FIRST FIELD MEASUREMENTS AND DEVICE IMPROVEMENTS FOR MULTI-SPECTRAL VOLUME SCATTERING METER (MVSM)

Ligi, Martin[1]; Reinart, Aivo[1]; Tõnnisson, Teofilus[2]; Reinart, Anu[1]

1. Tartu Observatory, Tõravere, Estonia, info@to.ee martin.ligi@to.ee
2. Interspectrum OU, Tõravere, Estonia, info@interspectrum.ee

ABSTRACT

The optical volume scattering function (VSF), which describes the angular distribution of light scattered from an incident beam, is a fundamental inherent optical property of the aquatic environment. Along with the spectral absorption coefficient, VSF is one of the two inherent optical properties which describe the propagation of light in aquatic environment. Despite its fundamental nature, there's little known about the range of variability of the VSF in the aquatic environment. One of the main reasons of lack in the measurement data is that instruments, which have been used for measuring VSF, are complicated and there is no commercially available instrument able to take measurements of the function in full angular range.

Tartu Observatory in cooperation with company Interspectrum and MHI of Ukraine developed a prototype of the new instrument for scattering measurement - MVSM. It outperforms in most of the parameters industrial instruments currently used to measure VSF. It has modern programmable multicolour LED light source, measurement angles cover full angular range, interference filters in receiver enable fluorescence measurements at different wavelengths, and closed measurement volume eliminates the background noise and increases sensitivity and dynamic range. Instrument has modular design with 32-bit microcontroller in every module; software in modules executes under certified real-time operating system SafeRTOS allowing safe and robust multitasking as well as fast multiprocessor communication between modules.

In September 2013 the comparison measurements were carried out in Sevastopol, Ukraine. A set of scattering measurements were carried out in laboratory with pure water and with the water mixed up with 5 μm solid particles. On the basis of the information received from this testing, improvements were made and a new test with 5 μm particles was carried out in Tõravere. The third set of laboratory testing was made after the latest prototype release and 1-5 μm solid particles were used.

As the device is very complex, then we also ran a calibration exercise in the Tartu Observatory optics laboratory to find a set-up that would provide sufficient amount of data for calibration documentation.

In the poster the newest design features and software changes are presented together with testing results and results from the calibration exercise.

INTRODUCTION

The remote sensing data gathered by satellites is validated by combining with improved in-situ measurement methods. The measurement capability has been identified as the limiting factor for several research topics related to optical remote sensing of coastal and inland waters (1). The quality of results obtained in research activities increases according to the quality of the measurements from satellites combined with the reference ground measurements with portable instruments.

The volume scattering function (VSF), which describes the angular distribution of light scattered from an incident beam, is a fundamental inherent optical property of the aquatic environment. Along with the spectral absorption coefficient, VSF is one of the two inherent optical properties which describe the propagation of light in aquatic environment. The VSF is used in

- the studies of the radiative transfer,
- the light propagation and image degradation,
- the interpretation of remote sensing measurements,
- investigations of particle shape,
- the photosynthetic productivity in the water bodies.

Despite its fundamental nature, there is little known about the range of variability in the VSF in the aquatic environment. This is mainly because the measurements of the function are difficult to perform. A lot of currently used radiate transfer models are based on a very limited set of measurements, which are made over 20 years ago. For the correct calculations of the radiate transfer, it is essential to know the variations of the phase function. Instruments, which have previously been used for measuring VSF, were complicated, bulky and most importantly: they are not able to take measurements of the function in full angular range (2).

Under the ESA PECS project ORAQUA, the first prototype of new Multispectral Volume Scattering Meter (MVSM) was developed. First field test were performed in Sevastopol Marine Institute and comparison of measured and modelled functions allow make final version of the prototype ready. According to data received from these tests, the device is developed for production under ESA PECS project QUALITY.

METHODS

The measurement principles implemented in the device, are based on static scatter approach. Photomultiplier tube (PMT) is used to detect scattering light at different angles. Device's mechanistic approach involves a use of a special periscope prism and a novel light shadow method.

Figures 1 and 2 show a diagram of the Multi-spectral Volume Scattering Meter (MVSM). The light source, the photodetector, and the prism stepping motor for the angular scanner are placed in three separate hermetically isolated cans, mutually oriented at 90° with respect to the working volume of the device. The working volume is contained within a light trap assembly consisting of central measurement chamber of light absorptive black material (Derlin) enclosing a volume of approximately 1.5 liter, with provision for free exchange of ambient fluid. The water is slowly stirred within the chamber by rotation of the periscope; complete rotation about the axis is normally set to about 30 seconds.

