Inexpensive but robust approaches for determining optical and biogeochemical properties

Mike Twardowski and Emmanuel Boss

The problem: sensors are too expensive to be deployed at large quantities on the scales of interest to coastal populations (e.g. resolve tides, weather and beaches, be deployed in the developing world).

=> limits significantly the relevant and available data.

Why is it so?

1. Pressure-resistant housing (most in-situ sensors are rated to 600m).
2. Accuracy requirement (e.g. to trace deep water masses).
3. Limited market.
4. Limited resources for some research groups and communities.

What can we do to change this situation?

1. Much of the data of interest is near surface.

2. Near the surface natural variability is large.

3. Bringing in industry (aquaculture, fisheries, tourism) creates a much larger market than science.

4. There are inexpensive but robust alternatives in some cases.

Additionally, a revolution is going on ➔ cheap electronics processors, communication and sharing.

1. Cheap microprocessors such as Arduino and Raspberry Pi have made building a sensor and/or a sensing platform a Lego-like activity.

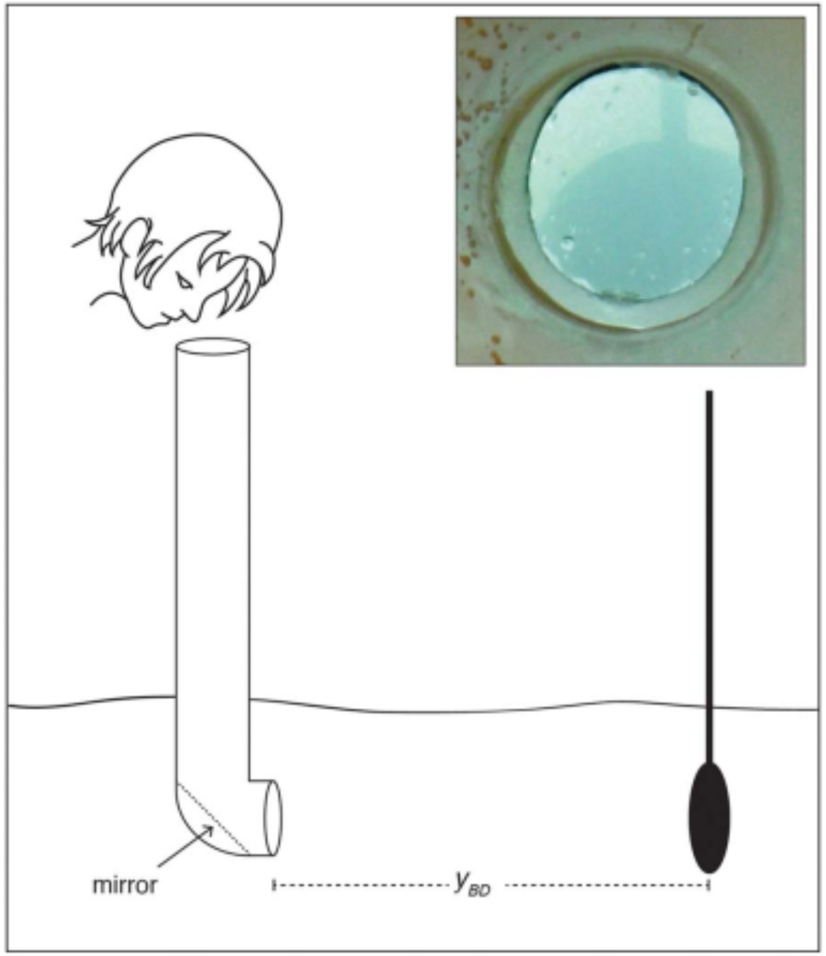
2. Communication via cell-phone, Wi-Fi and sat-com, provide near-real time data (e.g. for QC and adaptive sampling and incorporation to forecast).

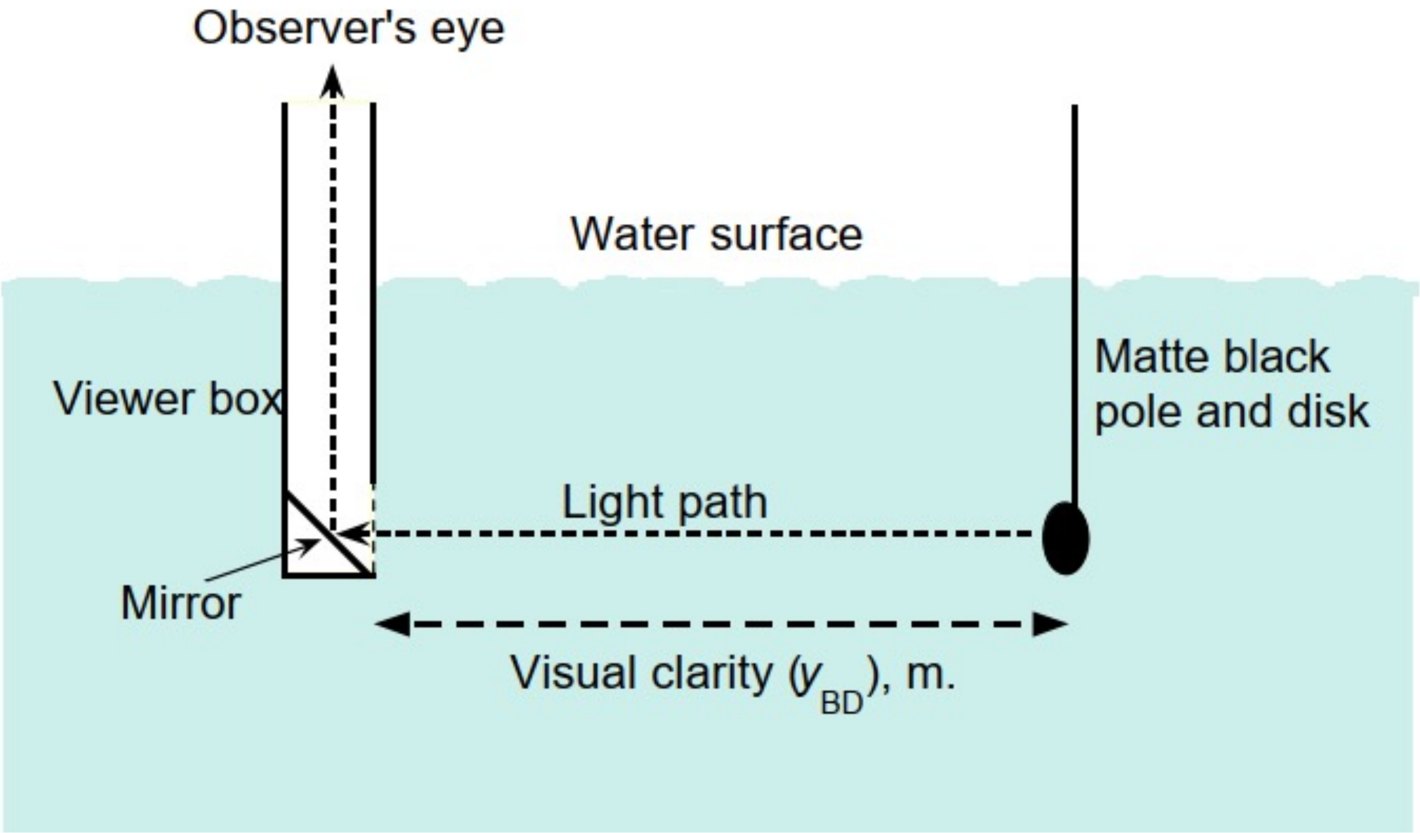
3. Sharing of ’recipes’ and ideas within/across communities allow for fast evolution and bug fixes (e.g. GitHub, instructables, Make magazine).

4. However, it is critical that uncertainties be associated with all measurements. Better to have no measurements than bad ones.

5. Full sensor characterizations essential for any custom device.

Attenuation (c) from horizontal vis with a black disk





Equipment list

Black disc method

tape measure

black disc viewer

black disc pole

Zaneveld and Pegau (2003)

$V = 4.8/\alpha$

α = photopic attenuation

$\alpha = c_{pg}(532)*0.9 + 0.081$

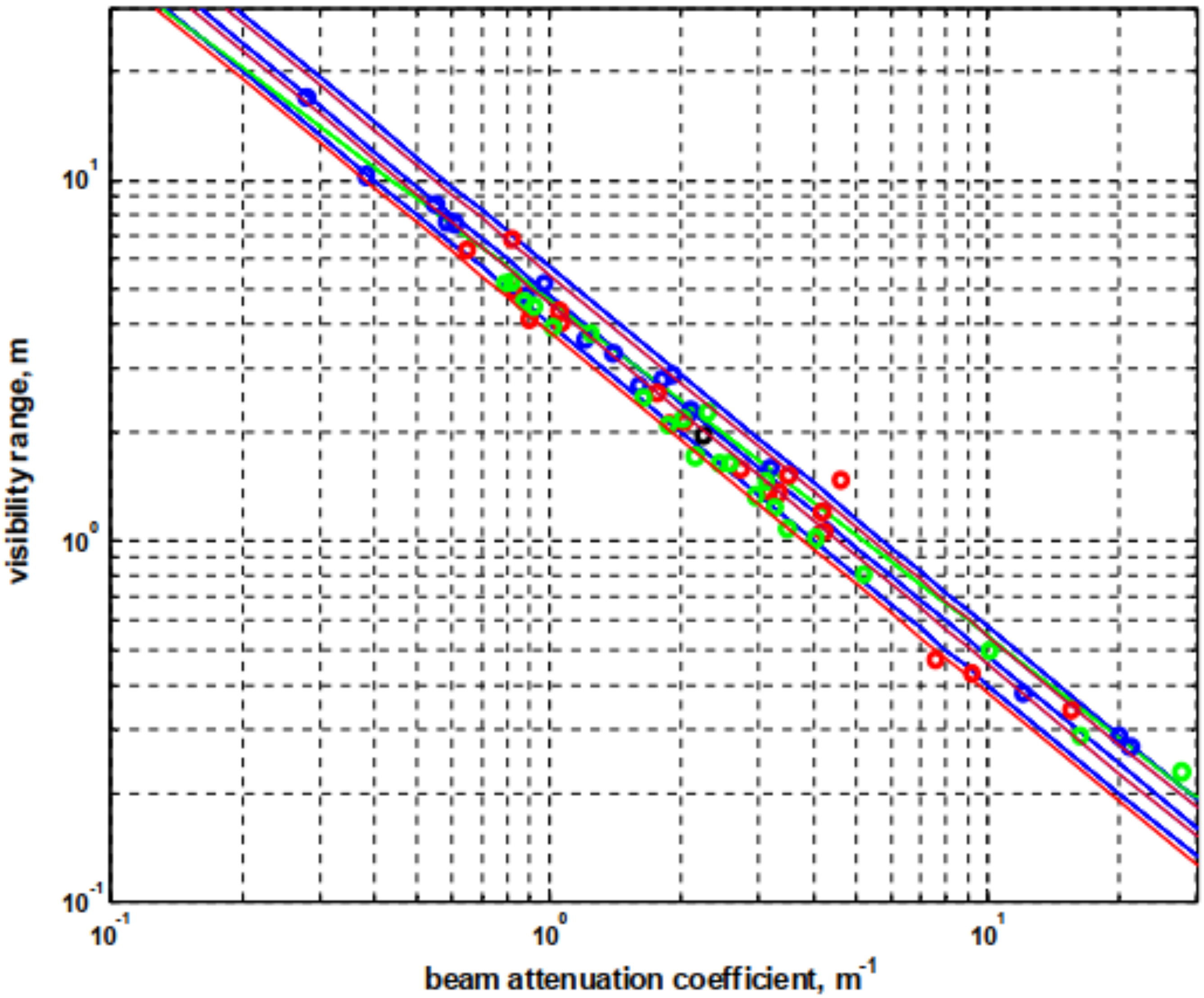
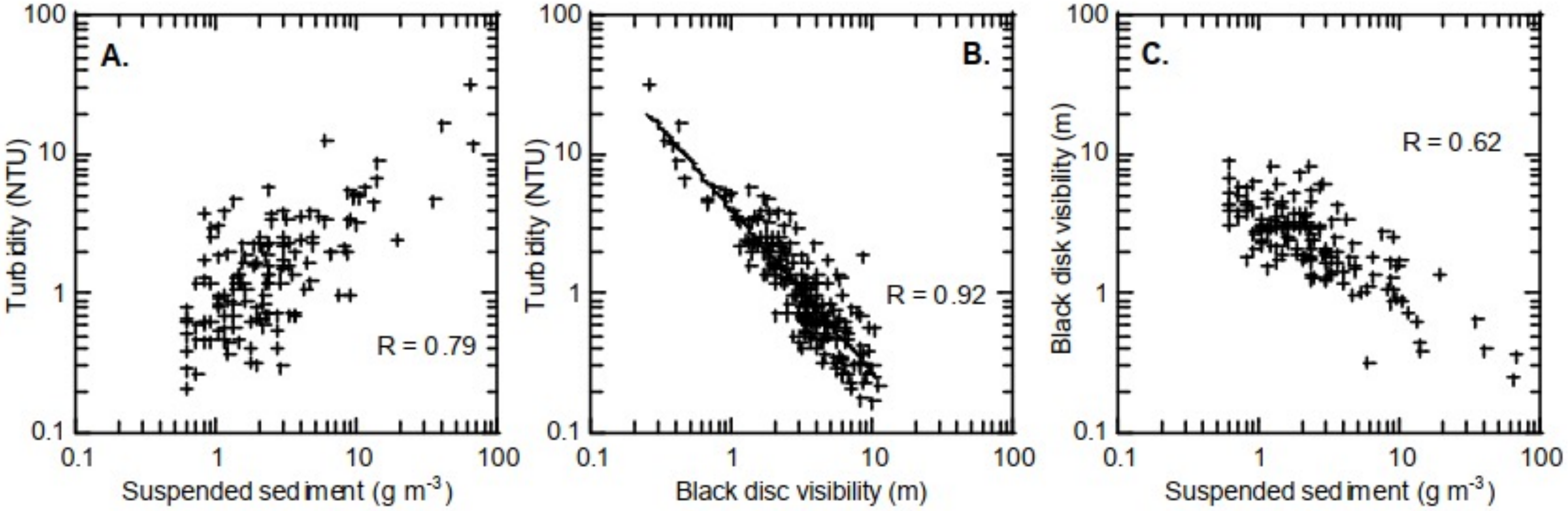


