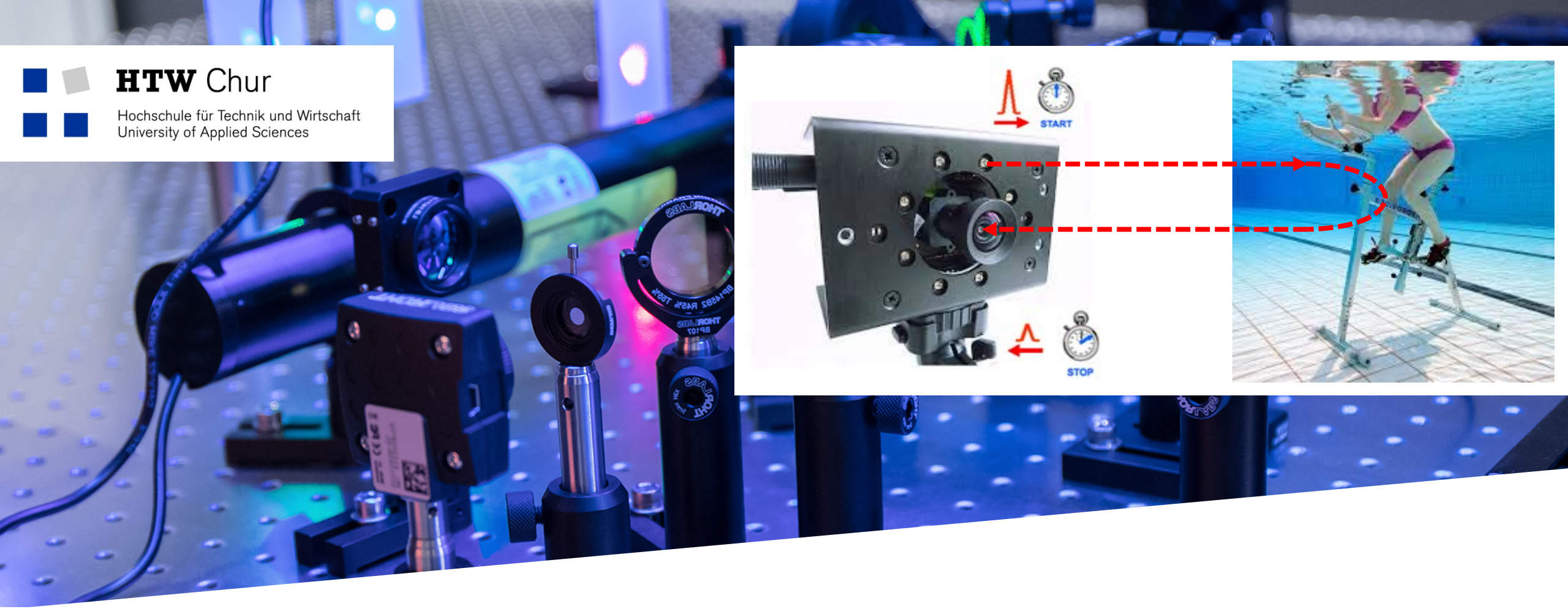
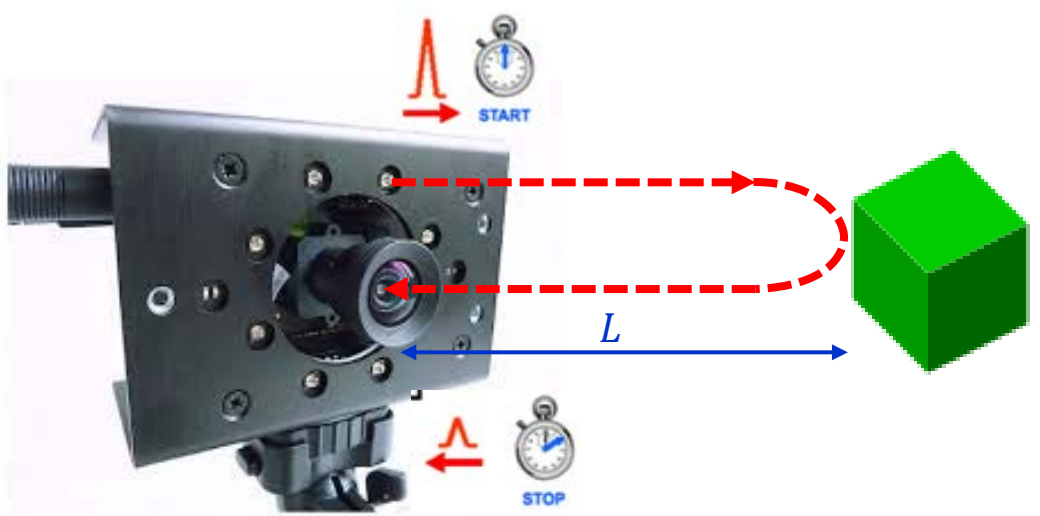


HTW Chur
Hochschule für Technik und Wirtschaft
University of Applied Sciences

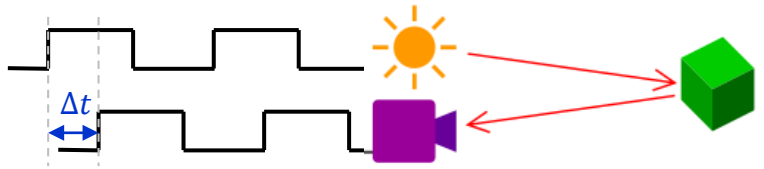
3D TOF Imaging in Underwater Settings

Hannes Merbold, **Gion-Pol Catregn**, and Tobias Leutenegger
University of Applied Sciences HTW Chur

Introduction to TOF range imaging



- TOF (= Time Of Flight) cameras illuminate objects with pulsed IR LEDs
- Light pulses are reflected at objects and imaged onto the camera chip
- Each pixel records intensity and time difference Δt between emitted and reflected light pulse.
- Object distance can be determined through $L = \frac{c \cdot \Delta t}{2}$