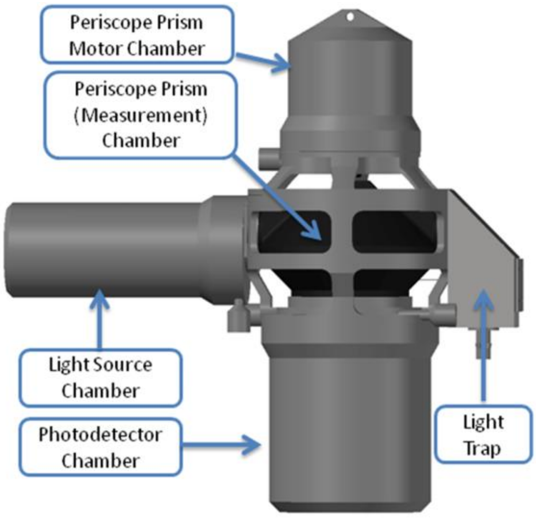

Figure 1: Layout of the MVSM modules

As the scanning motor rotates, scattered light is continuously directed by the periscope prism into the hermetic case of the photodetector assembly, where it is focused by an objective into the center of the field stop, and then directed onto the photodetector – photomultiplier (PMT) photocathode. Before the photocathode rotating wheel with 8 color filters was placed. The filter set can be adjusted if desired. The acceptance angle of the photodetector, determined by both the objective focus and the field stop, has 3 changeable sizes. The scattering volume function measurement is performed under continuous rotation of the periscope prism. The intensity of the directly attenuated flux is measured at 0°.

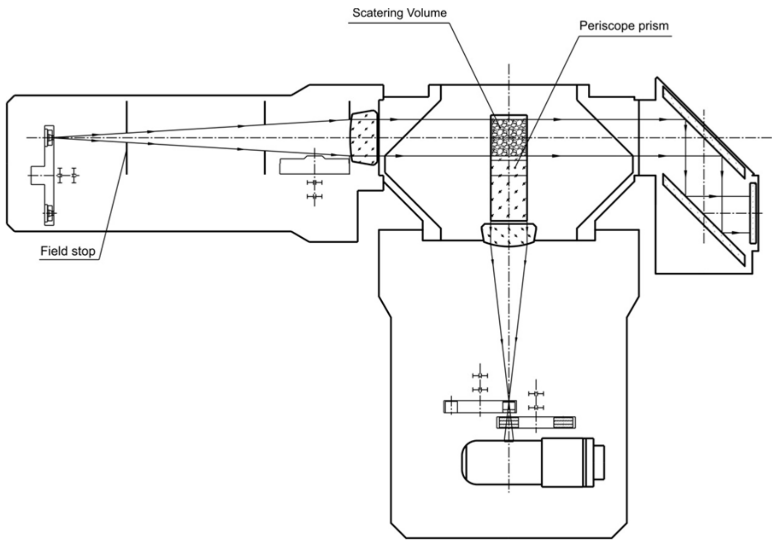

Figure 2: Schematic diagram of measurement

The main and novel feature of the schematic is the use of a rotating, specially designed periscope prism. The prism rotates around the photodetector/photomultiplier (PMT) assembly axis that extends through the center of the scattering volume. The main advantage is that the light source and the PMT are fixed during the measurement process. The special shape of the periscope prism and its precisely adjusted dimensions provide the opportunity to measure scattered light across all three angular regions with an angular resolution of 0.3˚. The angular range and resolution is achieved by precise measurement of the prism position and making direct beam attenuation measurement (*c* in m^{-1}). Since the light source and the photodetector units are fixed, increasing their dimensions (length) does not result in significant design complexity, and the scanning arrangement is significantly simplified and reduced in size as a result.

The light source is a set of intensive light emitting diodes (LED) with a diameter of the radiative area about 3 mm. It provides up to 800 mW radiant flux depending on the spectral range of the LED. The light beam penetrates through an objective window into the water (sample volume) contained in a baffled chamber and irradiates the scattering volume. Light path length in the water (sample volume) is 133 mm. The width of the light beam is controlled by a changeable diaphragm. The changeable diaphragm looks like a cylinder with pairs of slits for beam pass. The cylinder rotation is controlled by Slit Stepper Motor. Each slit is intended for beam gating (narrow beam or wide one depending on angle band measurement). There is possibility to adjust slightly beam width matching cylinder turn.