Fig. 3. Horizontal visibility of a 200 mm diameter black target. Blue points, Davies-Colley, "green" c-meter; red points, Zaneveld, c(532)*0.9+0.081; black point, Twardowski $c_{pg}(532)*0.9+0.081$; green points, Pegau, $c_{pg}(532)*0.9+0.081$;
blue lines vis. range = $y = 4.8/\alpha$ and +/- 20% lines;
green line vis. range= $y = (5.207 - 0.368 \ln y)/\alpha$;
red lines vis. range = $y = 4.55/\alpha$ and +/- 20% lines; $r^2 = 0.985$.



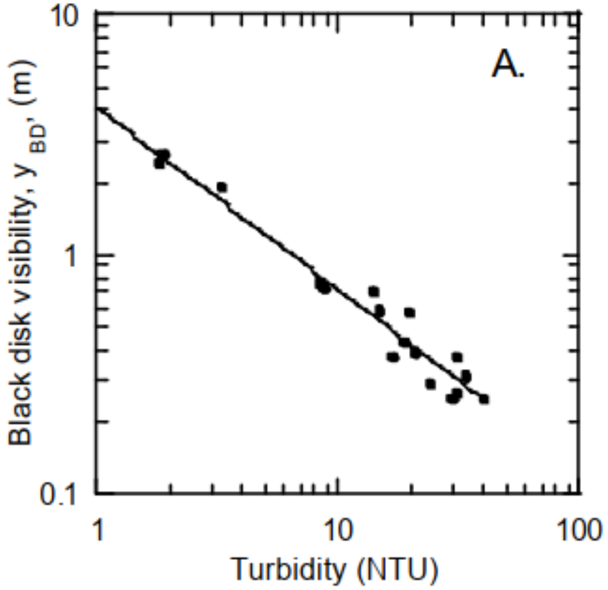


Figure 2. Mutual relationships of visual clarity, turbidity (Hach 2100A) and suspended sediment concentration in 97 New Zealand rivers (each river site sampled up to three times—n = 274 in total). Panel A. turbidity versus suspended sediment, B. turbidity versus black disc visibility, C. black disc visibility versus SSC. (Figure 3 of Davies-Colley and Close, 1990—used with permission)

Smith and Davies-Colley

Faecal contamination and visual clarity in New Zealand rivers: correlation of key variables affecting swimming suitability

Rob Davies-Colley, Amanda Valois and Juliet Milne

Journal of Water and Health
2018

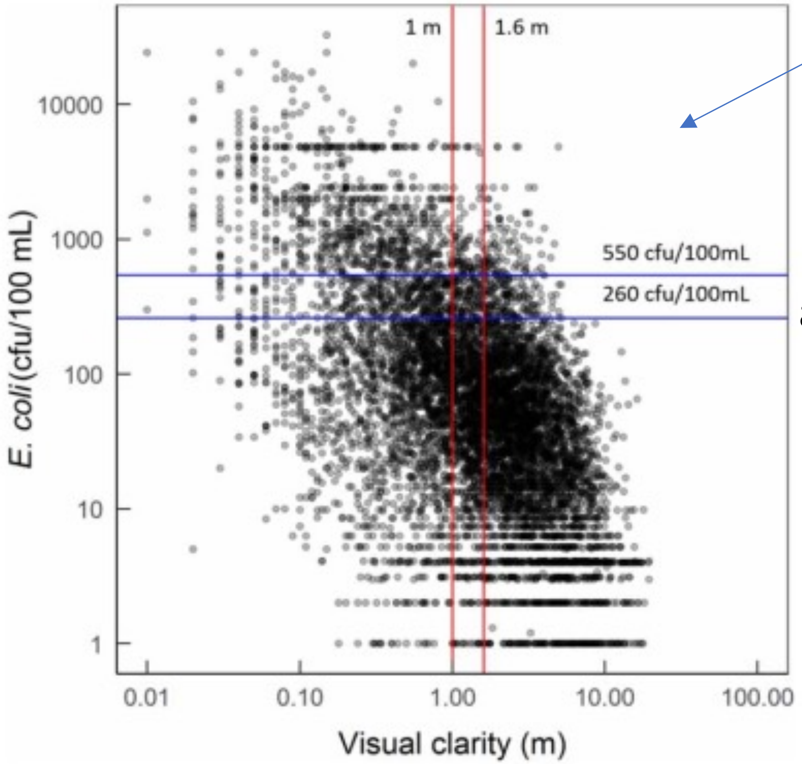


Figure 6 | *E. coli* vs visual clarity at 64 river sites in the NRWQN, 2006–2015, in relation to existing guidelines for swimming water quality in NZ. The horizontal lines represent ALERT (260 cfu/100 mL) and ACTION (550 cfu/100 mL) levels for *E. coli* from MfE/MoH (2003); the vertical lines represent guidelines for visual clarity (1.6 m is from MfE (1994) and 1.0 m an indicative – informal – guideline for visual degradation of water appearance). Only about 1% of points fall into the top-right sector representing relatively high microbial risk (>550 cfu/100 mL) when water is relatively clear (>1.6 m).

<1% samples fall in high E. coli, high vis quadrant

action
alert

<1.6 horizontal vis has been official Ministry for the Environment criteria for safe to swim in NZ since 1994

https://environment.govt.nz/assets/Publications/Files/microbiological-quality-jun03.pdf

Tube with black disk

Depending on arm length, one person can take a clarity tube reading (far right), or it may be easier with two people.

Ministry for the Environment 1994. “Water Quality Guidelines No. 2: Guidelines for the Management of water colour and clarity”. Ministry for the Environment, Wellington, N.Z

Equipment list

Clarity tube method

bucket

clarity tube

magnets


AQUA MEDIC


50
AQUA MEDIC

Fig. 1 SHMAK clarity tube for measuring water clarity. (Photo: Helen Ricketts.)

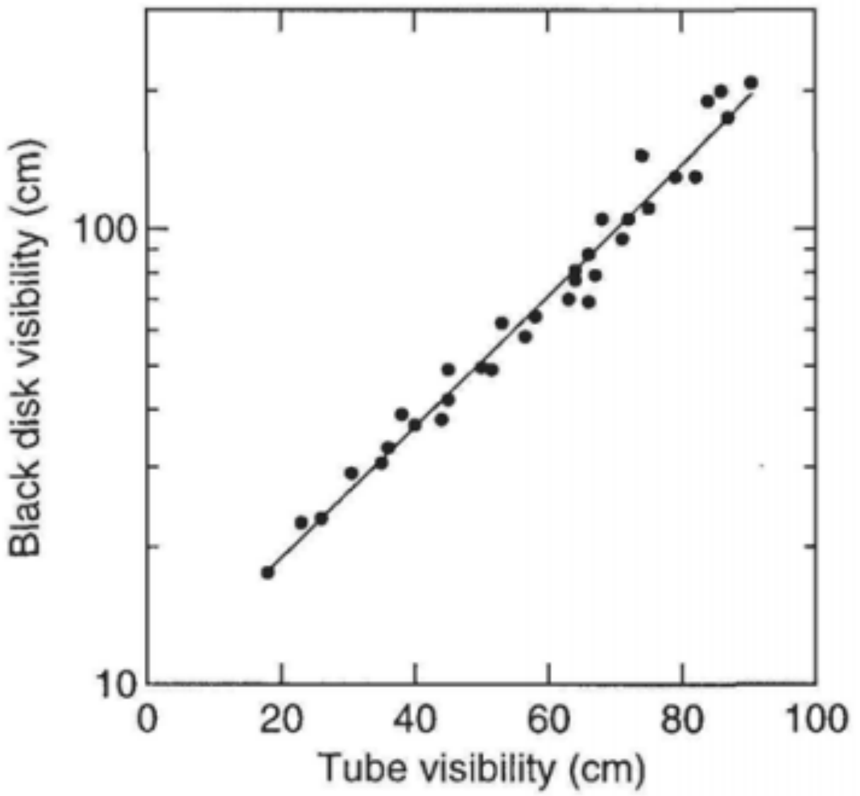


Fig. 4 Black disk readings (logarithmic scale) versus clarity tube readings (y_{BD} versus y_{CT}) (black background).

$$y_{BD} = 7.28 \times 10^{[y_{CT}/62.5]}$$

NZ safe to swim: >1 m vis with black disk in tube

Kilroy and Biggs (2002)

Secchi disk depth: theory

Contrast reduction theory for detecting target for any direction:

apparent contrast of target

attenuation coefficient

viewing angle relative to straight up

$$\frac{C_r(\theta,\phi,r)}{C_0(\theta,\phi,0)} = \exp[-cr + K(\theta,\phi,z)\, r\cos(\theta)]$$

inherent contrast of target

range

diffuse attenuation coefficient

Parameters are for *photopic* spectral response

Preisendorfer (1963), Duntley (1976) but work originated in 1940's; extensively validated

Secchi disk depth: theory

Contrast reduction theory for detecting target for any direction:

$$\frac{C_r(\theta,\phi,z)}{C_0(\theta,\phi,z_T)} = \exp[-cr + K(\theta,\phi,z)\, r\cos(\theta)]$$

At some range, contrast between a target and background will no longer be discernible, i.e., the limiting contrast threshold will have been reached:

$$C_L \equiv \frac{C_r(\theta,\phi,z)}{C_0(\theta,\phi,z_T)}$$, and

$$V = -\ln(C_L) / [c - K(\theta,\phi,z)\cos(\theta)]$$

$$\boxed{\textit{For Secchi disk: } Z_{SD} = -\ln(C_L) / [c + K]}$$

C_I

Issues ….