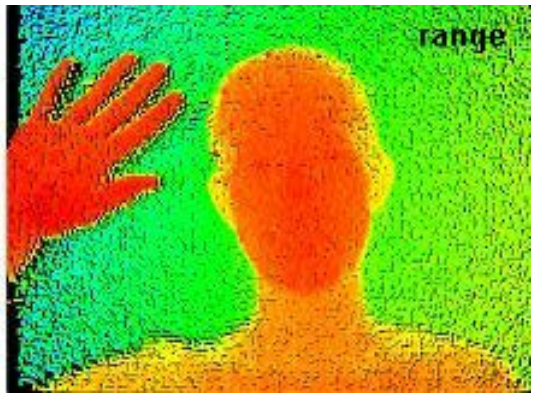
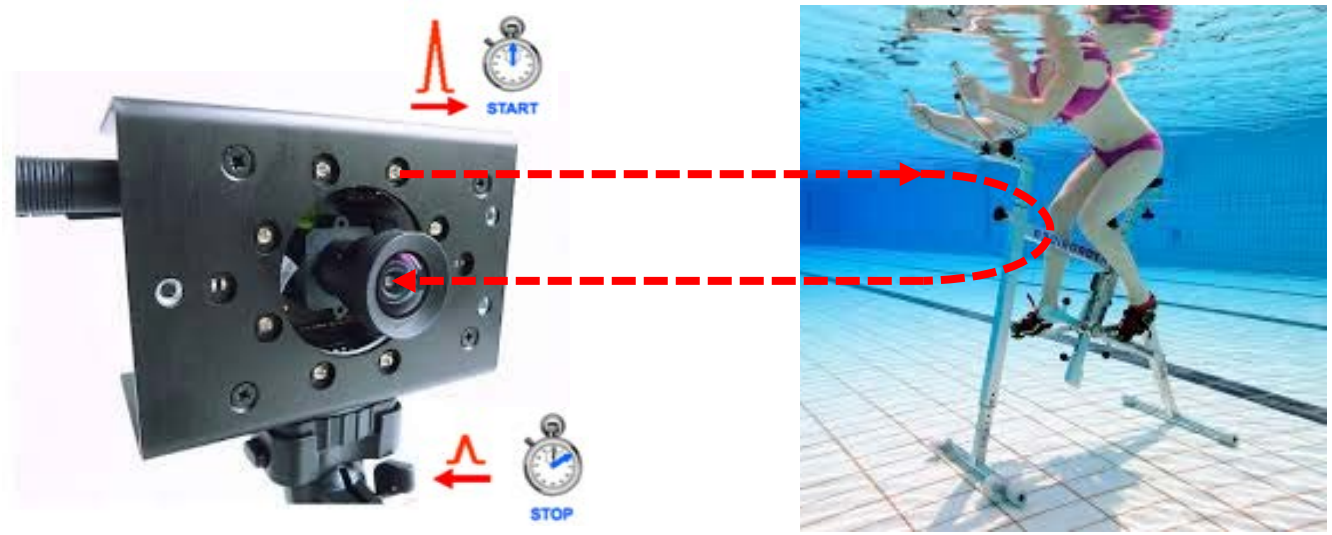


Image sources: Ineltro; http://www.mariofrank.net/3dcameras.html; https://en.wikipedia.org/wiki/Time-of-flight_camera

Projetct goal and motivation

- Project goal is to optimize TOF cameras for underwater range imaging.
- Motivation: Monitoring motion cycles of rehabilitation patients on underwater training bikes.



swissrehamed

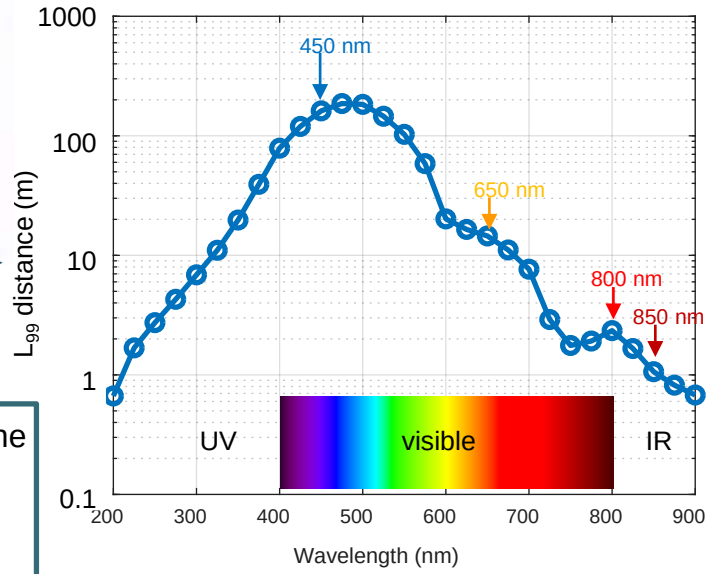
Image sources: Ineltro; Hydrorider

What is the difficulty?

- TOF Kameras use IR LEDs at 850 nm where water is strongly absorbing.

Distance after which 99% of the incident itensity is absorbed.

$$L_{99}(\lambda) = -\frac{\ln(0.01)}{\alpha(\lambda)}$$

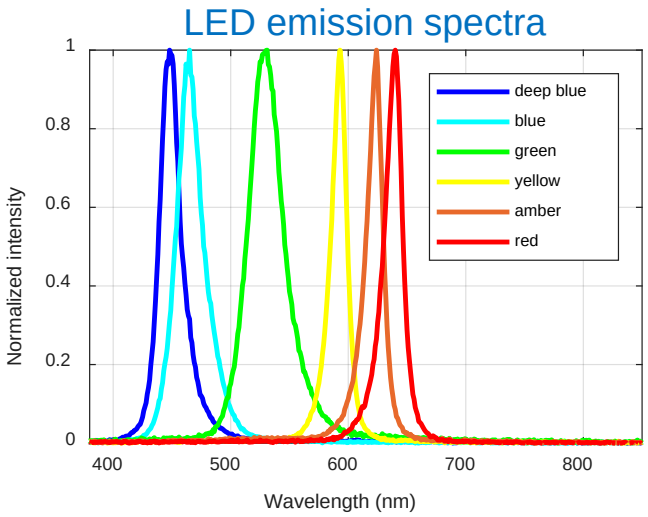


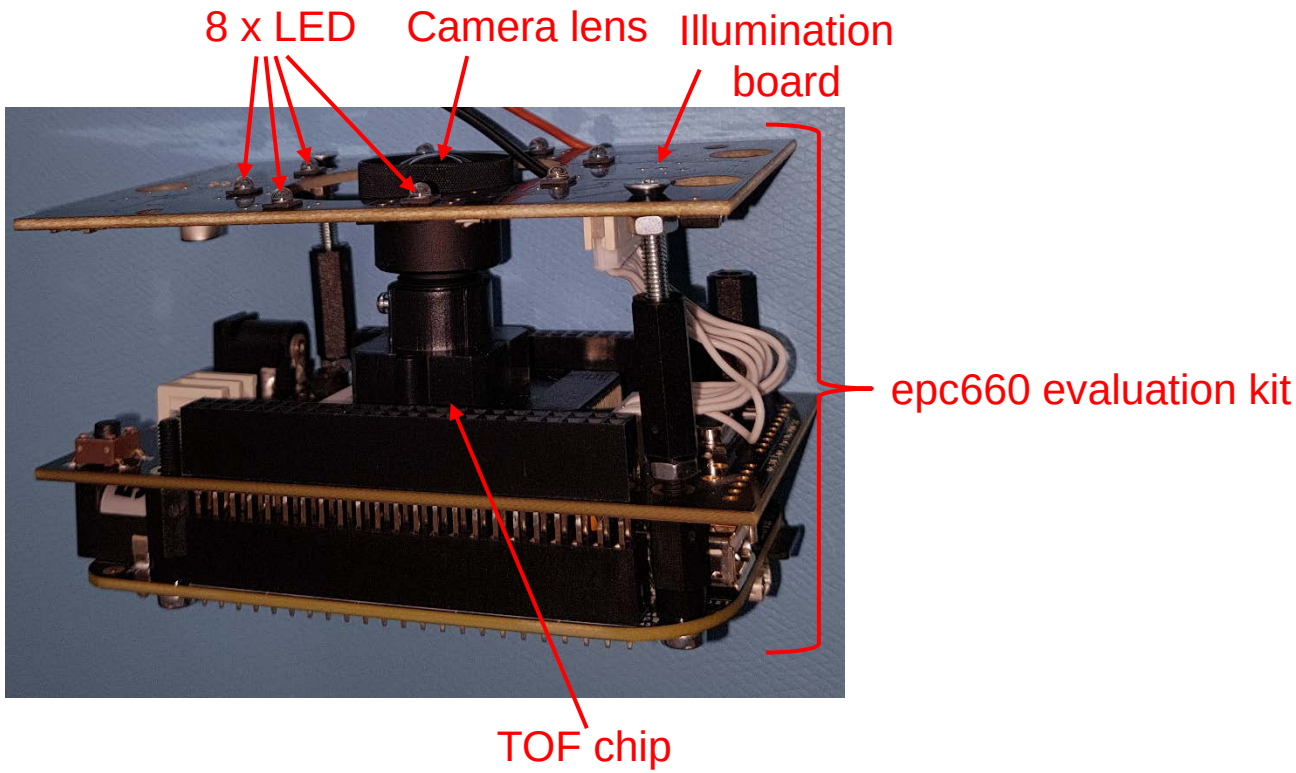
Wave-length	L_{99} distance	Attenuation after 2 x 1 m
850 nm	1.0 m	0.017%
800 nm	2.3 m	1.97 %
650 nm	14.5 m	53.0%
450 nm	161.7 m	94.4 %

