The Automated Unmanned Surface Vehicle LimnoVIS as a Tool for Measuring BRDF in Inland Waters

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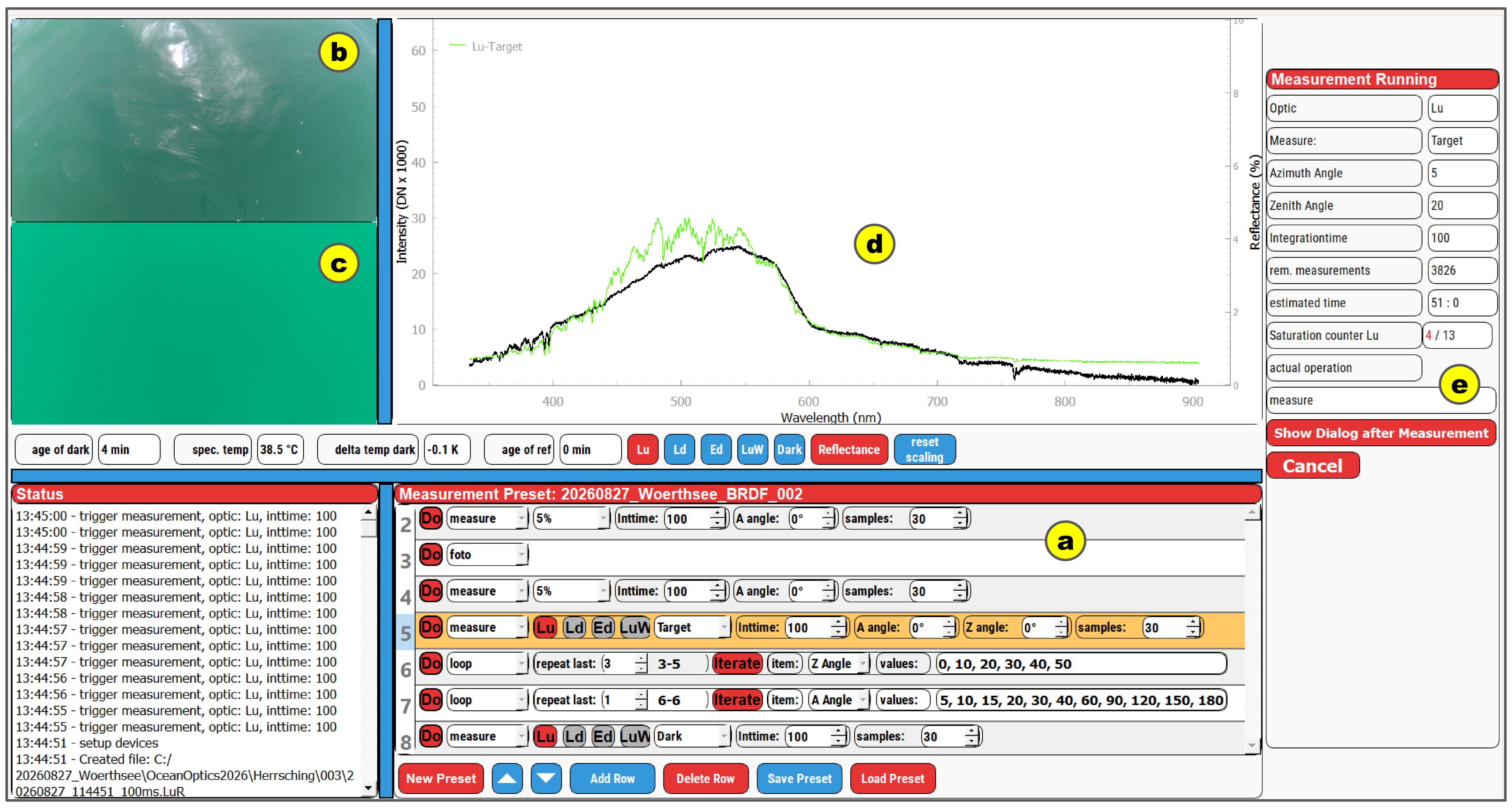