For Secchi disk: $Z_{SD} = -\ln(C_L) / [c + K]$

- When Z_{SD}, c, and K are determined, large range observed in $-\ln(C_L)$
- White vs black vs black/white quadrants
- Size of disk
- Shady side vs sunny side (i.e., glint)
- Cloudy vs sunny
- Wavy surface
- Sun elevation
- Scattering albedo (b/c)
- Eye adaptation to ambient lighting
- Observing altitude above water

$-\ln(C_L)$ typically varies from ~5-10 (Bukata 2005)

All noted by Secchi in 19th century (Pitarch 2020)

sensors

Printable Secchi disk:

MDPI

Article

A Printable Device for Measuring Clarity and Colour in Lake and Nearshore Waters

Robert J. W. Brewin [1,2,*,†], Thomas G. Brewin [3,†], Joseph Phillips [3,4], Sophie Rose [3,4], Anas Abdulaziz [5], Werenfrid Wimmer [6], Shubha Sathyendranath [1,2] and Trevor Platt [1]

Using a view box

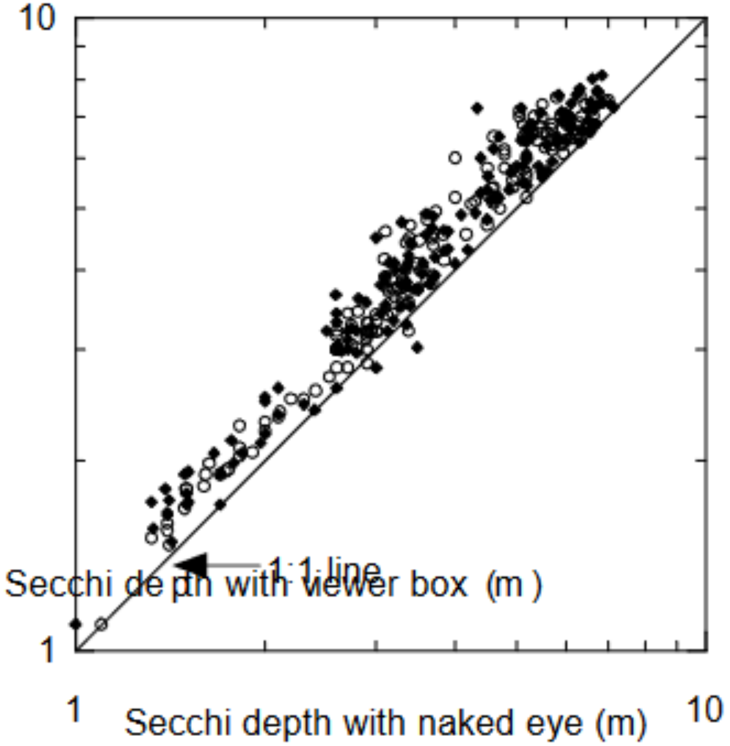


Figure 1. Relationship between Secchi depth measurements made with the aid of a viewer box and the naked eye. The open and closed symbols refer to measurements made on the sunny and shady side of the boat, respectively.

David Smith, Director of Aquatic Studies, New York City's DEP, https://acwi.gov

Remote Sensing of Environment 169 (2015) 139–149

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/rse

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Remote Sensing Environment

Secchi disk depth: A new theory and mechanistic model for underwater visibility

CrossMark

ZhongPing Lee [a,*], Shaoling Shang [b,*], Chuanmin Hu [c], Keping Du [d], Alan Weidemann [e], Weilin Hou [e], Junfang Lin [a], Gong Lin [b]

Earth & Environment | ZhongPing Lee

A new theory for Secchi depths

For 150 years, oceanographers have assessed water clarity using a simple, robust method first devised by an Italian priest. Until recently, however, researchers have struggled to match field observations made using these 'Secchi disks' to theoretical models. Through dedicated research, Dr ZhongPing Lee at the University of Massachusetts, Boston, and colleagues from other institutes in China and the USA, have revolutionised the theory and model regarding this depth, and obtained results consistent with nearly a century of past observations. The methods have become

Covering roughly 71% of our planet's surface, the water contained in oceans and lakes underpins the survival of many different ecosystems, both marine and land based. Yet increasingly, human activities are altering several key characteristics of aquatic environments worldwide – including their temperatures and populations of microscopic organisms – each of which are inflicting various levels of damage on the ecosystems. To determine the influence of these changes, researchers have developed a wide variety of techniques to assess water quality.

Among the most popular and important probes for the quality of water is its

Some controversy….

LIMNOLOGY and OCEANOGRAPHY

ASLO

Limnol. Oceanogr. 00, 2018, 00–00

doi: 10.1002/lno.10940

Resolving the long-standing puzzles about the observed Secchi depth relationships

Zhongping Lee, [1]* **Shaoling Shang**, [2]* **Keping Du**, [3] **Jianwei Wei** [1]

[1]School for the Environment, University of Massachusetts Boston, Boston, Massachusetts
[2]State Key Lab of Marine Environmental Science, Xiamen University, Xiamen, China
[3]State Key Laboratory of Remote Sensing Science, School of Geography, Beijing Normal University, Beijing, China

Lee et al. (2015)

Secchi disk depth: A new theory and mechanistic model for underwater visibility

ZhongPing Lee [a,*], Shaoling Shang [b,*], Chuanmin Hu [c], Keping Du [d], Alan Weidemann [e], Weilin Hou [e], Junfang Lin [a], Gong Lin [b]

1. Questions path radiance being same over target vs adjacent background
    - Background path radiance will be brighter directly adjacent to a white disk target, but this effect diminishes to nil near secchi disk depth
    - Makes an exception for horizontal viewing: "This may occur because most of the surrounding light over the target and the background are strong radiances in the horizontal directions as demonstrated with field observations (Zaneveld and Pegau, 2003)."
2. Questions contrast definition as $[L_T – L_B]/ L_B$
    - This is Weber contrast definition that has been validated extensively throughout many disciplines
    - Suggests we should be using absolute radiance differences only

Justification given as size of disk relative to spatial resolving capability of human eye

- "Due to this extremely fine resolution of the human eye, the relationship between the pixel size of the collected image and the size of a target will depend on the distance (z) and the size of the target"
    - This is spatial frequency (Hou et al. 2007)
    - But doesn't obviously explain reasoning for 1+2 (at least for me)

Visibility ranges from modulation transfer function (MTF) imaging theory

<u>Using relationships from Hou, Lee, Weidemann (2007), the following can be derived:</u>

Limiting contrast of detector
(~0.02 for human eye)

total
scattering

disk
size

$$V = \frac{1}{c - \cos(\theta_v)K}\left[-ln\left(\frac{C_L}{2M_0}\right) + \frac{bd}{4\pi\theta_0}\right]$$

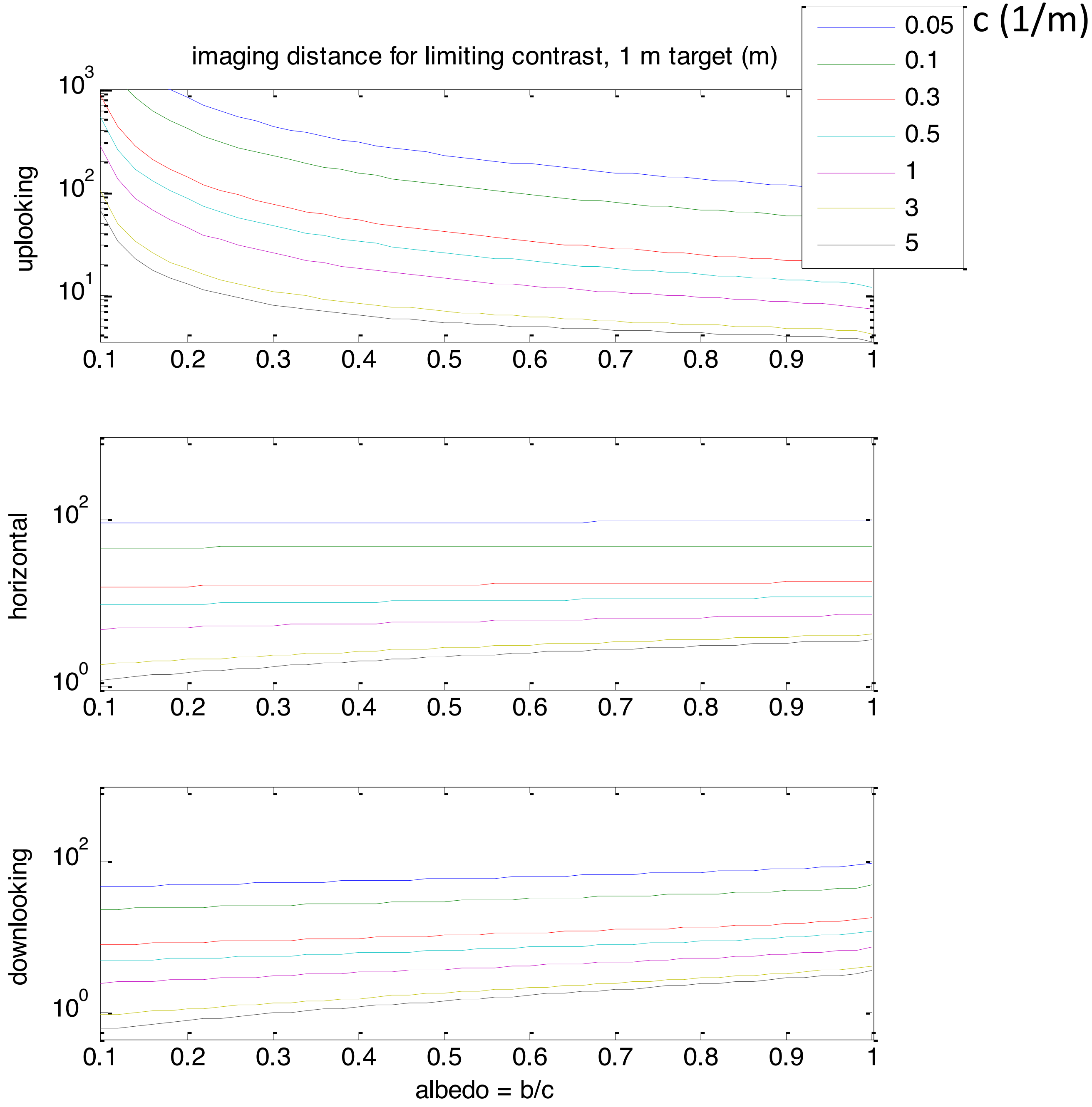
Looking up: θ_v = 0 deg
Looking horizontal: θ_v= 90 deg
Looking down (Secchi): θ_v= 180 deg