Image sources: Ineltro; DesignNomad

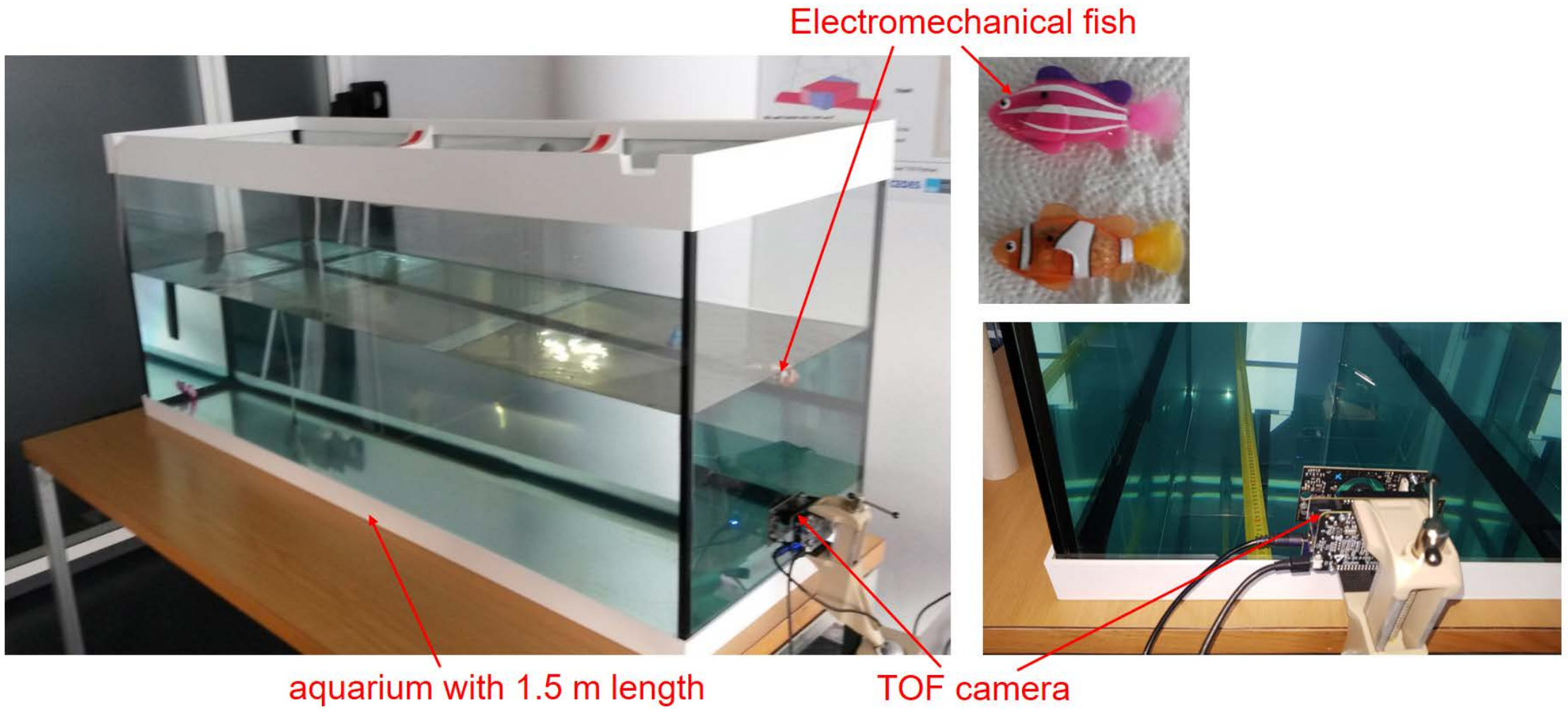
Our approach

- Based on Espros epc660 evaluation kit.
- Populated seven illumination boards with different LEDs spanning the range from 450 to 850 nm.