To perform successful VSF measurements in the full angle range, different approaches have to be used for different scattering angles. For the small angles 0˚ – 16˚ the problems are the high level of background light generated by the direct beam and the need to avoid the fall of the direct beam to the prism receiving surface; the last is avoided by moving the light source away from the central line up to 12 mm (Figure 3). The intensity of the direct beam in the small angle region is several orders of magnitude greater than the scattered light. To avoid background light effects, the measurement chamber has a special shape and all surfaces are made with minimum scattering as well as the light beam has highly parallel shape.

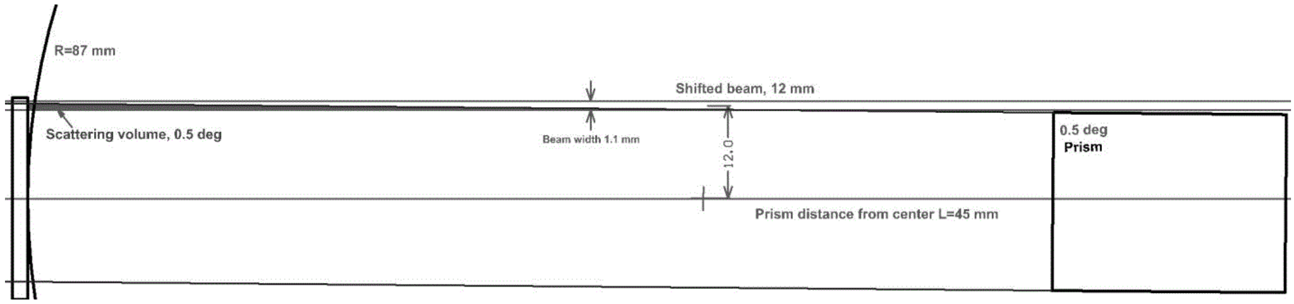

Figure 3: Prism location and scattering volume for 0.5˚ scattering angle.

To easily switch from laboratory to in situ measurements, the device was fitted with Seabird SBE 5P pump. The pump is powered through the same cable as MVSM is controlled so it's easy to install and use.

Several tests were conducted to evaluate the performance of the device. A set of scattering measurements were carried out in laboratory conditions with pure water mixed with the 5 µm solid particles. Results of the measured volume scattering function (VSF) were compared to model-calculated VSFs. Seawater samples measurements were carried out on the Oceanographic platform of the MHI NASU situated near Katsiveli village at a distance of 600 m from the shore at coordinates 44°23'N 33°59'E from September 18 to 19, 2013.

The test measurements showed the necessity to equip MVSM device with the water pump and also to add depth measurement system to make possible the automatic measurements when device is immersed to the water body. After investigating several pump models from different companies a SBE 5P submersible pump from Sea-Bird Electronics, Inc was found to be the best in current system. To control the pump and measure the pressure an additional electronic module was designed, built and attached to the device. As some users prefer using the device mostly in laboratory conditions, then the pump section was made so, that it is easy to remove it.

RESULTS

Results of the measured volume scattering function (VSF) and model-calculated VSFs, for 3 different wavelengths are presented in the figures 4-6. No model data was available for every wavelength and nearest wavelength data was selected for comparison. Measurements were made at the angle range from 16˚ to 164˚ with narrow slit, as the beam shifting option programming was not finished for the time experiment was carried out.

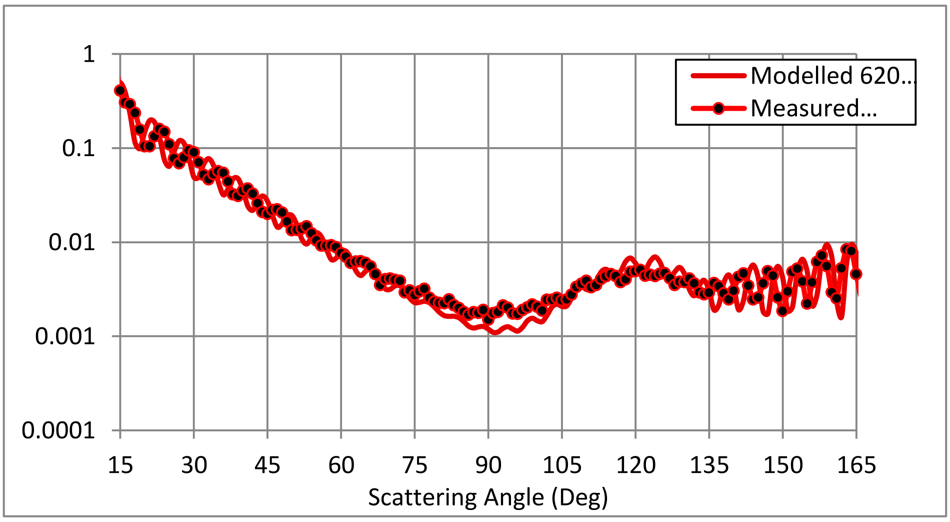

Figure 4: Measured scattering at 660 nm and modelled scattering at 620 nm.