Source modulation (contrast)
Equal to 1 for black/white

term for
near forward
scattering

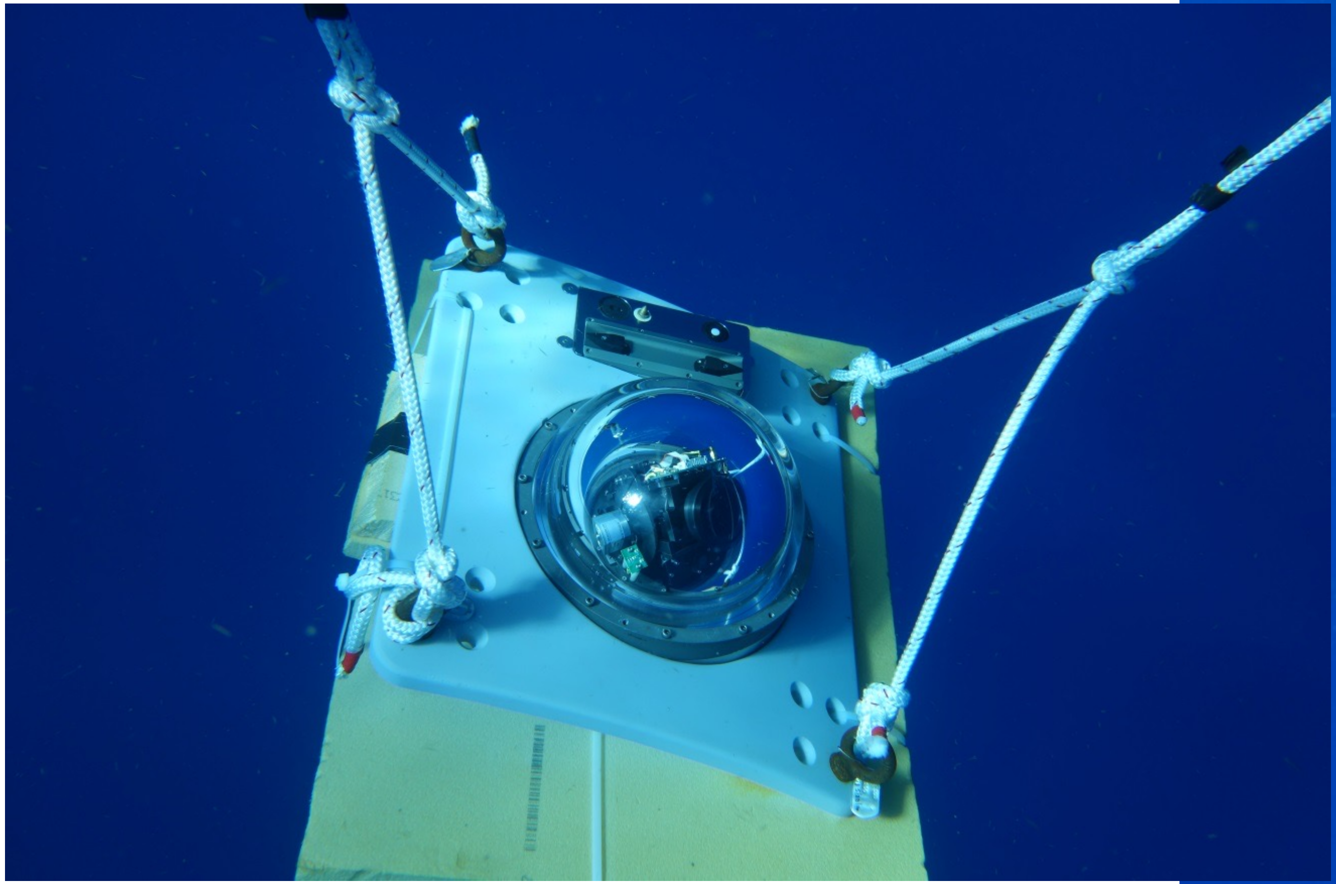
Note:
a = K$\bar{\mu}$ (Gershun's Eq)
and
c = a + b

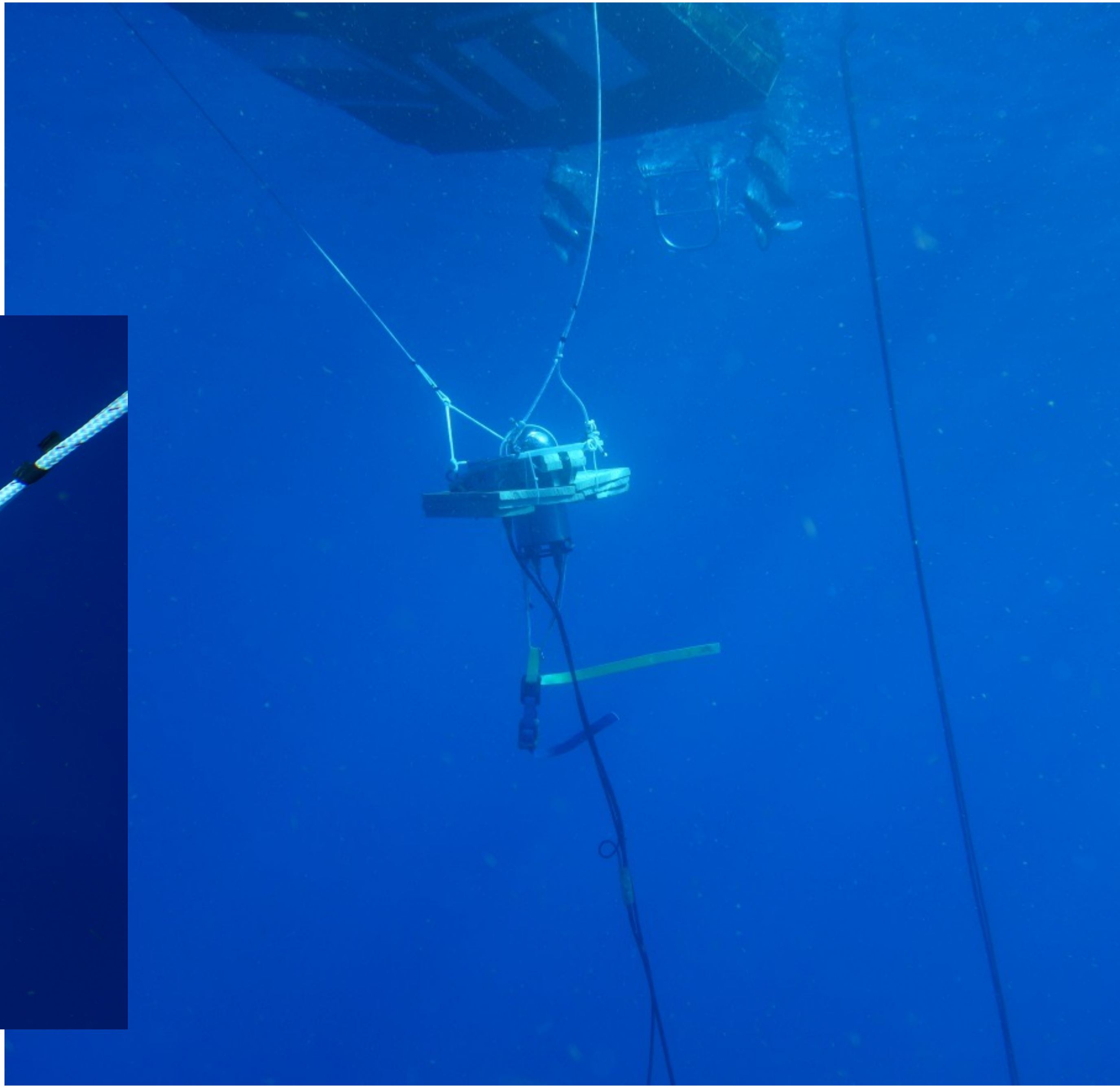
Consistent with Contrast Reduction Theory but includes terms for disk contrast and size



imaging distance for limiting contrast, 1 m target (m)
c (1/m)
0.05
0.1
0.3
0.5
1
3
5
uplooking
horizontal
downlooking
10^3
10^2
10^1
10^0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
albedo = b/c

It works



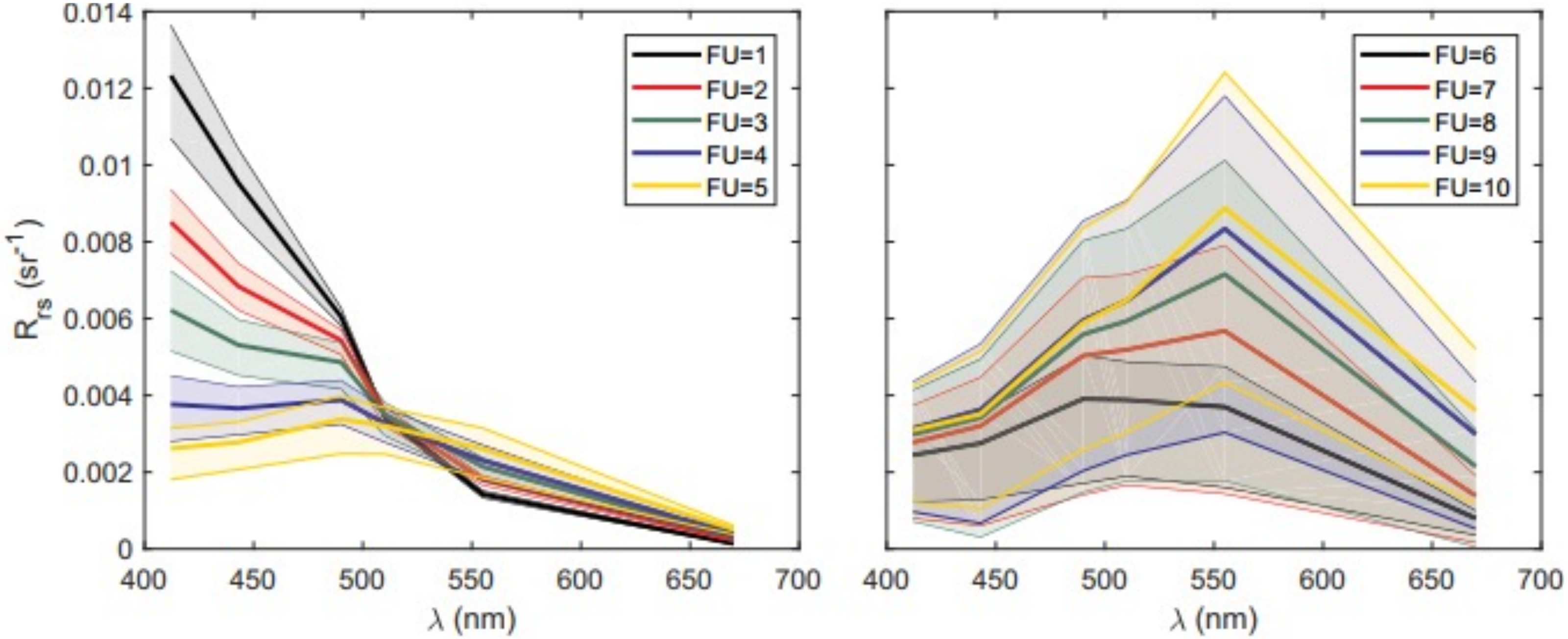


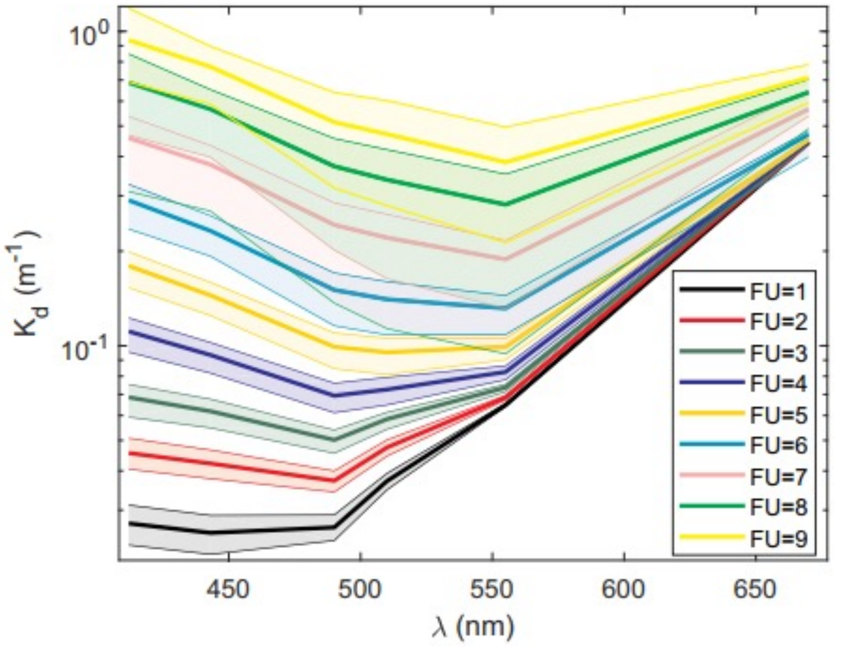
Forel-Ule color scale

- Pitarch et al. (2019)
  - Can derive Kd
  - Other parameters with increasing errors…

Deploy over white Secchi disk

Pitarch et al. (2019) RSE





Bold traces outlining gray areas are 25%-75% of cases

Fig. 9. Diffuse attenuation coefficient of downwelling irradiance of the first 9 FU classes, representing the median in bold line and the interval between the 25th and 75th percentiles in shaded band. For a complete description, the reader is referred to Table A2.