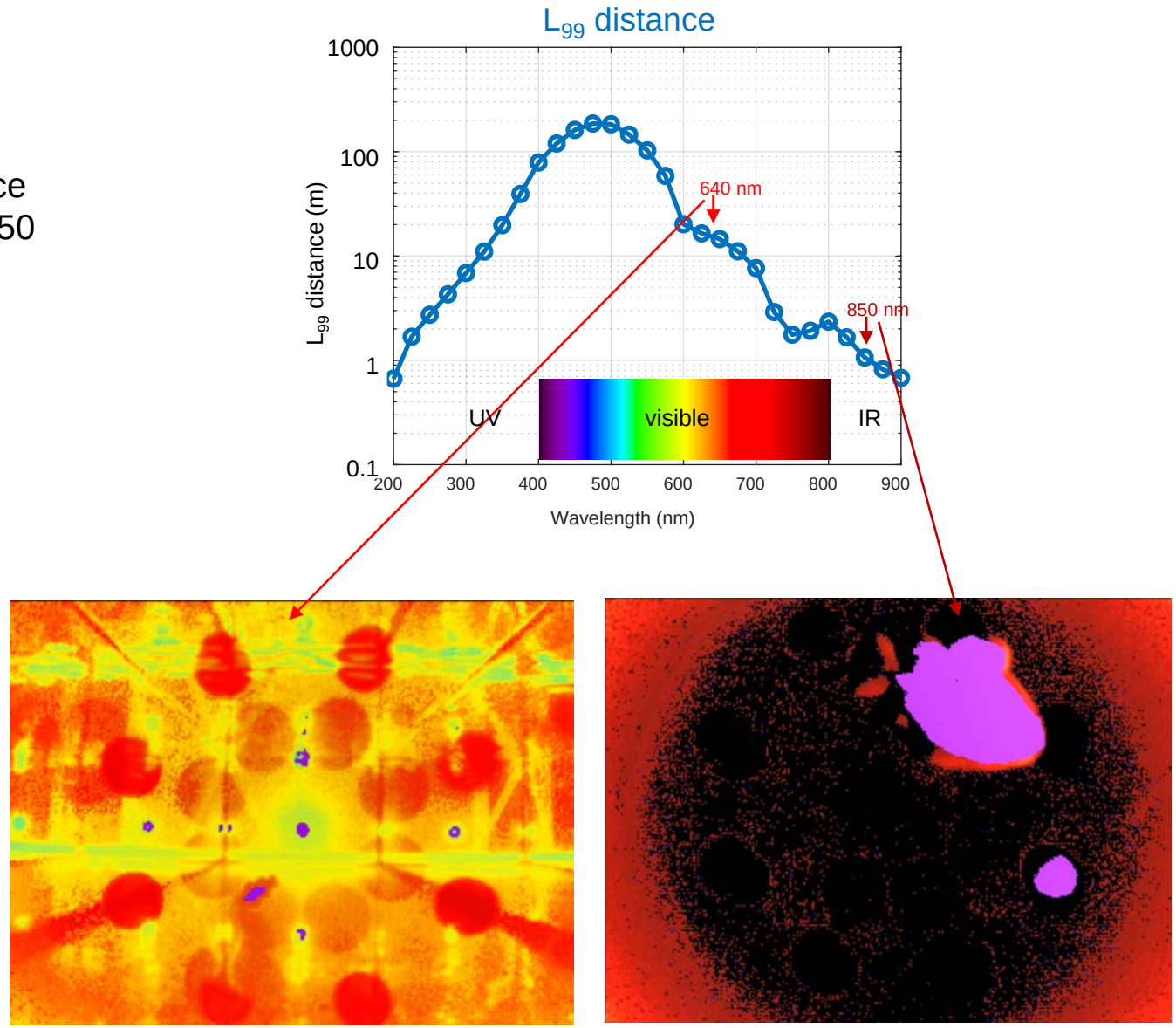


Experimental Setup

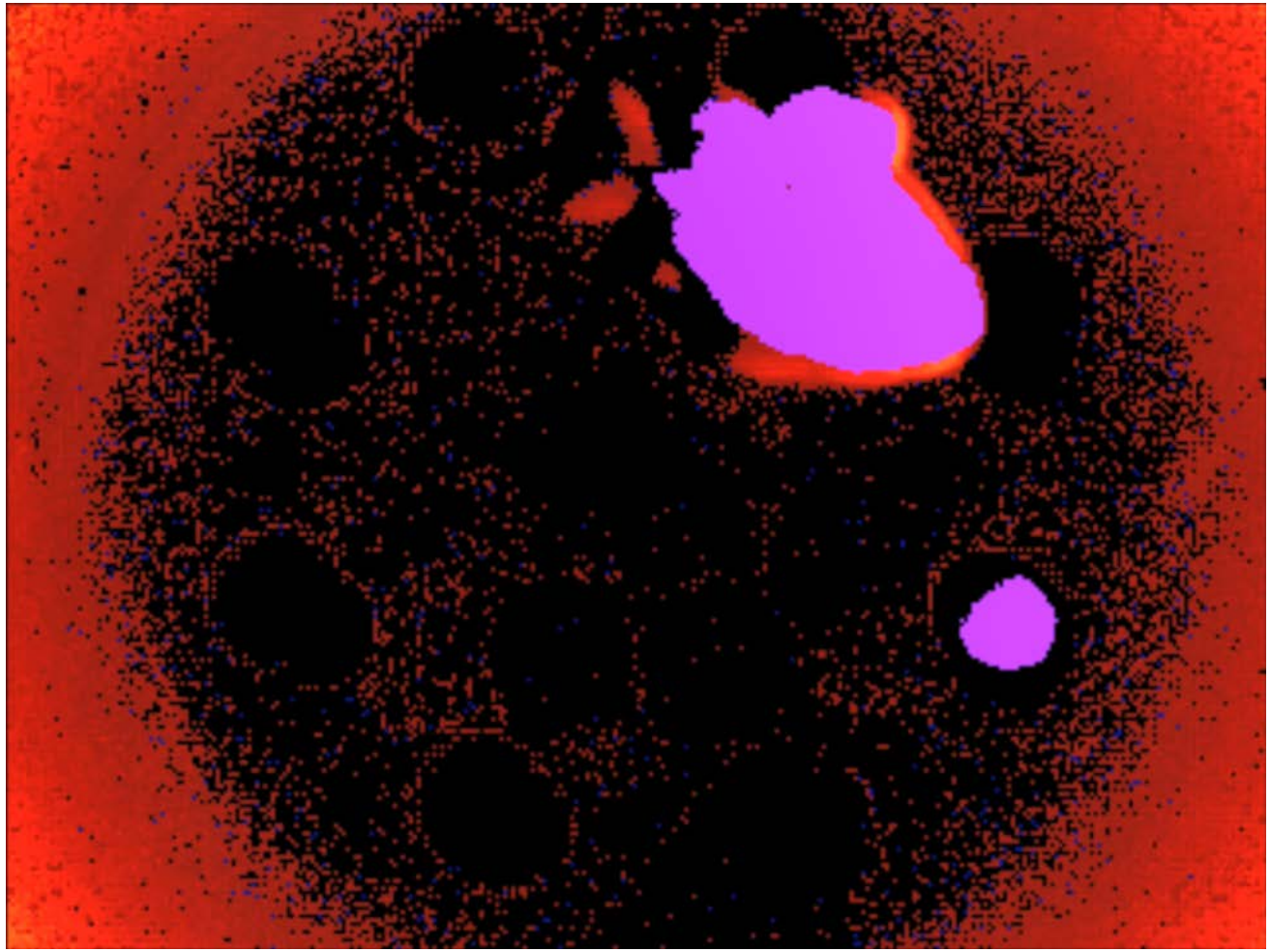


Proof-of-concept

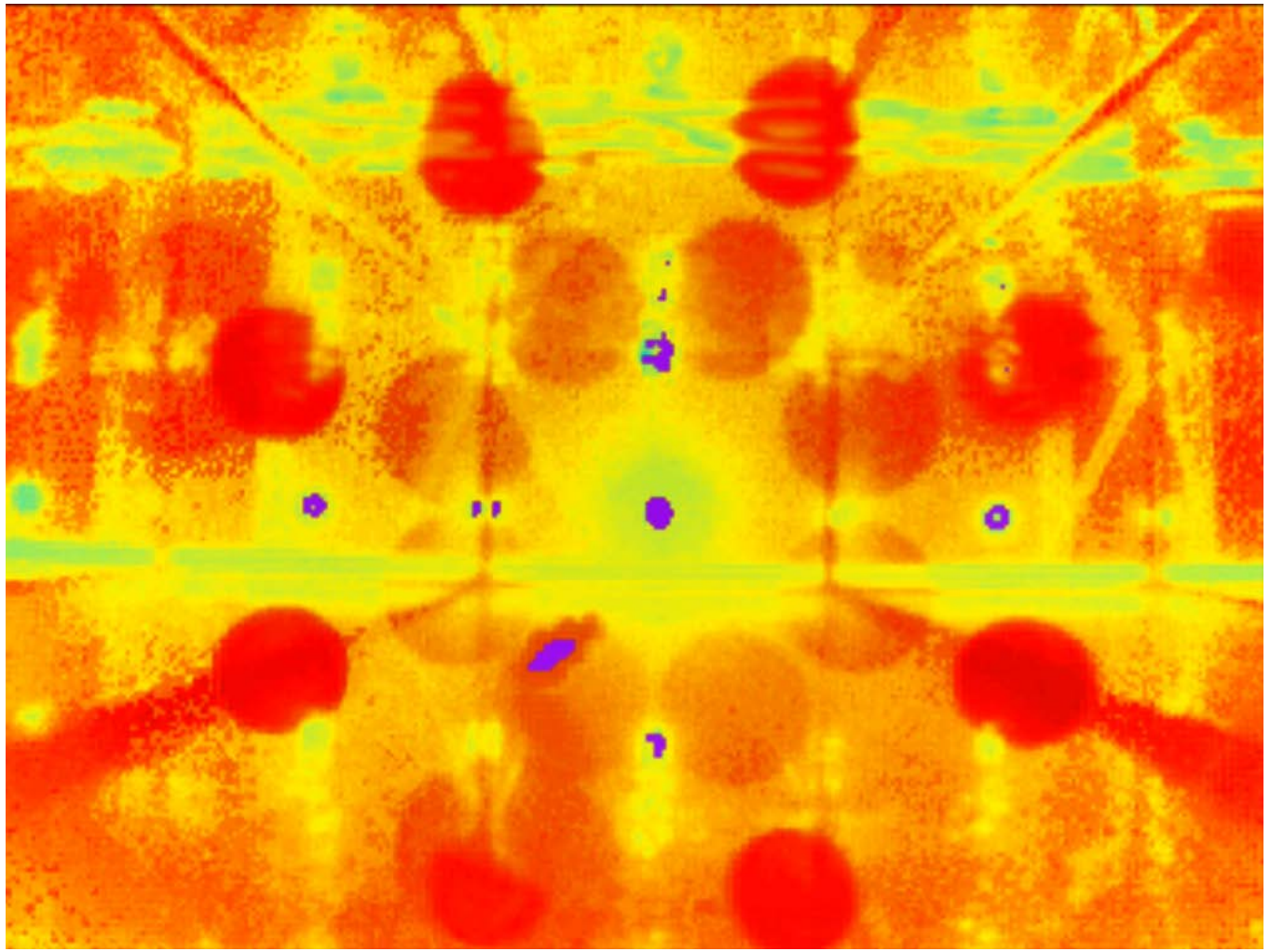
We compare the attainable performance of underwater TOF range imaging at 850 nm and 640 nm.



Proof-of-concept: near-IR light at 850 nm



