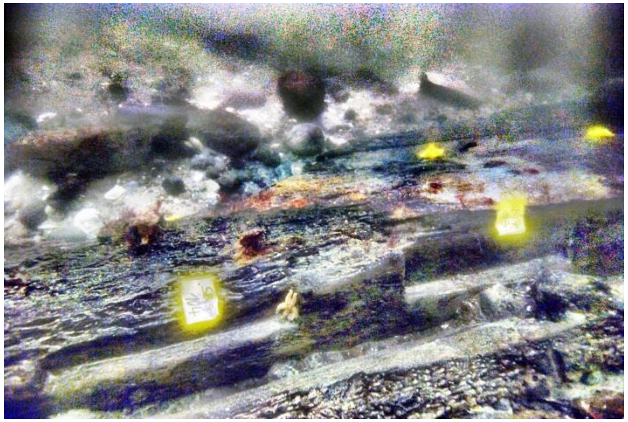
Color Enhancement

input image

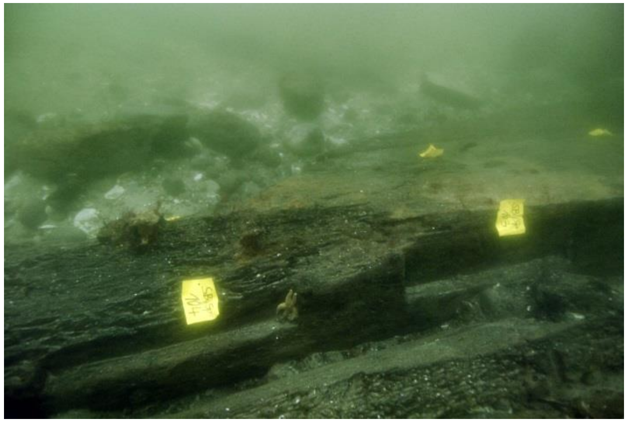
contrast stretching Iqbal et al. 2007



adaptive histogram equalization



Bazeille et al. 2006



Recovery of Underwater Visibility and Structure by Polarization Analysis

- veiling light is partially polarized in waters close to the surface (i.e. illuminated by sunlight)
- inspired by marine animal vision
- assumption veiling light is dominant cause of degradation
- capture 2 images with polarization filter in front of the camera (turned by 90°)
- allows to determine veiling light component -> can be removed
- amount of veiling light allows to determine up-to-scale depth map of scene

Schechner and Karpel 2005, Treibitz and Schechner 2006

Recovery of Underwater Visibility and Structure by

Result images of polarized descattering have been removed in this version due to copy right reasons.
Please refer to the link below.

input images (left: natural illumination, right: artificial, polarized illumination)

results

all images from: http://webee.technion.ac.il/people/yoav/research/underwater.html and http://webee.technion.ac.il/people/yoav/research/active-descattering.html

Schechner and Karpel 2005, Treibitz and Schechner 2006

References

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J. S. Jaffe. Computer modeling and the design of optimal underwater imaging systems. IEEE Journal of Oceanic Engineering, 15(2):101–111, 1990.

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K. Iqbal, R. A. Salam, A. Osman, and A. Z. Talib. Underwater image enhancement using an integrated colour model. IAENG International Journal of Computer Science, 34:2, 2007.

S. Bazeille, I. Quidu, L. Jaulin, and J.-P. Malkasse. Automatic underwater image pre-processing. In Proceedings of the Charactersation du Milieu Marin (CMM06), pages 16–19, 10 2006.

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Y. Y. Schechner and N. Karpel. Recovery of underwater visibility and structure by polarization analysis. IEEE Journal of Oceanic Engineering, 30(3):570–587, 2005.

A. Sedlazeck, K. Köser, and R. Koch. 3D reconstruction based on underwater video from ROV kiel 6000 considering underwater imaging conditions. In Proc. OCEANS '09. OCEANS 2009-EUROPE, pages 1–10, May 11–14, 2009.

T. Treibitz and Y. Y. Schechner. Active polarization descattering. IEEE Transactions on Pattern Analysis and Machine Intelligence, 31:385–399, 2008.

Further Reading

Jeff Kaeli, John Leonard, Hanu Singh, Visual Summaries for Low-Bandwidth Semantic Mapping with Autonomous Underwater Vehicles, to appear in the proceedings of AUV 2014

Wrap Up

- light is absorbed and scattered when traveling through water
- effect can be modeled and simulated by Jaffe-McGlamery model
- for color restoration, model is simplified, depth maps or polarized images are required
- color enhancement encompasses methods applying sets of image filters in order to improve colors