Fig. 1: Control software for the LimnoVIS spectrometer system: (a) fully configurable measurement sequencer. Live views of: b) tilted above-surface camera, c) sub-surface nadir camera, d) measured spectrum (DN and R) and e) parameters of the currently running measurement

LimnoVIS

LimnoVIS (Fig. 2) is an unmanned surface vehicle (USV) developed at the German Aerospace Center (DLR) for the collection of hyperspectral in-situ data at inland waters. Its small footprint prevents the influence of a larger ship's hull or superstructures on the measurements. With its capability to stay at a certain position and to change the orientation at the same time and its gimbal-stabilized spectrometer foreoptics, it makes a tool perfectly suited for systematic BRDF measurements on water.

Fig. 2: The unmanned data acquisition platform LimnoVIS with its hyperspectral measurement system

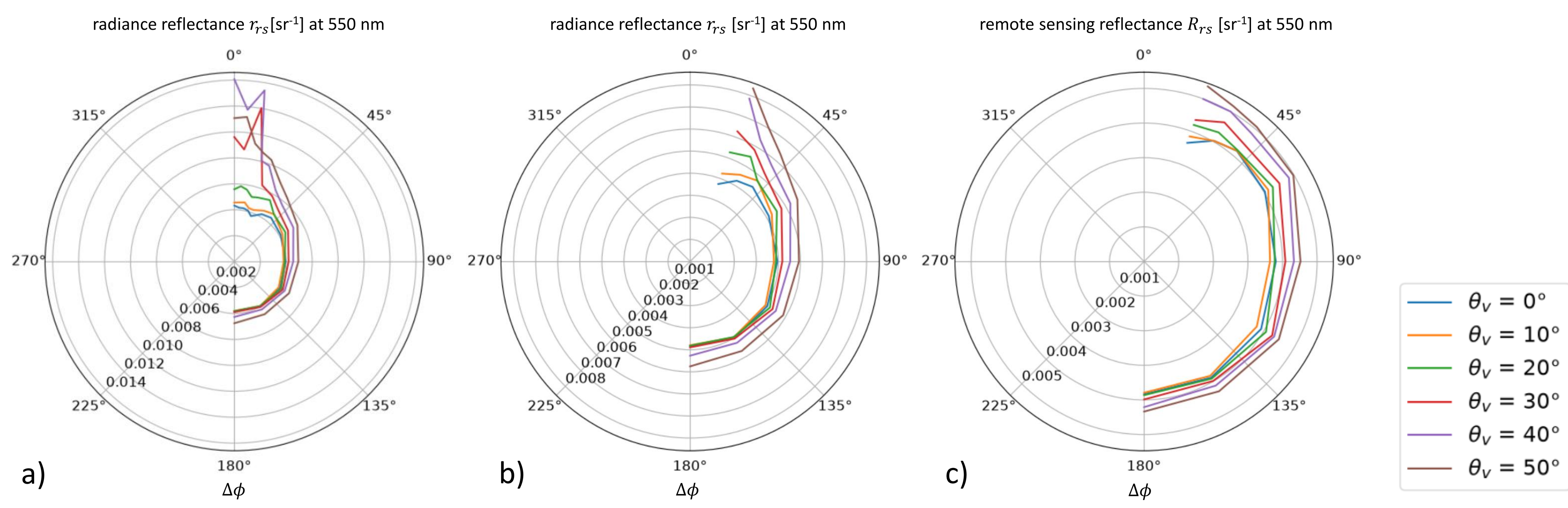

Fig. 3: Polar plots of BRDF measurements at 550 nm: a) r_{rs} with $\Delta\phi$ = 0 - 180°, b) r_{rs} with $\Delta\phi$ = 20 - 180°, c) R_{rs} with $\Delta\phi$ = 20 - 180° (glint corrected with WASI). Sun position: ϕ_s = 193° and θ_s = 39°