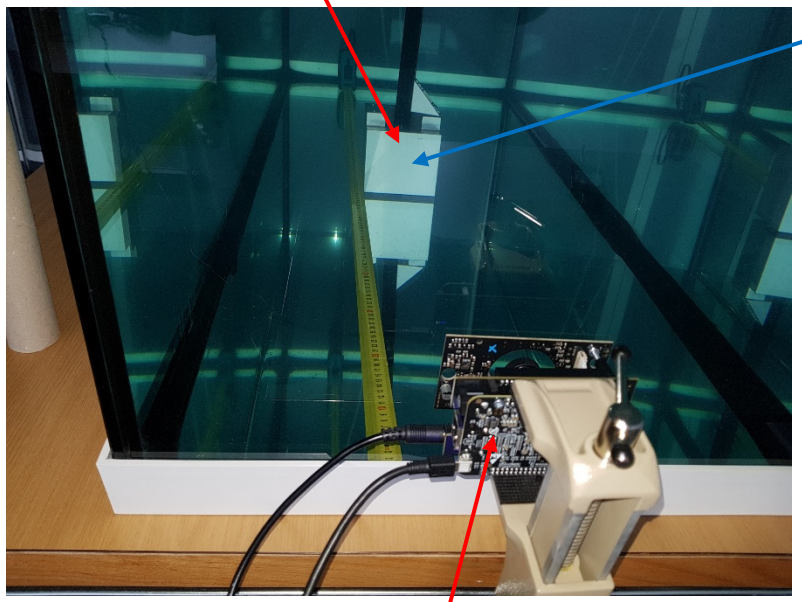
Proof-of-concept: red light at 640 nm



Amplitude versus set distance

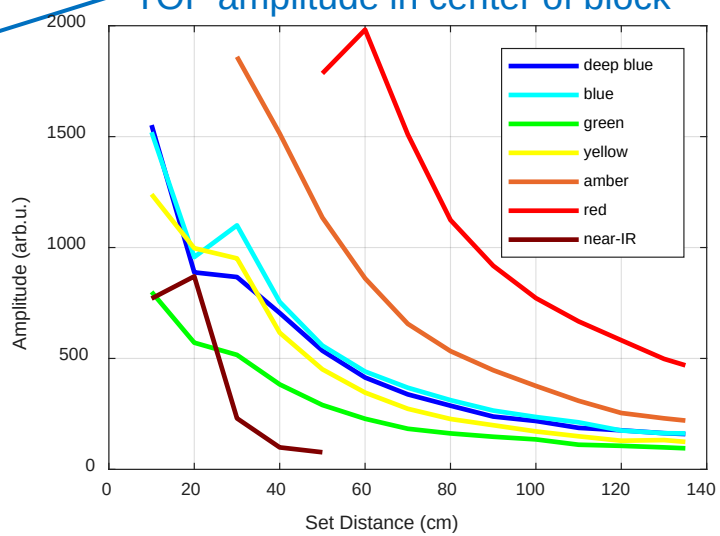
- TOF amplitude determined for different object distances L in water and different illumination colors.

Aluminum block, distance varied
(10, 20, …, 130 cm)



