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Technical notes: A detailed study for the provision of measurement uncertainty and traceability for goniospectrometers

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ABSTRACT

The measurement uncertainty and traceability of the Finnish Geodetic Institutes's field gonio-spectro-polarimeter FIGIFIGO have been assessed. First, the reference standard (Spectralon sample) was measured at the National Standard Laboratory of MIKES-Aalto. This standard was transferred to FGI's field reference standard (larger Spectralon sample), and from that to the unmanned aerial vehicle (UAV), reference standards (1 m^2 plates). The reflectance measurement uncertainty of FIGIFIGO has been estimated to be 0.01 in ideal laboratory conditions, but about 0.02–0.05 in typical field conditions, larger at larger solar or observation zenith angles. Target specific uncertainties can increase total uncertainty even to 0.1–0.2. The angular reading uncertainty is between 1° and 3°, depending on user selection, and the polarisation uncertainty is around 0.01. For UAV, the transferred reflectance uncertainty is about 0.05–0.1, depending on, how ideal the measurement conditions are.

The design concept of FIGIFIGO has been proved to have a number of advantages, such as a well-adopted user-friendly interface, a high level of automation and excellent suitability for the field measurements. It is a perfect instrument for collection of reference data on a given target in natural (and well-recorded) conditions. In addition to the strong points of FIGIFIGO, the current study reveals several issues that need further attention, such as the field of view, illumination quality, polarisation calibration, Spectralon reflectance and polarisation properties in the 1000–2400 nm range.

1. Introduction

Remote sensing instruments observe targets at a distance, to provide usable information for further decisions. The physical doctrine of remote sensing requires the observation data to be scaled and calibrated to physical

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quantities (measures), and the data analysed with physical models. Validation of the physical models, calibration of the sensors, and assessment of the performance of the complete system, requires accurate and thorough measurements of the target signal, both in situ and in the laboratory. Reliable measurements require that the measurement systems are well calibrated.

Radiation measurements can be performed on at least 11 dimensions, including the following:

- 3D spatial,
- 4D angular (directions of observation and illumination),
- spectral (usually 1D, in Doppler radar and in some special cases 2D),
- 2D polarised,
- time.

A common observational and instrumental strategy is to try to keep some of these dimensions fixed and measure only in 2–4 dimensions, but this is not always possible. Thus one may enter quite a complicated picture, or obtain inaccurate results if the dependence on all these dimensions are not fully understood.

Systematic measurements of the angular dimensions, or the bidirectional reflectance factor (BRF), can be performed in the laboratory and in the field using gonioradiospectrometers. These instruments have typically a turning measurement head allowing radiance measurements in different angles. Some important goniometers that are used in remote sensing applications are EGO, FIGOS, ASG, FIGIFIGO [58,26,52,54,64,39,61,42]. More measurements have also been performed by [30,18,9,31,3]. There are at least two field goniometers that can measure also linear polarisation, the FIGIFIGO in Finland [62], and one in the Northeast Normal University in China [60,11]. Both of these instruments use ASD FieldSpec Pro as the sensor, and a rotating calcite wedge polariser (Glan-Thompson prism), and can thus measure detailed spectral polarisation.

An alternative construction for larger homogeneous areas is to use a turning sensor on a platform [10,9], and PARABOLA [4]. Rondeaux and Guyot [49], Rondeaux and Herman [50] measured polarisation on a crane at a height of 20 m. Shibayama et al. [57] mounted the imaging polarimeter on top of a small truck. Ghosh et al. [15] used a tripod and tilted the spectrometers at three angles.

More laboratory oriented devices are GEFE [12,48] and the backscattering goniometer at FGI [29]. Many other goniometer systems have further been used [51,28,34,6,1,56,40,22,47,41]. Field spectroscopy is thoroughly reviewed by Milton et al. [35]. For single scattering measurements of course another range of goniometers exists, such as the Granada setup [36].

Aerial remote sensing of larger (often heterogeneous) target areas is possible using unmanned aerial vehicle (UAV) systems, which may include visual spectrum, infrared, or near infrared cameras as well as many other task-specific sensors. Reflectance measurement by UAVs has been investigated in several recent studies. Hakala et al. [19] used a micro UAV equipped with a consumer-level RGB camera to take directional reflectance measurements of snow. The results were promising; the authors concluded that the method should be further developed. Also Grenzdoorffer and Niemeyer [17] used area-format RGB images, but their approach was based on a multi-camera system with vertical and oblique viewing cameras. Schwarzbach et al. [55], Hueni et al. [27] and Burkart et al. [5] installed a spectrometer in a UAV to measure directional reflectance. By integrating a field spectrometer and the airborne spectrometer, these systems were able to achieve very accurate directional reflectance measurements. These investigations have proven the feasibility of the UAVs for the reflectance measurement, but also needs for further development have been identified, such as improving the spectral properties of sensors used or improving the level of automation.

A new UAV based measurement system was developed to measure BRF [25]. The method is based on a UAV and a spectral imager that collects area format spectral data cubes with stereoscopic and multi-view setups. The traceable reflectance measurement is based on reflectance panels that are positioned in the area of interest. A set of spectrally well-behaving UAV-reference targets were constructed. BRFs of targets were measured in laboratory using the FIGIFIGO, and these data were used as the reference value for the UAV images. The idea is to have at least one reflectance panel in each image.

The advantages in the concept of FIGIFIGO are as follows. The instrument is highly automatic and communicates via a controlled computer with an implemented simple and user-friendly interface. This allows users to set up the instruments, not only the wanted optics (including any option for a computer-turned linear polariser) at the beginning of the measurement series, and to modify a number of details, such as the initial position of the sensor, the range of further automated zenith turns and length of the turnable arm. The assembly and operation of the instrument are fast and efficient in both, laboratory and field conditions. It is battery powered and easily portable, including possible transportation by plane, car, boat or sledge. The system includes a sky camera to detect the goniometer orientation and a pyranometer to monitor the illumination conditions. A fine tune mirror is used for spatial correction of the optics footprint. Calibration of the system has significantly increased the measurement robustness and acquired data reliability, and has provided the operators with information on how to operate the instrument in the most efficient and accurate way. Thus the provision of this kind of information is crucial.

Another important objective is to investigate the metrological traceability of the FIGIFIGO measurements. According to the definitions of Bureau International des Poids (BIPM) [http://www.bipm.org], Metrology is the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology. A core concept in metrology is (metrological) traceability, defined as "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty. In many remote sensing applications, traceability is an important aspect, because the traceability