Underwater Depth Imaging using a Time-of-flight Single-photon Counting Approach: Preliminary Studies

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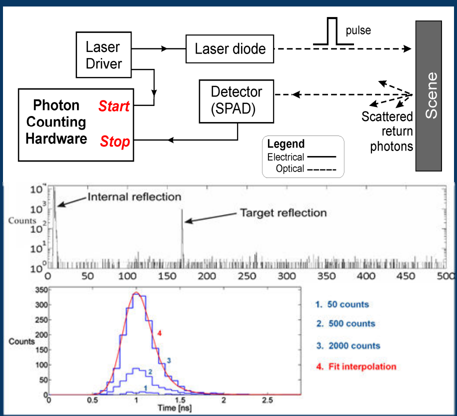
Introduction

The aim of the project is to develop a single photon counting system that can achieve centimetre-scale depth resolution at long ranges (tens of metres) underwater. This technology has been successfully used in air over kilometre ranges and under a variety of daylight and weather conditions [1, 2]. The purpose of this project is to adapt the current technology and assess its performance for underwater use, develop a prototype, and demonstrate it in a variety of environments.

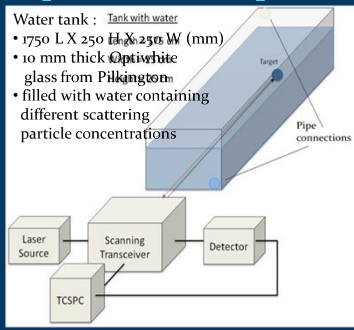
Photon Counting Time-of-Flight Technique

The technique of time-correlated single-photon counting (TCSPC) has been used since the 1960's, mainly for the measurement of fast, low-level light signals in, for example, time-resolved fluorescence measurements.

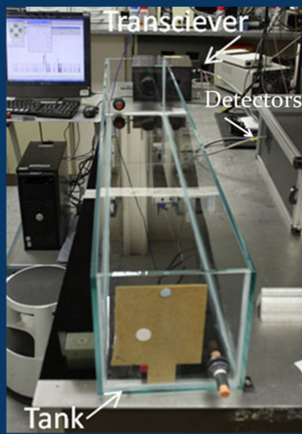


The technique measures the time difference (or "micro-time") between an optical input pulse (typically a repetitive laser signal) and a photon event recorded by a single-photon detector.. Over many laser pulses, a histogram of the number of photon counts versus micro-time can result in a statistically accurate representation of the actual optical transient signal being measured [1].

Experimental Setup



Schematic of the experimental setup.



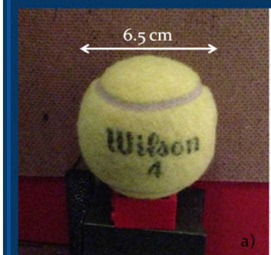
Supercontinuum System (NKT):
• Supercontinuum source (485-2400 nm)
• Tunable filter (VIS-nIR crystal, 500 – 850 nm)
• Fiber delivery system (armoured and collimated output)

Supercontinuum System (NKT).

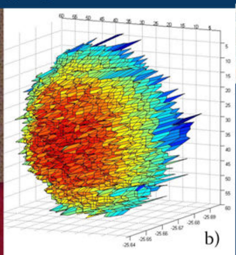
Si-SPAD Detector:
• SPCM-AQR-Single Photon Counting Module

Results

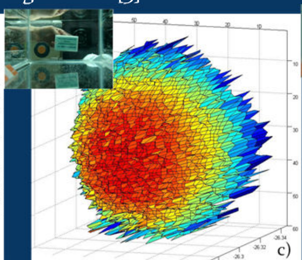
Depth profile measurements of target objects at a distance of 1.85 m were made in air and for several water conditions. The pictures show the depth profile of a tennis ball in air (b), in clear water (c) and in 67 l of water containing 6.7 ml of Maalox (d). In the last profile (d) a higher wavelength is used because of the high concentration of scatters in water, since higher is the scattering higher is the best wavelength to use [3].



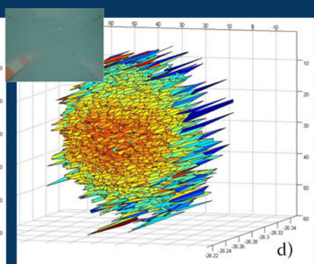
Picture of the target.



Tennis ball depth profile in air at λ=570 nm.



Tennis ball depth profile in clear water at λ=570 nm.



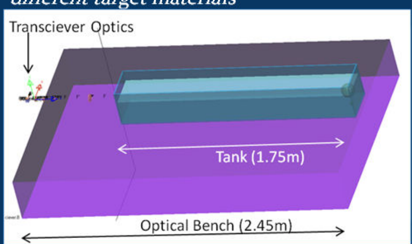
Tennis ball depth profile in murky water at λ=670 nm.

Conclusions and Future Work

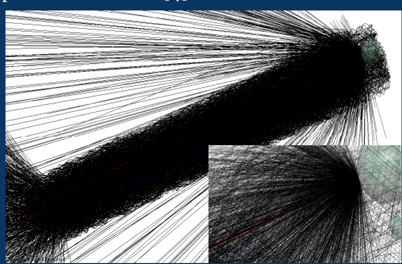
A time of flight single photon counting approach for underwater depth imaging has been explained. Targets at 1.85 metres have been scanned in clear and murky water, the results presented here show that time-correlated single-photon counting technique works well for underwater depth profile measurements. Because of the scattering, a much longer study has to be made for the murky water. For this reason to understand which wavelength is the best in water and Maalox, the future work includes obtaining the return signal from a Spectralon target and it will be studied at three wavelengths (λ=531, 570 and 670 nm), at different distances and different concentration of Maalox in water. Moreover depth profile measurements will be made of several target objects at different standoff distances, for a variety of water conditions. For having more realistic simulations, the data obtained from the measurements will be used to refine and verify the model, in parallel with the experimental work.

Modelling

A model of our experimental setup has been developed using LightTools, a commercially available software program by Synopsys. The model simulates the propagation of the transmitted laser beam, and the return photons, in water under several conditions:
• different concentrations of scattering spherical particles in water [4]
• different wavelengths
• different target materials



Model of the experimental setup



Simulation in clear water
(glass tank and water hidden from view)

Simulation parameters

Source Configuration	Wavelength = 550 nm
	Aim Sphere = 2°
	Diameter = 5 mm
	Radiometric Power = 1 W
Target material	Plastic
Target shape	Sphere
Number of rays visualized	100

References

[1] A. McCarthy, et al. , "Long-range time-of-flight scanning sensor based on high-speed time-correlated single-photon counting", Appl. Opt. **48**, 6241-6251 (2009).
[2] G. S. Buller, R. J. Collins, "Single-photon generation and detection", Meas. Sci. Technol. **21**, 012002 (2010).
[3] E. Young, et al. , "Underwater-airborne laser communication system", P.Soc.Photo-Opt Ins, **4975**, 146-157 (2003).
[4] S. Q. Duntley, "Light in the sea", J. Opt. Soc. Amer. **53**, 214-233 (1962).

Acknowledgements

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