TOF camera,
200 µs integration time

TOF amplitude in center of block



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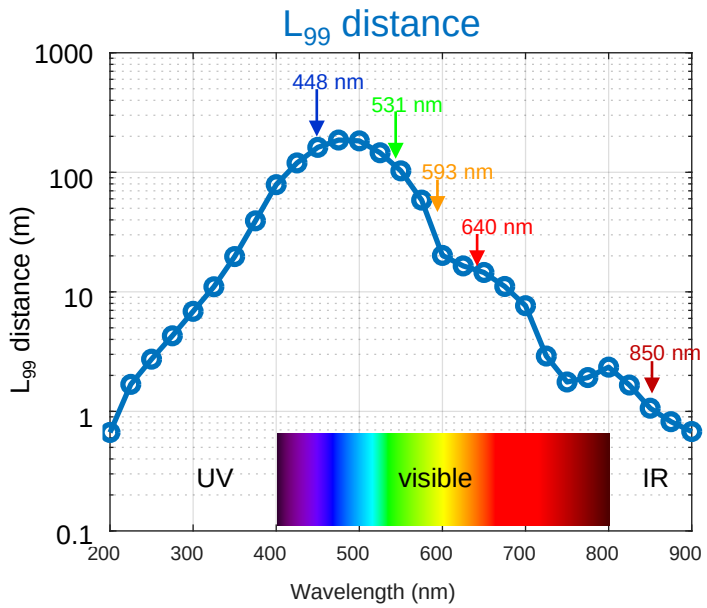
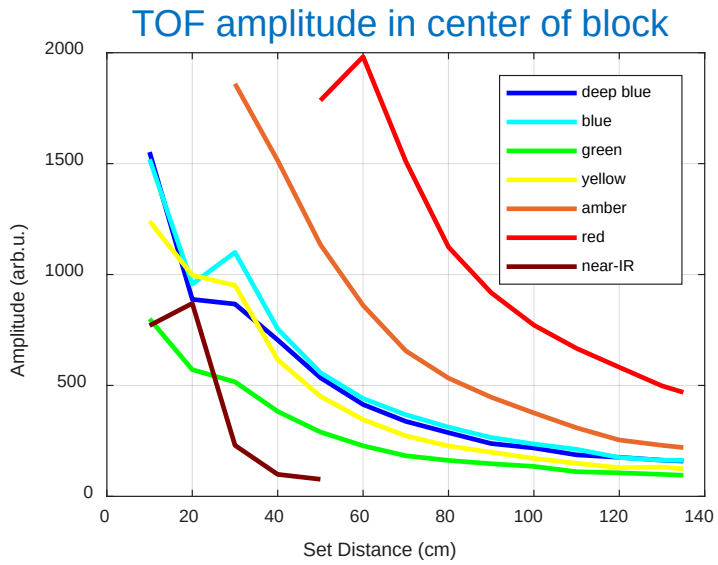
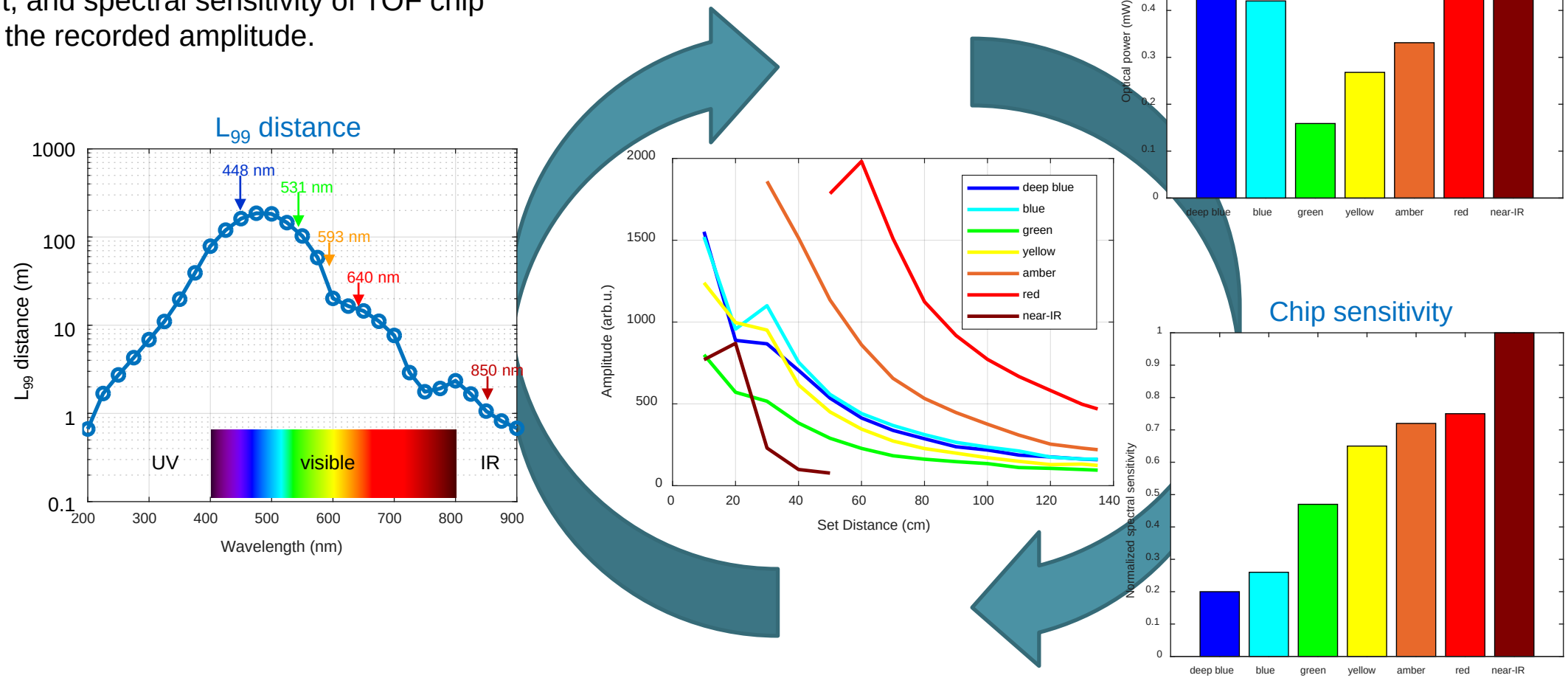


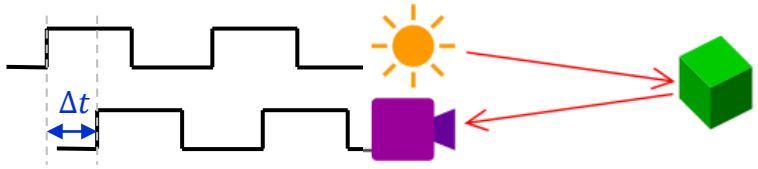


Amplitude versus set distance

- Interplay of water absorption, optical power of emitted light, and spectral sensitivity of TOF chip determines the recorded amplitude.

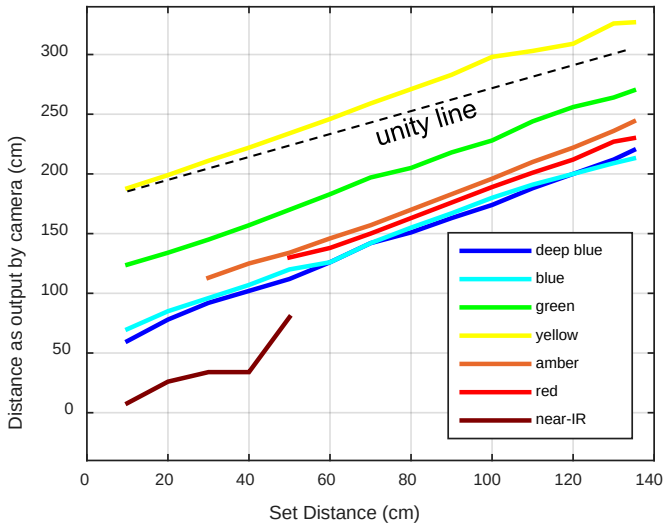


Output distance versus set distance



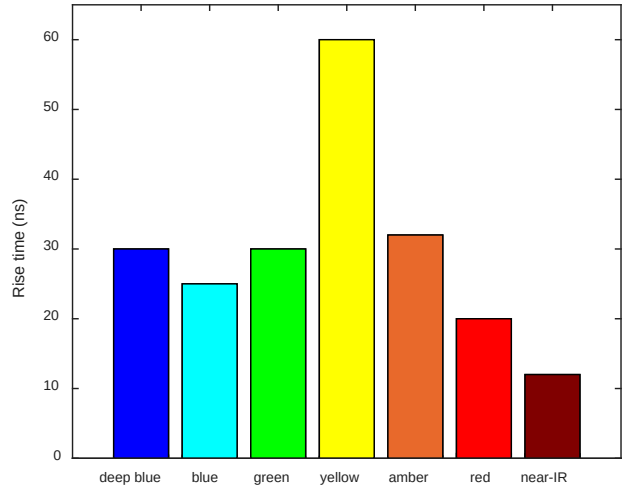
- Output distance as determined by TOF camera was plotted versus set distance.
- Offset observed is attributed to rise times of LEDs
- Deviation from unity line accoring to $c = c_0/n$.