As an example, can derive light profiles for PAR with reasonable accuracy

Recap - derived optical parameters

can potentially solve for:

- Attenuation c
- Diffuse attenuation K_d
- Absorption a
- biogeochemical properties via proxies (or measure directly…)

Note:

$a = K\bar{\mu}$ (Gershun's Eq)

$c = a + b$

$K_d \sim a + b_b$

Published: October 2003

Horizontal sighting range and Secchi depth as estimators of underwater PAR attenuation in a coastal lagoon

Martín A. Montes-Hugo, Saúl Alvarez-Borrego & Alma D. Giles-Guzmán

Estuaries **26**, 1302–1309 (2003) | Cite this article

Abstract

Attenuation of photosynthetically available radiation (PAR) measured using a light meter, was related to Secchi disk, horizontal black disk and horizontal sighting ranges observed in a coastal lagoon of the Southern California Current System. Vertical attenuation coefficient (K_{PAR}) was calculated from radiometric PAR profiles. Vertical (Z_D) and horizontal (HS) sighting ranges were measured with white (Secchi depth or Z_{SD}, HS_W) and black (Z_{BD}, HS_B) targets. Empirical power models for the K_{PAR}-Z_{SD} (K_{PAR}=1.47 $Z_{SD}^{-1.13}$), K_{PAR}-Z_{BD} (K_{PAR}=0.98 $Z_{BD}^{-1.26}$), K_{PAR}-HS_W (K_{PAR}=1.22 $HS_W^{-1.14}$) and K_{PAR}-HS_B (K_{PAR}=0.73 $HS_B^{-1.07}$) relationships were developed. The parameters of these models may not apply to other water

Inexpensive digital sensors

Holographic imaging with cell phone

3D printed accessory
~$10

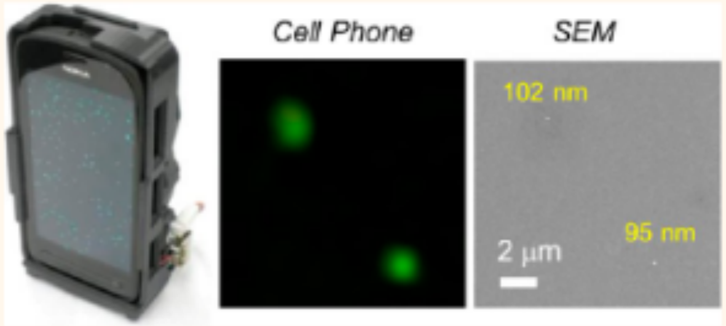
Particle size distributions

Fluorescent Imaging of Single Nanoparticles and Viruses on a Smart Phone

Qingshan Wei,[†,‡,§] Hangfei Qi,[‖] Wei Luo,[†] Derek Tseng,[†] So Jung Ki,[⊥] Zhe Wan,[†] Zoltán Göröcs,[†,‡] Laurent A. Bentolila,[§,⊥] Ting-Ting Wu,[‖] Ren Sun,[§,‖] and Aydogan Ozcan[†,‡,§,*]

[†]Electrical Engineering Department, [‡]Bioengineering Department, [§]California NanoSystems Institute (CNSI), [‖]Department of Molecular and Medical Pharmacology, and [⊥]Department of Chemistry and Biochemistry, University of California, Los Angeles (UCLA), California 90095, United States

ABSTRACT Optical imaging of nanoscale objects, whether it is based on scattering or fluorescence, is a challenging task due to reduced detection signal-to-noise ratio and contrast at subwavelength dimensions. Here, we report a field-portable fluorescence microscopy platform installed on a smart phone for imaging of individual nanoparticles as well as viruses using a lightweight and compact opto-mechanical attachment to the existing camera module of the cell phone. This hand-held fluorescent imaging device utilizes (i) a compact 450 nm laser diode that creates oblique excitation on the sample plane with an incidence angle of ~75°, (ii) a long-pass thin-film interference filter to reject the scattered excitation light, (iii) an external lens creating 2× optical magnification, and (iv) a translation stage for focus adjustment. We tested the imaging performance of this smart-phone-enabled microscopy platform by detecting isolated 100 nm fluorescent particles as well as individual human cytomegaloviruses that are fluorescently labeled. The size of each detected nano-object on the cell phone platform was validated using scanning electron microscopy images of the same samples. This field-portable fluorescence microscopy attachment to the cell phone, weighing only ~186 g, could be used for specific and sensitive imaging of subwavelength objects including various bacteria and viruses and, therefore, could provide a valuable platform for the practice of nanotechnology in field settings and for conducting viral load measurements and other biomedical tests even in remote and resource-limited environments.



acsnano
2013

Cheap sensors that are smart

They're multi-beam

Phathom's multi-beam turbidity sensors provide unrivalled accuracy that single-beam sensors simply can't supply. Phathoms generate multiple light beams that are synthesized into a ratio-metric algorithm that, once calibrated, precisely calculates turbidity or total suspended solids and self-compensates for common sources of measurement error.

Read about the technology

Sensors **2013**, *13*, 7872-7883; doi:10.3390/s130607872

- Spin off from an undergrad class project

OPEN ACCESS
sensors
ISSN 1424-8220
www.mdpi.com/journal/sensors

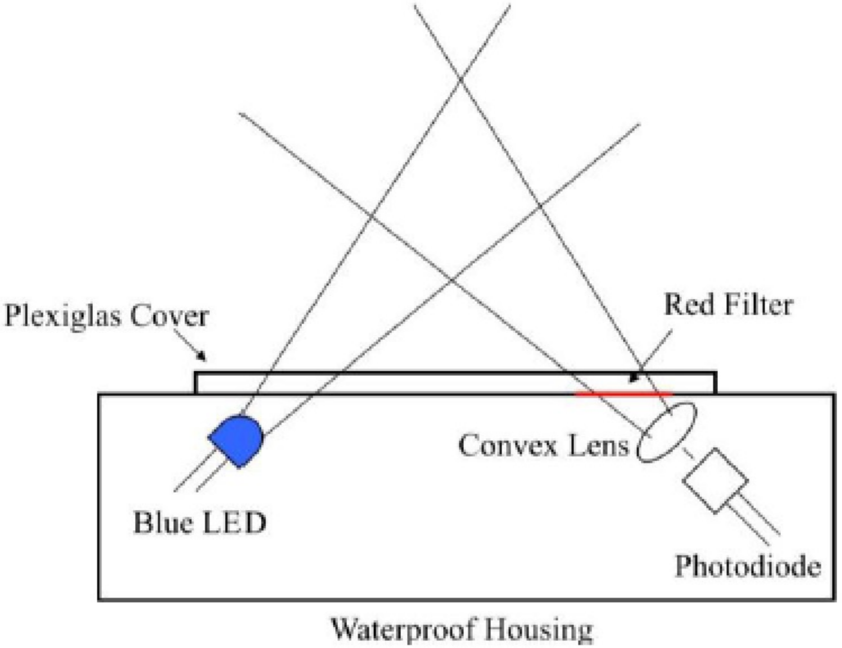
Article

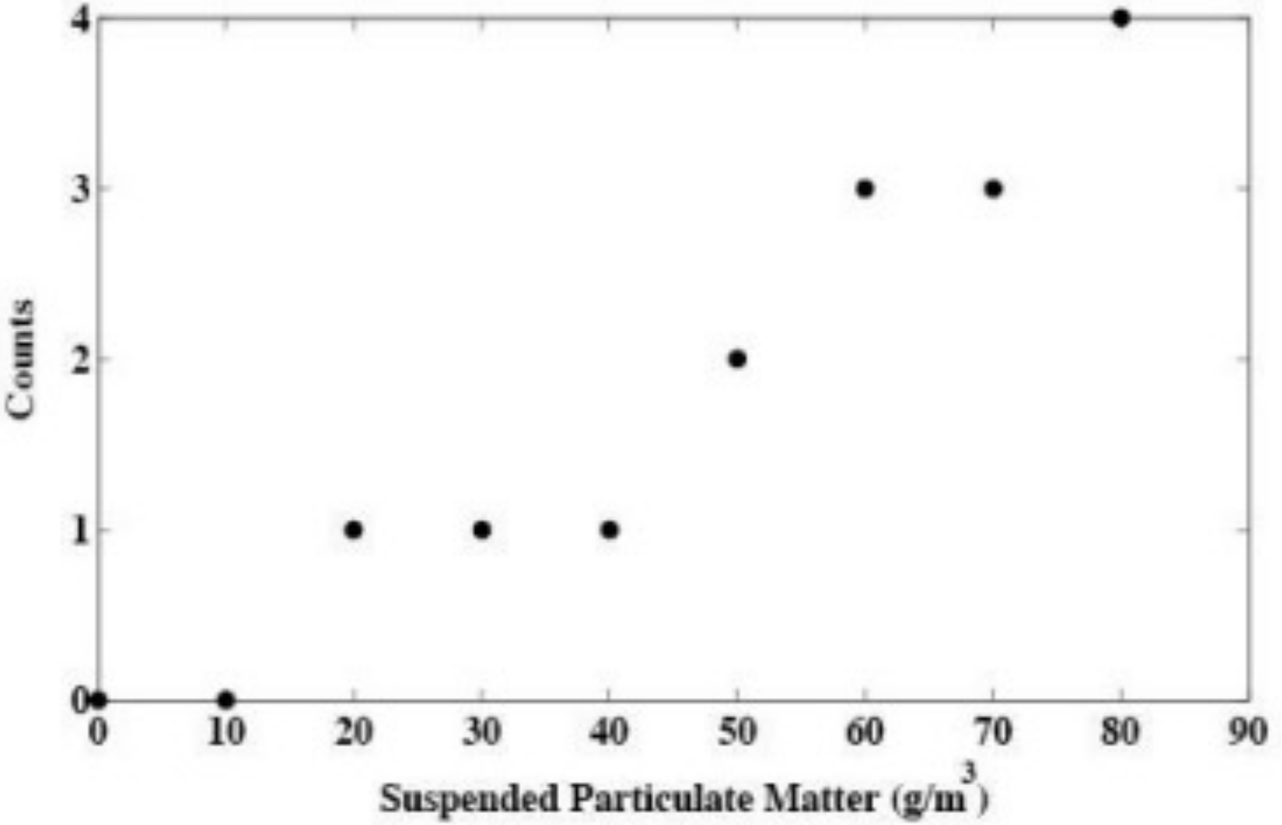
In situ Measurements of Phytoplankton Fluorescence Using Low Cost Electronics

Thomas Leeuw *, Emmanuel S. Boss and Dana L. Wright

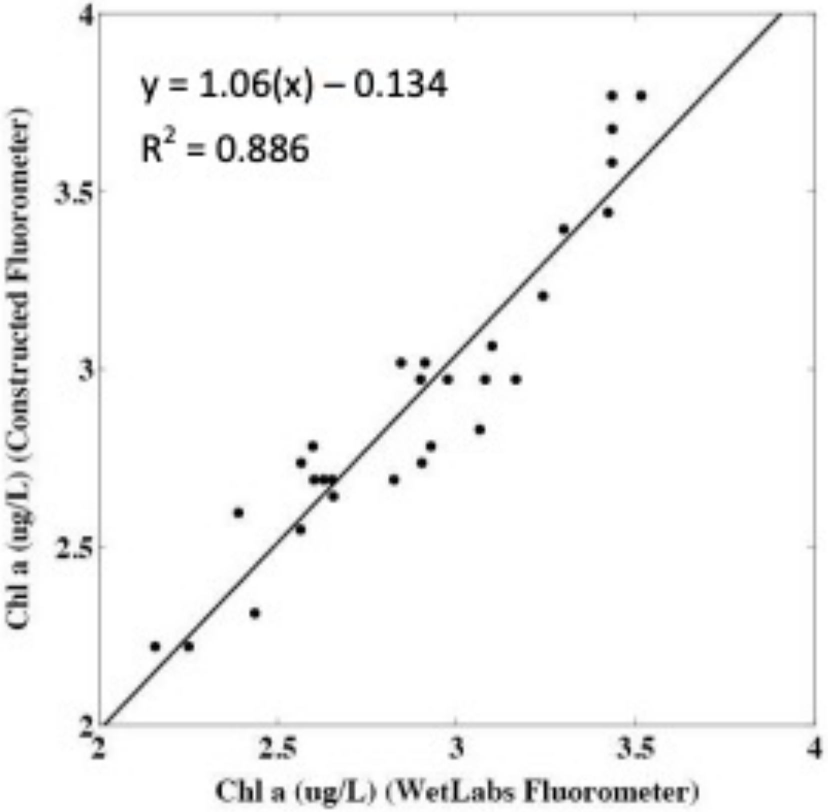
Table 1. List of prices (in US dollars) and sources for all components in the sensor.