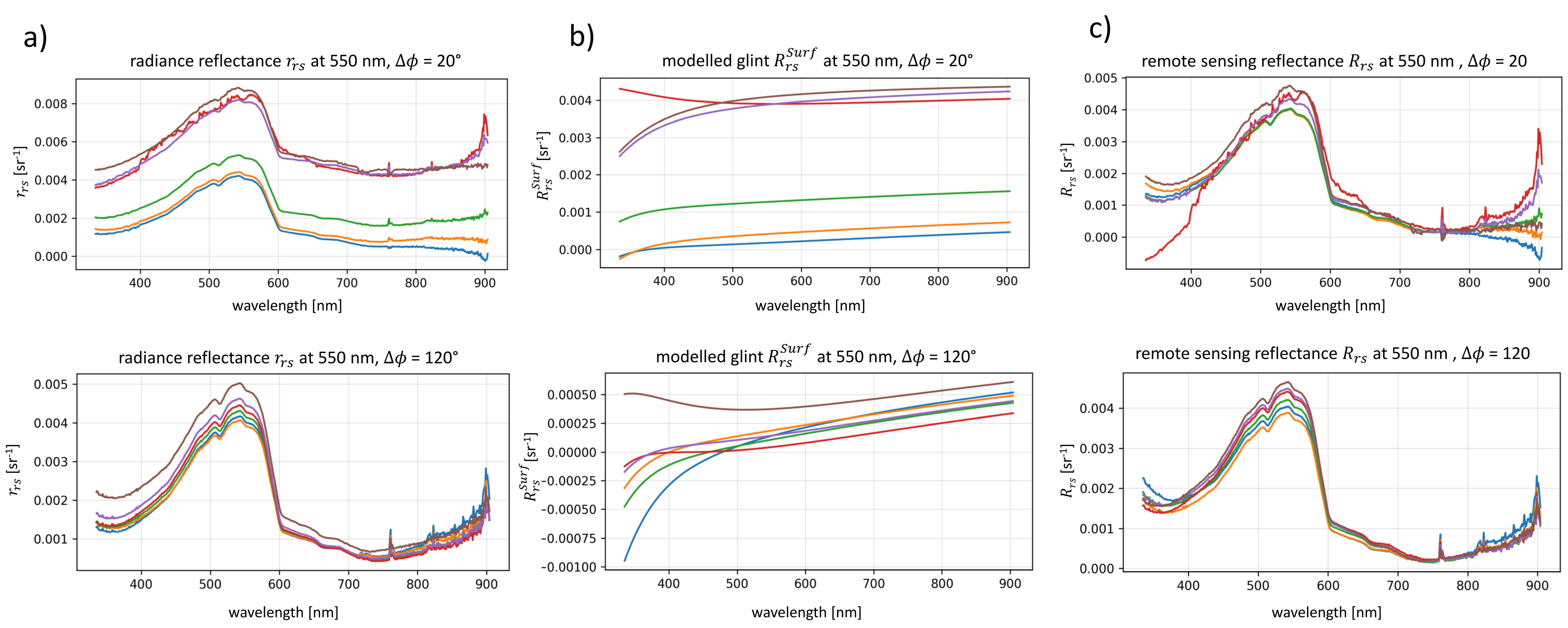

Fig. 4: Spectral plots of BRDF measurements at 550 nm: a) radiance reflectance r_{rs}, b) glint R_{rs}^{Surf} modelled by WASI c) remote sensing reflectance R_{rs} (glint subtracted). Top: $\Delta\phi$ = 20° with high glint, bottom: $\Delta\phi$ = 120° with low glint

Control Software

LimnoVIS can operate remotely controlled or autonomously. The control software for the spectrometer system (Fig. 1) allows for full control of all measurement parameters and provides a live view of the measurement status and results and also of the onboard cameras.

A fully configurable measurement sequencer (Fig. 1 a) allows for the definition and execution of complex series of measurements with the possibility to define iteration loops with varying parameters, as it is necessary for BRDF measurements.