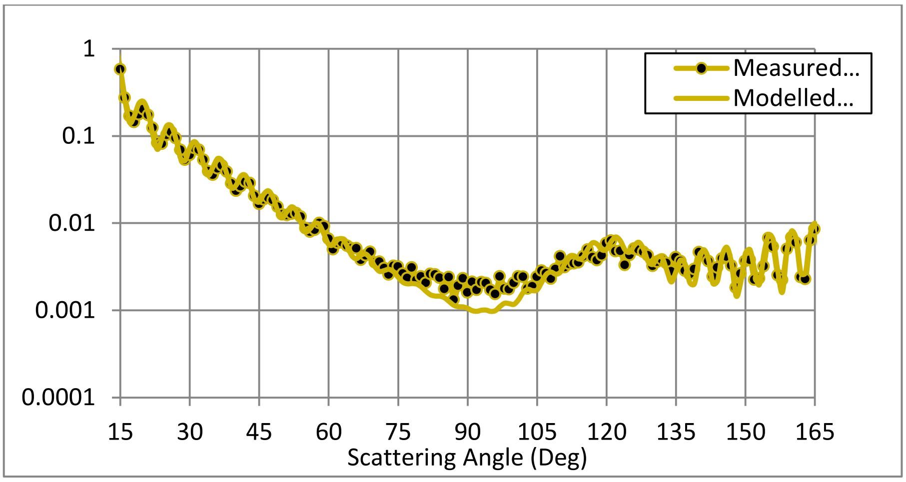

Figure 5: Measured scattering at 590 nm and modelled scattering at 590 nm.

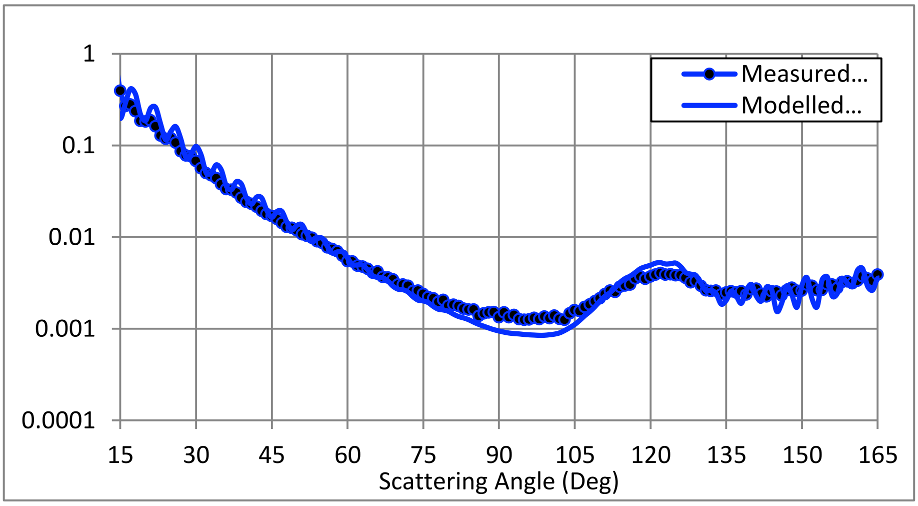

Figure 6: Measured scattering at 465 nm and modelled scattering at 456 nm.

The newly designed MVSM was tested against first prototype from MHI, to show that optimisation in hardware doesn't have an effect on the quality of measurements. The results are shown on figure 7. As the devices have fundamentally different light sources, then comparison at the exact same wavelengths was not available.