Component	Source	Price
Blue LED (LED420L)	ThorLabs	$28.49
Waterproof Box (Drybox 2500)	Otterbox	$20.49
Arduino Duemilanove	Amazon	$20.00
1/2" Convex Lens (f = 15 mm)	ThorLabs	$19.70
Photodiode (FDS100)	ThorLabs	$13.10
(2) 5 GΩ Resistor	Digi-Key	$10.20
Roscolux Filter Booklet	Edmund Optics	$9.70
SD Card Shield (Data Logger)	imall.iteadstudio.com	$9.50
2 GB SD Card	Amazon	$5.29
Operational Amplifier (OP07)	Digi-Key	$4.04
Printed Circuit Board	RadioShack	$2.00
(2) 10 Ω Resistor	Digi-Key	$0.24
10 pF Capacitor	Digi-Key	$0.29
Total		**$143.04**





Characterization of out of band response to particles



Comparison with commercial sensor

A water-quality application for the phone.

sensors

MDPI

Article

The HydroColor App: Above Water Measurements of Remote Sensing Reflectance and Turbidity Using a Smartphone Camera

Thomas Leeuw [1,*] and Emmanuel Boss [2]

2018

remote sensing

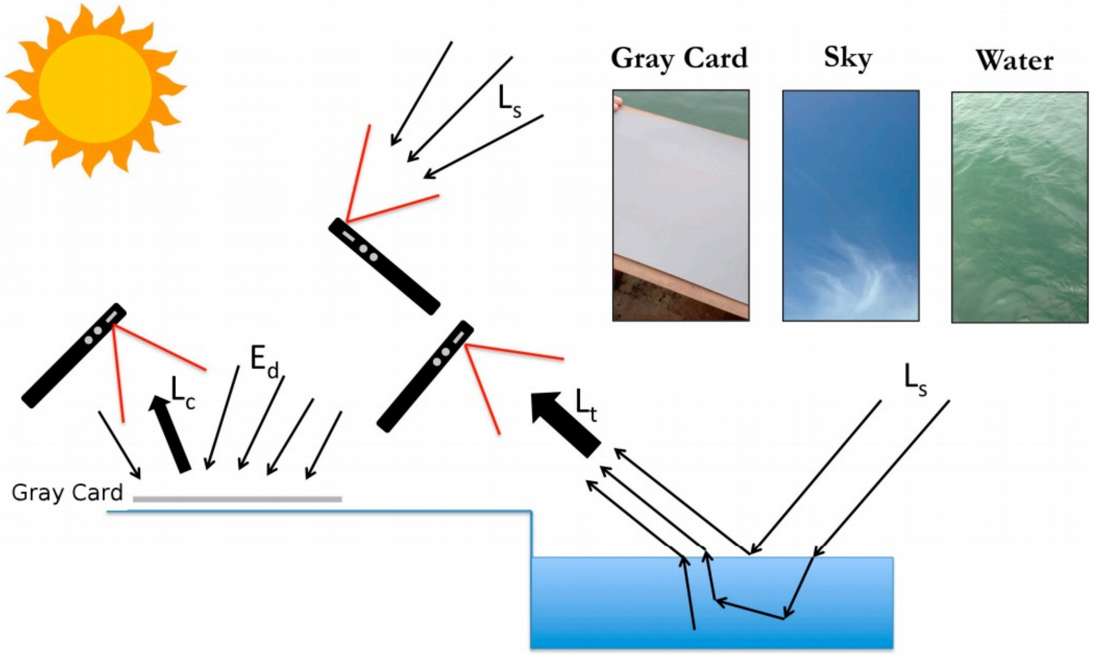
MDPI

Article

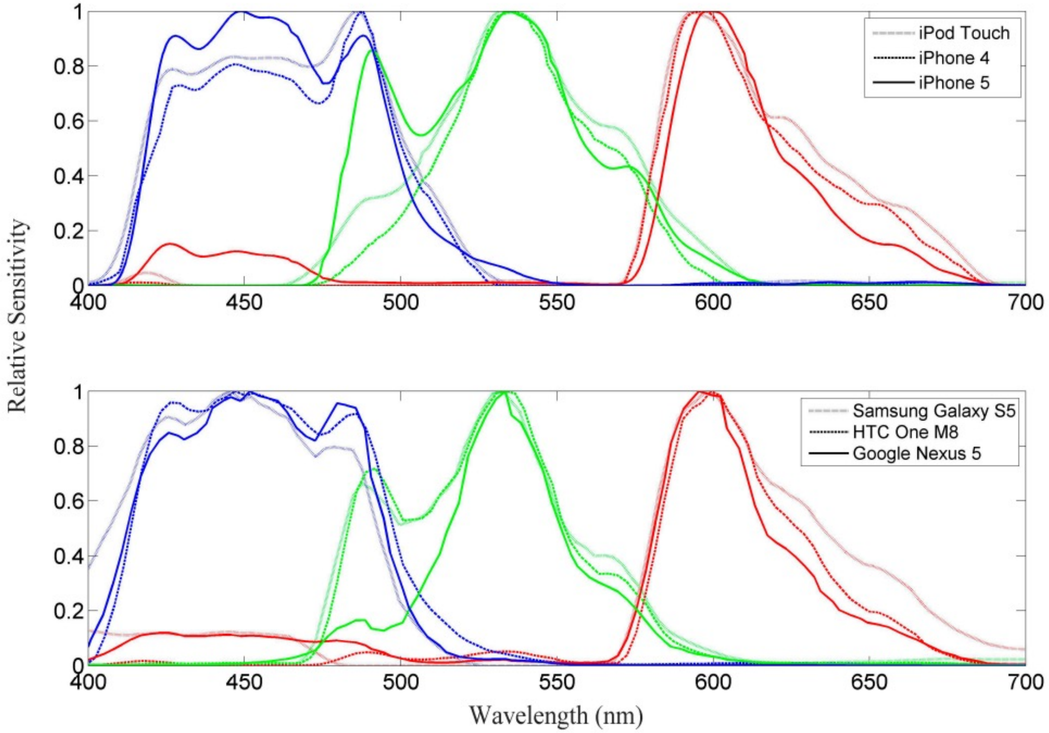
Is Ocean Reflectance Acquired by Citizen Scientists Robust for Science Applications?

Yuyan Yang [1,*], Laura L.E. Cowen [1] and Maycira Costa [2]

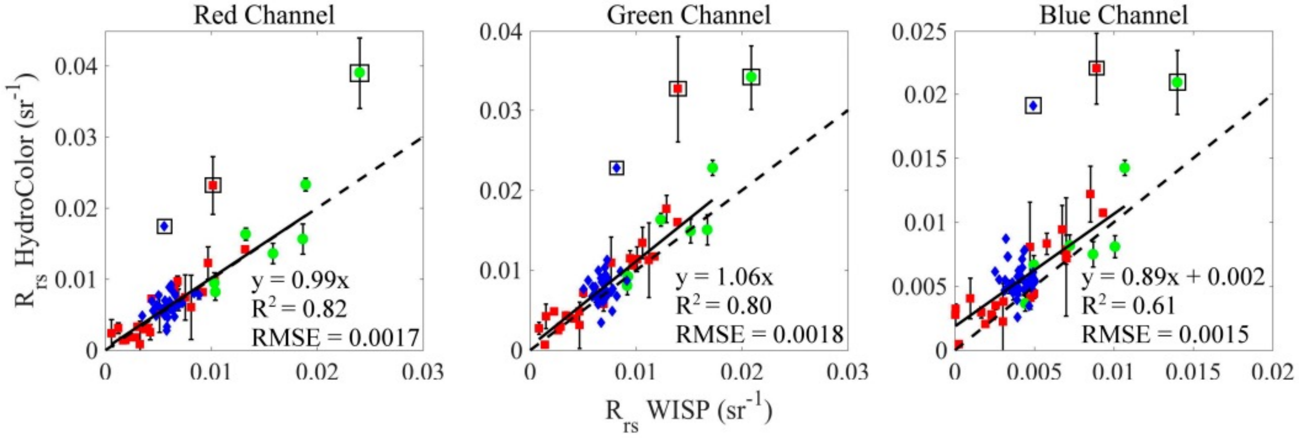
2018



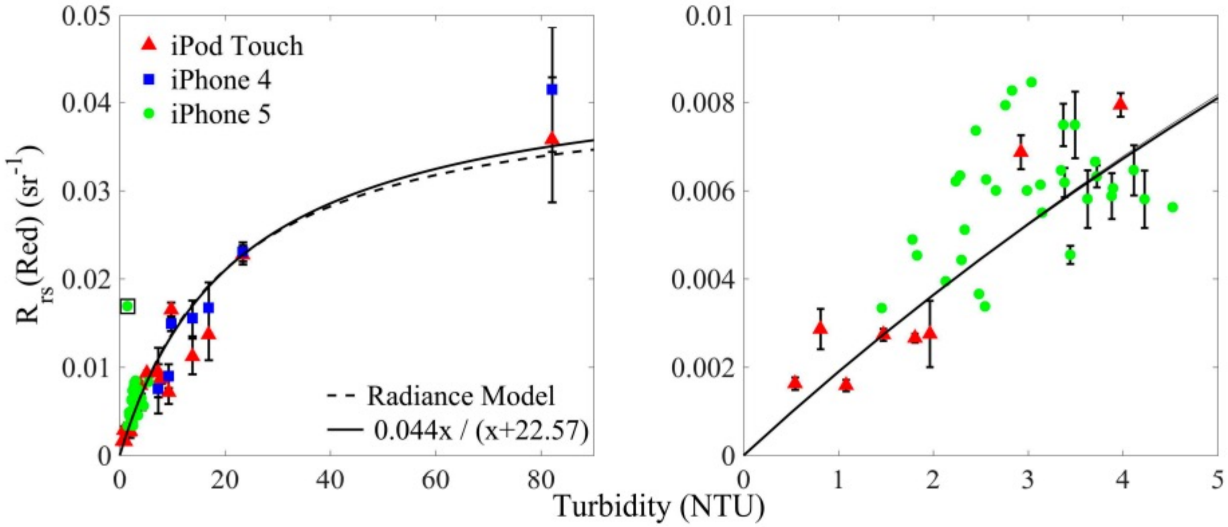
>8000 downloads (free).