Output distance



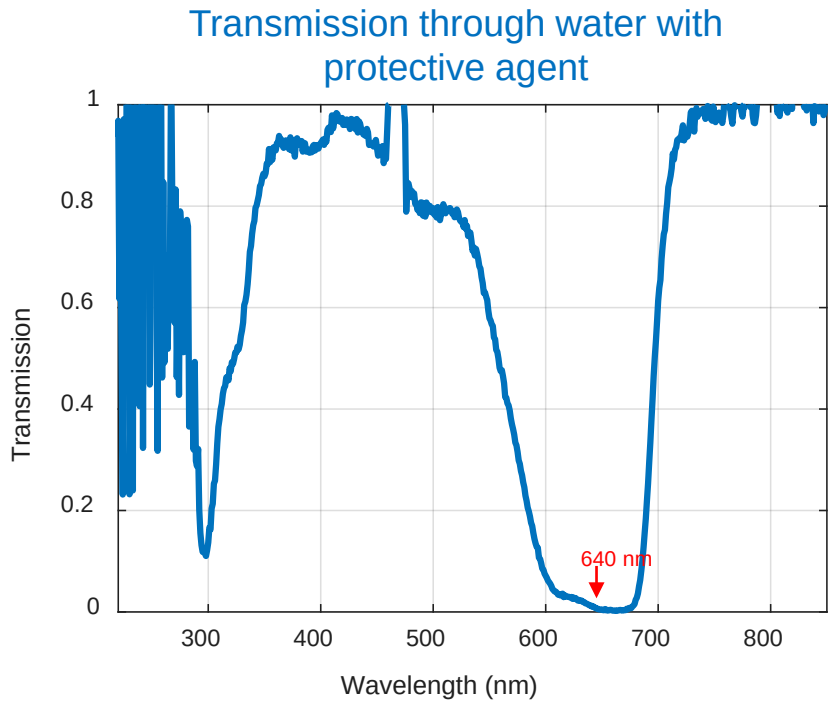
LED response to driving signal

LED rise times

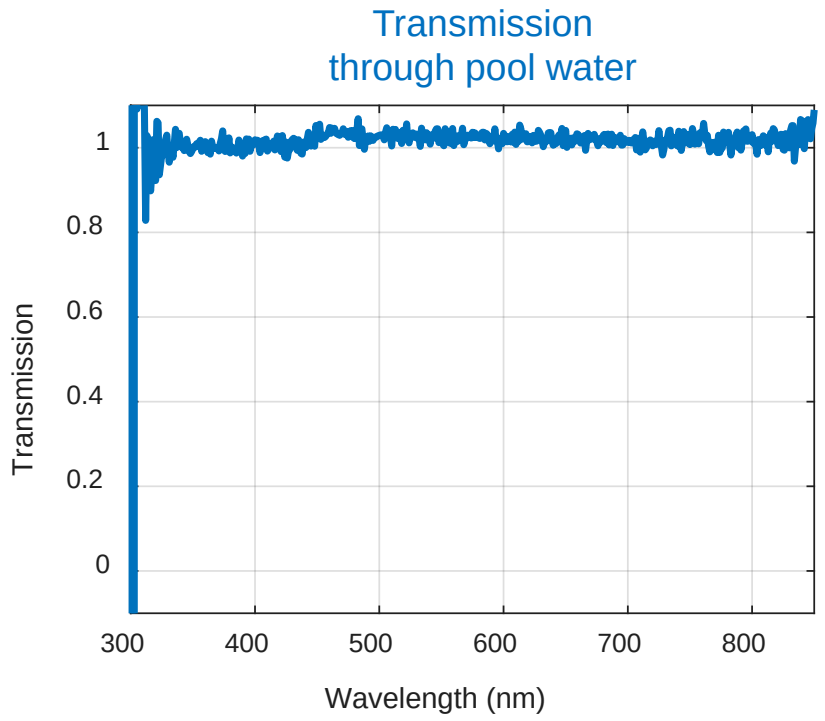


Other hurdles

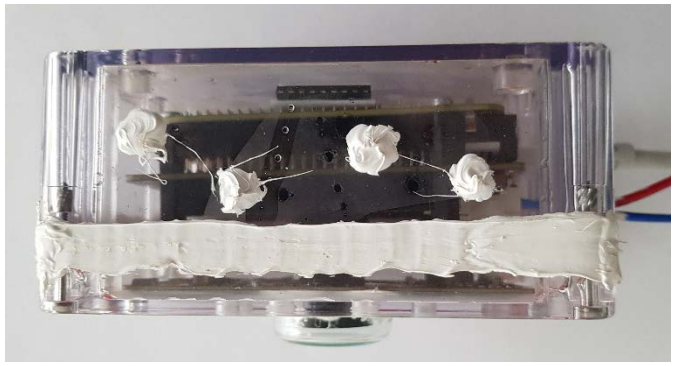
- Protective agents (to prevent growth of algae and bacteria) impact transmission.