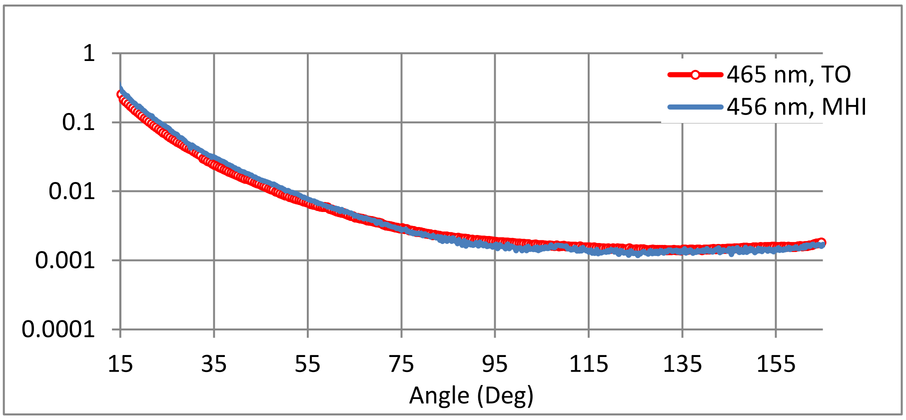

Figure 7: VSF measured by Tartu Observatory MVSM and MHI MVSM at depth 5 m for the wavelength pair 465/456 nm.

The complete set of VSFs from one measurement depth is shown on figure 8.

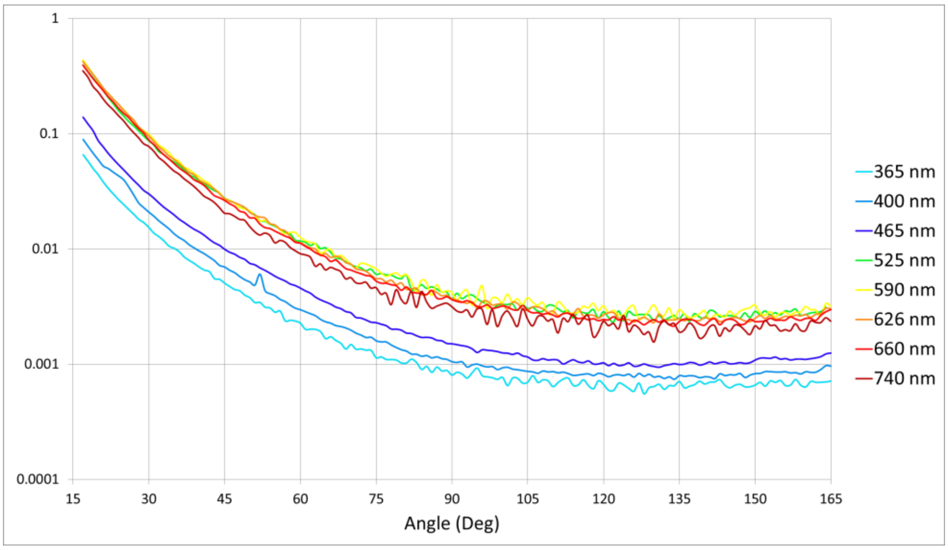

Figure 8: MVSM scattering, Normalized, Depth 5 m, 19.09.13.

CONCLUSIONS

Multi-spectral Volume Scattering Meter of Tartu Observatory (TO MVSM) outperforms in most of the parameters industrial instruments used to measure VSF. TO MVSM can be used to measure VSF with high accuracy at different wavelengths and in full angular range. The instrument has modern multicolour LED light source, measurement angles cover full angular range, interference filters in receiver enable fluorescence measurements at different wavelengths, and closed measurement volume eliminates the background noise and increases sensitivity and dynamic range. Instrument has modular design with 32-bit microcontroller in every module; software in modules executes under certified real-time operating system SafeRTOS allowing safe and robust multitasking as well as fast multiprocessor communication between modules.

First test measurements show that the device is stable and easy to use and gives similar results to modelled data. Further optimisation is still needed, before the device can be put into production.

ACKNOWLEDGEMENTS

The development of this device is funded by ESA PECS projects ORAQUA and QUALITY.

REFERENCES

Zibordi, G.; Ruddick, K.,; Ansko, I.; Moore, G.; Kratzer, S.; Icely, J.; Reinart, A., In situ determination of the remote sensing reflectance: an intercomparison, Ocean Sci. Discuss. **2012**, 9, 787-833; doi:10.5194/osd-9-787-2012. http://www.ocean-sci.net/8/567/2012/os-8-567-2012.pdf

Lee, M.E.; Lewis, M.R,. A new method for the measurment of the optical volume scattering function in the upper ocean. *J. Atmos. Ocean. Technol.* **2003**, *20*, 563–571. http://dx.doi.org/10.1175/1520-0426(2003)20<563:ANMFTM>2.0.CO;2