Characterization of phone cameras

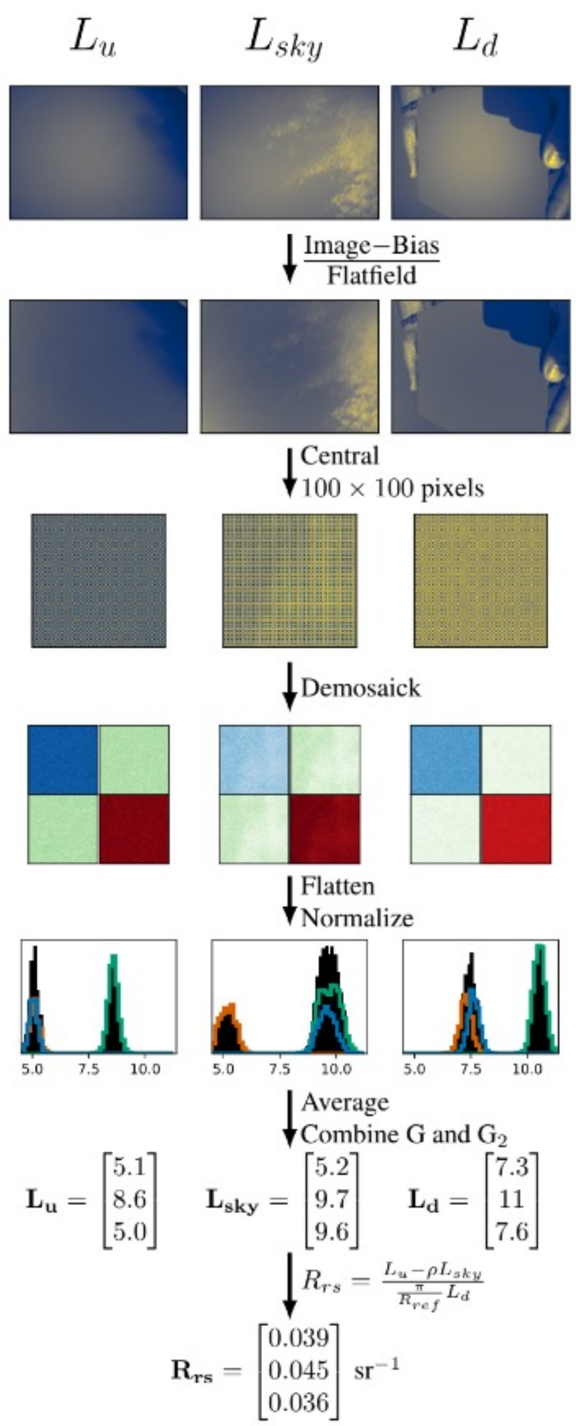


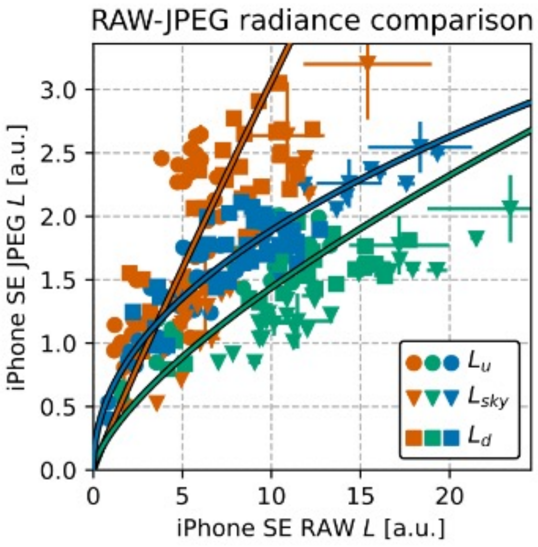
Comparison with commercial sensor for Rrs

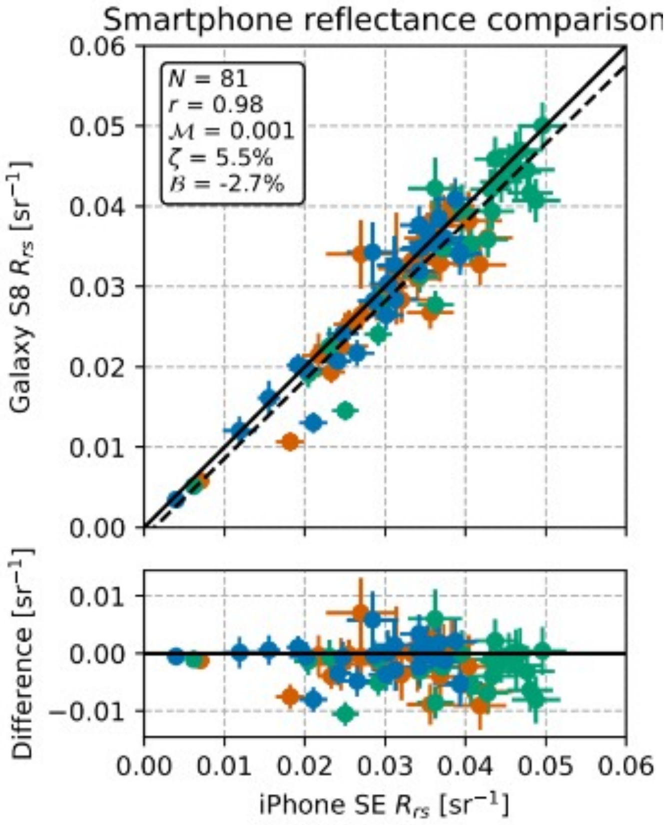


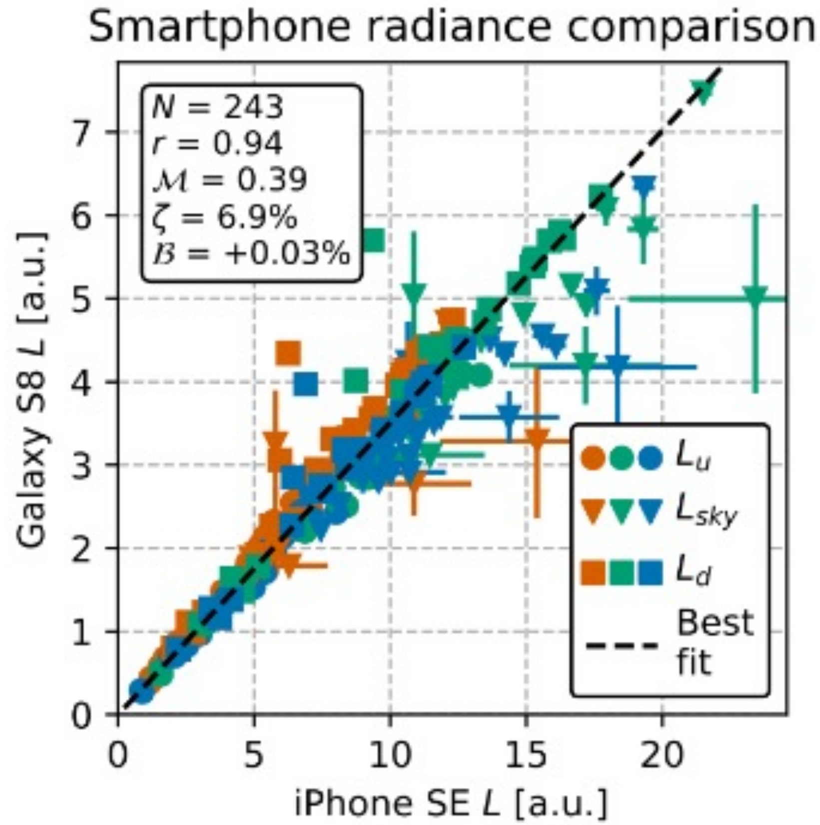
Turbidity vs. Rrs(red)