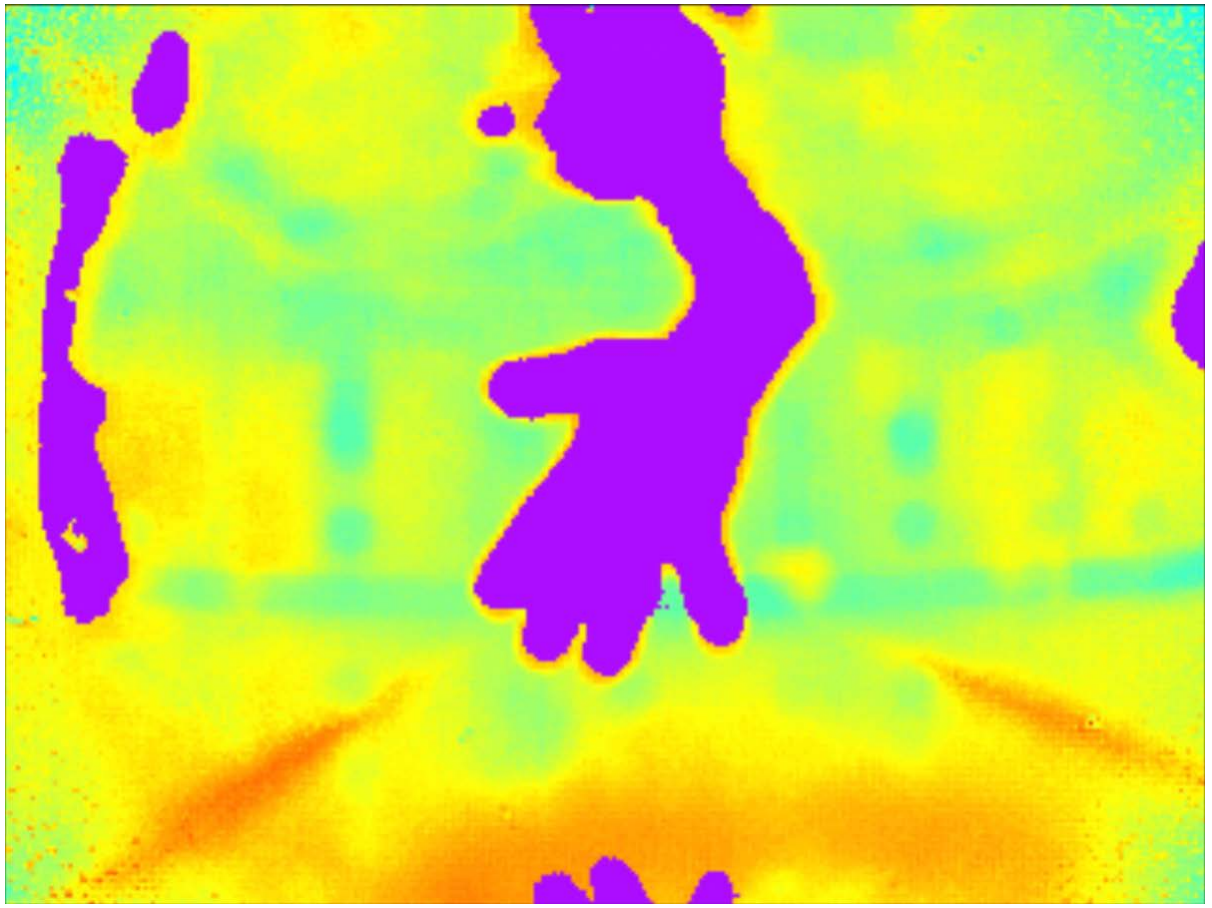


- Negligible impact of chlorine, e.g., in pool water.



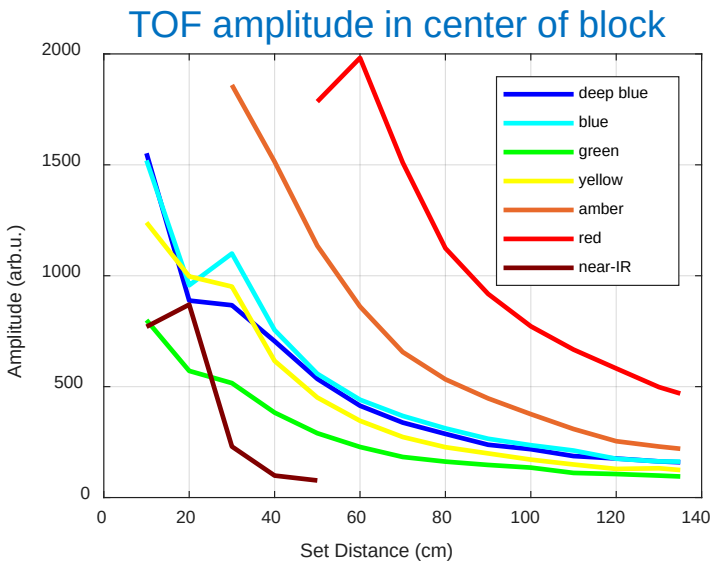
Water-proof casing

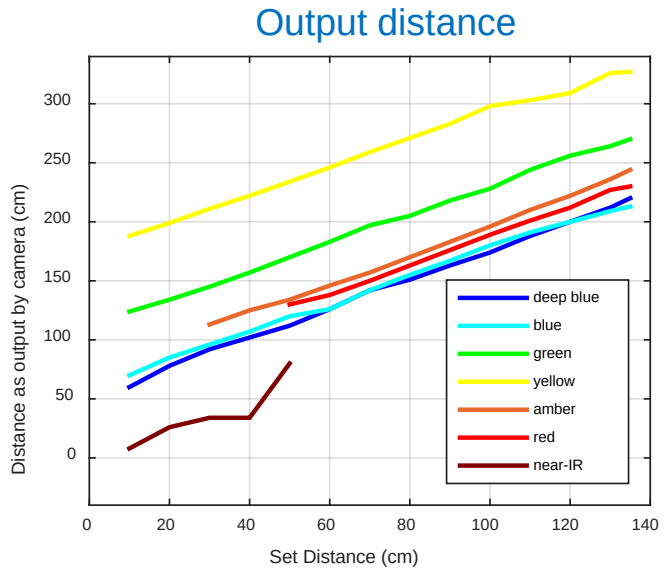




Summary

- Underwater TOF range imaging with object distances on the meter level can be realized, if visible rather than near-IR LEDs are used.
- Strongest amplitudes are obtained using red light at 640 nm. This is explained by interplay between absorption of water, optical LED power, and spectral chip sensitivity.
- Fast LEDs required and rise times need to be taken into account.





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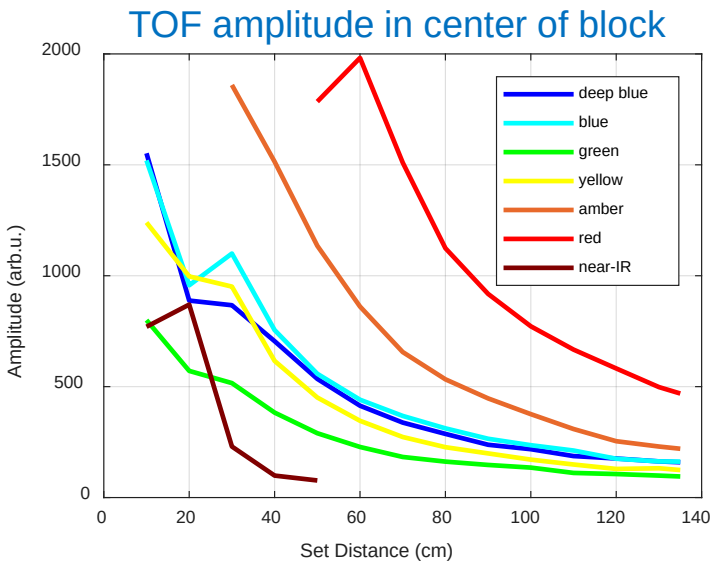

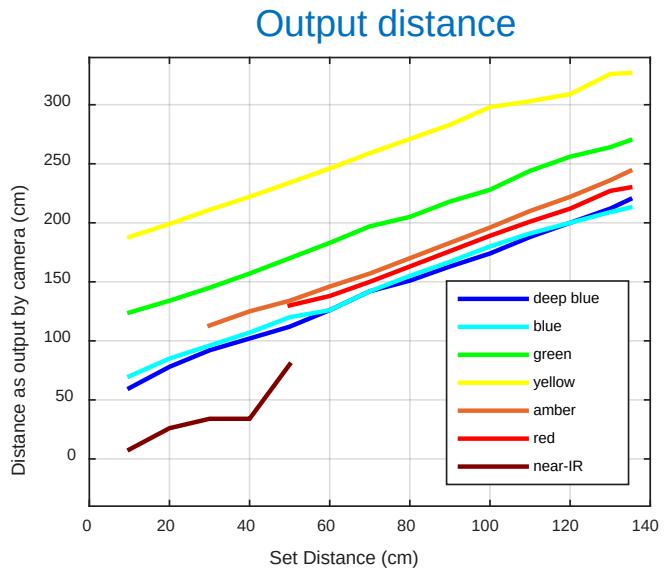

Thank you for your attention

hannes.merbold@htchur.ch

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