Example BRDF Measurements

Figures 3- 5 show selected results from an automated BRDF measurement sequence carried out in optically deep water at Lake Woerthsee in Bavaria on Aug. 27th, 2026. A series of L_u measurements were taken while iterating over azimuth angle differences of $\Delta\phi = \phi_v - \phi_s$ from 0° to 180° and viewing zenith angles θ_v from 0° to 50°.

Fig. 3 shows the BRDF of the measured radiance reflectance r_{rs} and the remote rensing reflectance R_{rs} which was derived from r_{rs} by subtracting the surface reflectance R_{rs}^{Surf}. The latter was modelled using the software WASI (Gege 2004). While measurements towards the sun with $\Delta\phi$ < 20° were not usable due to specular reflections of the sun, it was found that in the remaining range of $\Delta\phi \geq 20°$, consistent measurement results could be achieved (Fig. 3 a ,b). R_{rs} also shows plausible values (Fig. 3 c) .

Starting at $\Delta\phi$ = 20°, consistent measurements can be taken. Fig. 4 (top row) shows distorted measurements where the glint correction fails only for $\theta_v \sim \theta_s$. Measurements with $\Delta\phi \geq 20°$ show plausible results over the whole range of θ_v. This is shown in the example with $\Delta\phi$ = 120° in Fig. 4 (bottom row).

Fig. 5 shows the dependency of the mean remote sensing reflectance R_{rs} on θ_v (left) and on $\Delta\phi$ (right).

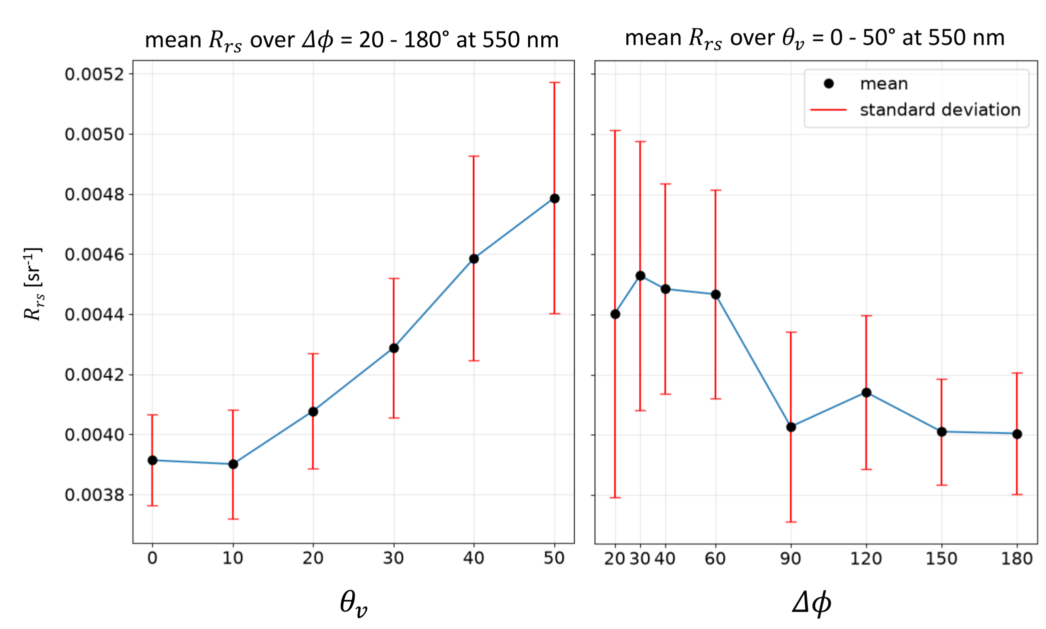

Fig. 5: Dependency of R_{rs} on viewing zenith angle θ_v (left) and azimuth difference $\Delta\phi$ (right)

P. Gege (2004): The water colour simulator WASI: An integrating software tool for analysis and simulation of optical in-situ spectra. Computers & Geosciences 30, 523–532.

DLR