Improving phone apps using raw data



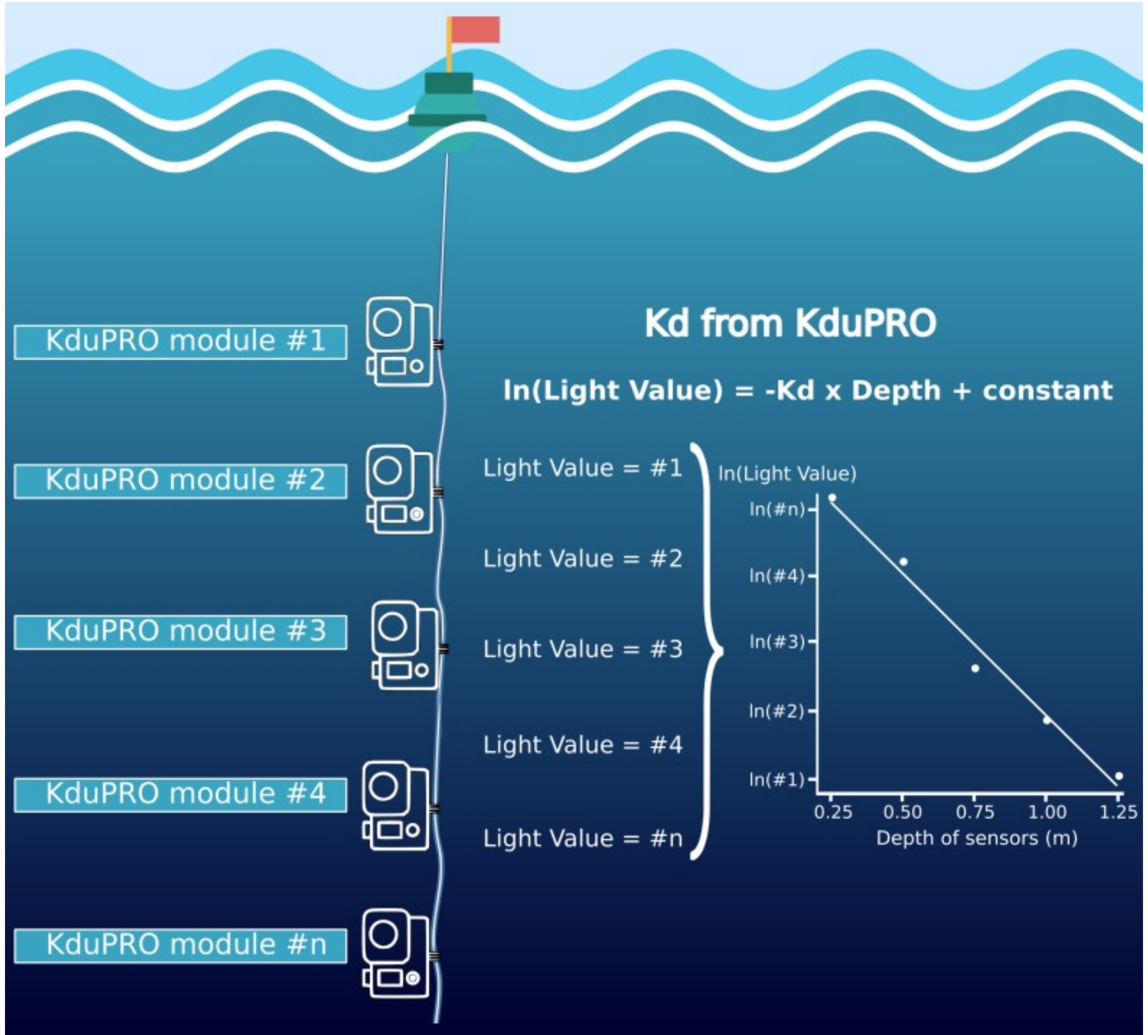






KduPRO

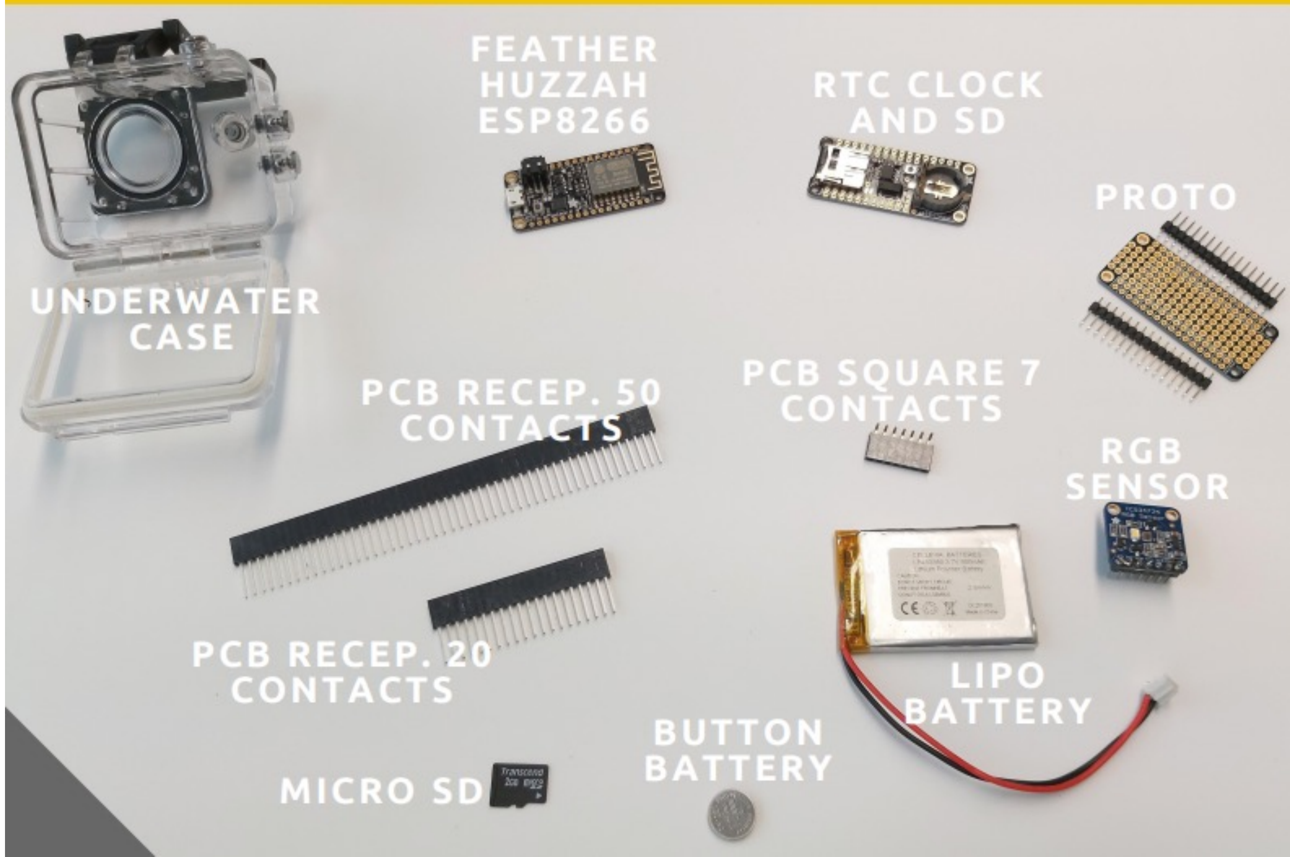
Measuring attenuation at RGB

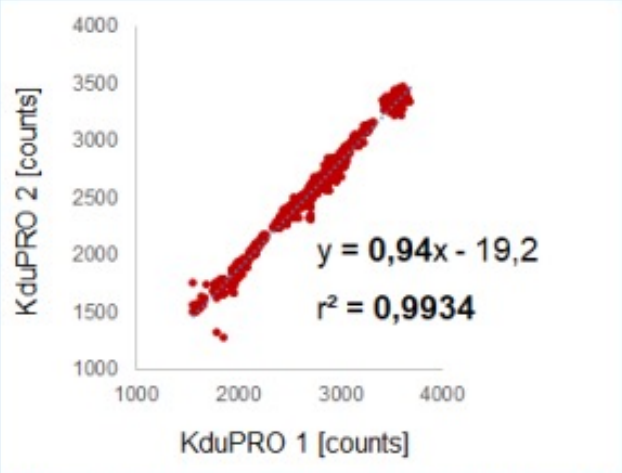


Hardware components

Component	*Cost (€)*
Feather HUZZAH ESP8266	19.49
Adalogger FeatherWing RTC Clock and SD	9.60
FeatherWing Proto	5.31
Underwater case (GoPro or similar)	15.69
TCS34725 color RGB sensor	11.76
Lithium-ion Polymer Battery	8.41
MicroSD	13.39
CR1220 Button Battery 3V	1.33
PCB socket 2.54 mm square 7 contacts	2.19
PCB Receptacle 2.54 mm board-to-board 20 contacts	3.47
PCB Receptacle 2.54 mm board-to-board 50 contacts	6.67
	Total
	97.31

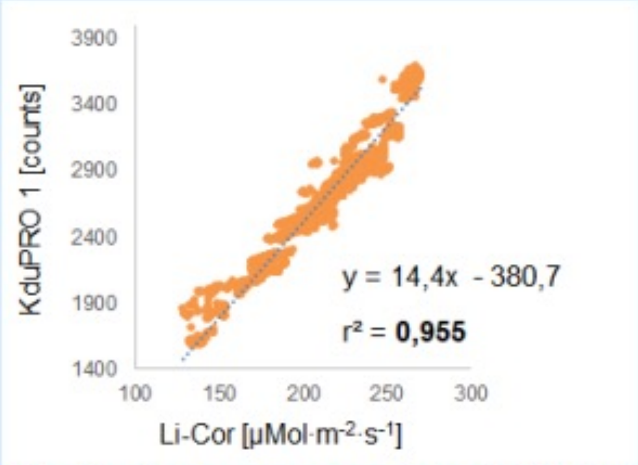
Budget for build one module of KduPRO





Relation between different modules of KduPRO

Reproducibility



Relation between one module of KduPRO and Li-COR Li-192 reference sensor

Validation of radiance

Turbidity sensors

Sensors **2014**, *14*, 7142-7155; doi:10.3390/s140407142

OPEN ACCESS
sensors
ISSN 1424-8220
www.mdpi.com/journal/sensors

Article

An Affordable Open-Source Turbidimeter

Christopher D. Kelley [1,*], Alexander Krolick [2], Logan Brunner [1], Alison Burklund [1], Daniel Kahn [1], William P. Ball [1] and Monroe Weber-Shirk [3]

The Turbidity Tube: Simple and Accurate Measurement of Turbidity in the Field

Written April 2006 for the requirements of
CE 5993 *Field Engineering in the Developing World*
and
FW 5770 *Community Planning and Analysis*

Article | Open Access | Published: 20 June 2022

Open-source, low-cost, in-situ turbidity sensor for river network monitoring

Jessica Droujko & Peter Molnar

Scientific Reports **12**, Article number: 10341 (2022) | Cite this article

Fluorometers:

IEEE Photonics Journal Measurement of Chlorophyll and CDOM

Lensless Miniature Portable Fluorometer for Measurement of Chlorophyll and CDOM in Water Using Fluorescence Contact Imaging

Lior Blockstein and Orly Yadid-Pecht, *Fellow, IEEE*

Department of Electrical and Computer Engineering, University of Calgary, Calgary, AB T2N 1N4, Canada

DOI: 10.1109/JPHOT.2014.2326665

Photosynthesis Research (2019) 142:361–368
https://doi.org/10.1007/s11120-019-00673-2

TECHNICAL COMMUNICATION

Check for updates

A guide to Open-JIP, a low-cost open-source chlorophyll fluorometer

Harvey Bates[1] · Alonso Zavafer[1] · Milán Szabó[1,2] · Peter J. Ralph[1]

Received: 27 May 2019 / Accepted: 9 September 2019 / Published online: 20 September 2019

Calibration for fluorometers:

Set of Secondary Emission Standards for Calibration of the Spectral Responsivity in Emission Spectroscopy

J. A. GARDECKI and M. MARONCELLI*
Department of Chemistry, The Pennsylvania State University, University Park, Pennsylvania 16802

J Fluoresc (2006) 16:581–587
DOI 10.1007/s10895-006-0086-8

ORIGINAL PAPER

The Calibration Kit *Spectral Fluorescence Standards*—A Simple and Certified Tool for the Standardization of the Spectral Characteristics of Fluorescence Instruments

D. Pfeifer · K. Hoffmann · A. Hoffmann · C. Monte · U. Resch-Genger

Imaging systems:

Cold Spring Harbor Laboratory

bioRxiv

THE PREPRINT SERVER FOR BIOLOGY

bioRxiv posts many COVID19-related papers. A reminder: they have not been formally peer-reviewed and should not guide health-related behavior or be reported in the press as conclusive.

New Results

Follow this preprint

PlanktonScope: Affordable modular imaging platform for citizen oceanography

Thibaut Pollina, Adam G. Larson, Fabien Lombard, Hongquan Li, Sebastien Colin, Colomban de Vargas, Manu Prakash

doi: https://doi.org/10.1101/2020.04.23.056978

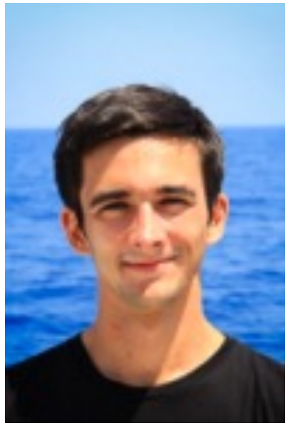
Göröcs et al. *Light: Science & Applications* (2018)7:66
DOI 10.1038/s41377-018-0067-0

ARTICLE — Open Access

A deep learning-enabled portable imaging flow cytometer for cost-effective, high-throughput, and label-free analysis of natural water samples

Zoltán Göröcs[1,2,3], Miu Tamamitsu[1,2,3], Vittorio Bianco[1], Patrick Wolf[1], Shounak Roy[1], Koyoshi Shindo[1], Kyrollos Yanny[2], Yichen Wu[1,2,3], Hatice Ceylan Koydemir[1,2,3], Yair Rivenson[1,2,3] and Aydogan Ozcan[1,2,3]

 DIY-Oceanography section in the Oceanography Magazine



Inlinino

A MODULAR SOFTWARE DATA LOGGER FOR OCEANOGRAPHY

By Nils Haëntjens and Emmanuel Boss 2020

Using IoT tools to broadcast data to phones/tablets

Software based datalogger.

Time stamps and logs data from analogue and digital sensors.

Graphical interface – real time data.

Works on PCs, Macs and Linux.

Used to log: AC-S, LISST, Eco-bb3, Seapoint fluoromter, Hyper-bb, CTD…. All simultaneously on the same computer.

https://inlinino.readthedocs.io/en/latest/

Buoy systems:

Aquacultural Engineering 80 (2018) 28–36

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aque

Design and operation of a low-cost and compact autonomous buoy system for use in coastal aquaculture and water quality monitoring

Wiebke Schmidt[a,b,*], David Raymond[b], David Parish[b], Ian G.C. Ashton[a,b], Peter I. Miller[c], Carlos J.A. Campos[d], Jamie D. Shutler[a]

Hindawi Publishing Corporation
Journal of Sensors
Volume 2015, Article ID 920168, 23 pages
http://dx.doi.org/10.1155/2015/920168

Research Article

Oceanographic Multisensor Buoy Based on Low Cost Sensors for Posidonia Meadows Monitoring in Mediterranean Sea

Sandra Sendra, Lorena Parra, Jaime Lloret, and José Miguel Jiménez

Wrap up

- Robust analog methods exist for potentially determining *c* and *K*… *a, b,* b_b may also be potentially derived
- An ongoing revolution in inexpensive electronic and optical components provides new opportunities to develop inexpensive, robust sensors
- Validation and closure between methods is highly desirable to quantify uncertainties
- Analog methods are useful if expensive optical sensors are not available for research, but can also be very useful metrics as a gut check on highest quality measurements
- Many applications relating to water quality and imaging can accommodate larger uncertainties associated with many of these methods