DUAL FIELD-OF-VIEW GONIOMETER SYSTEM FIGOS

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KEY WORDS: Goniometer, FIGOS, Dual Field-of-View, BRDF, Multiangular, Hyperspectral, Spectrodirectional, Incoming Diffuse Radiance

ABSTRACT:

Almost all natural surfaces exhibit an individual anisotropic reflectance characteristic due to contrasting optical properties of surface elements and background as well as an uneven distribution of illuminated and shadowed areas. The bidirectional reflectance distribution function BRDF is a basic quantity which describes the reflectance characteristic. Many applications, such as BRDF correction of remote sensing data and quantitative retrieval of vegetation parameters require accurate knowledge of the spectrodirectional surface reflectance properties. However, the directly observed quantity in field experiments is affected by atmospheric conditions which need to be accounted for when retrieving the target specific BRDF. The most exact BRDF retrieval from field goniometry measurements can be achieved by considering the diffuse irradiance at angular resolution. However, most goniometer systems are not able to simultaneously collect the reflected and incoming radiances at high spectral and angular resolution.

The dual field-of-view (FOV) goniometer system FIGOS of the Remote Sensing Laboratories (RSL, Switzerland) has this capability and is presented here for the first time along with a full field BRDF retrieval concept proposed by Martonchik et al. (Martonchik, 1994). The dual FOV FIGOS is based on the proven field goniometer system FIGOS extended by two ASD FieldSpec-3, each pointing in opposite directions. Reflected and incoming radiance measurements are performed simultaneously and at the same angular and spectral resolution. The first spectrodirectional dual field-of-view dataset was obtained in summer 2006 in Gilching, Germany. Both a natural and an artificial target were measured. The evaluation showed that the dual field-of-view goniometer system FIGOS substantially supports not only data collection for full field BRDF retrievals but also direct comparisons of field and laboratory measurements. Due to its reliable performance and known characteristics it has the potential to be a reference instrument for extensive field and laboratory experiments.

1. INTRODUCTION

In remote sensing research goniometry is widely used to assess spectrodirectional reflectance properties of selected natural or artificial targets. Almost all surfaces exhibit an individual anisotropic reflectance characteristic. This behaviour is due to the contrast between optical properties of surface elements and background as well as the uneven distribution of illuminated and shadowed areas. The concept which describes the reflectance characteristic of a specific target area is called the bidirectional reflectance distribution function (BRDF). Accurate knowledge of the surface BRDF is important for many applications such as BRDF correction of remote sensing data and quantitative retrieval of vegetation (Huber, 2007; Strub, 2002; Weiss, 2000), snow (Painter, 2002) or soil (Gobron, 2000) parameters. Furthermore, BRDF knowledge supports the determination of the surface albedo which is a crucial parameter in modelling the Earth's radiation budget. The surface albedo is defined as the directional integration of reflectance over all sun-view geometries. Practically, an estimate of the albedo is inferred from the measured nadir reflectance since corresponding satellite sensors often operate at only one or a few view angles (Barnsley, 2004; Bruegge, 2002; Kaufman, 1997). Consequently, the surface BRDF often is not considered which may lead to large errors in the retrieved albedo (Maurer, 2002; Schaepman, 2006) and subsequent climate models.

Goniometer systems observe the reflected radiation from a multitude of well-defined angles and can therefore provide a more accurate data basis for model validation as well as for calibration purposes of air- and spaceborne data. However, in field experiments the incoming radiation is anisotropic and permanently varies due to changing atmospheric conditions and sun zenith angle. Therefore the directly measured quantity in field experiments is affected by atmospheric conditions and called hemispherical conical reflectance factor (HCRF), corresponding to hemispherical illumination and conical observation. The specific target BRDF needs to be reconstructed ("retrieved") from the measured HCRF. The most exact BRDF retrieval from field goniometer measurements can be achieved using an algorithm (Martonchik, 1994) which considers the irradiance at angular resolution. However, few goniometer systems are able to simultaneously collect reflected and incoming radiances at the same angular and at high spectral resolution. Current examples include the known Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA III) and the Gonio Radiometer Spectrometer System (GRASS). Parabola III, which is used for MISR data validation purposes (Abdou, 2000; Bruegge, 2000), is collecting the reflected and incident radiances on a spherical grid of 5° and in 8 spectral channels. GRASS is currently being developed at the National Physical Laboratory (NPL), Teddington, UK (Pegrum, 2006). It shows a promising and novel dual view design, but has not yet reached an operational status.

In order to meet the abovementioned observation criteria for the BRDF retrieval algorithm RSL tested a preliminary dual FOV setup in summer 2005 using the traditional FIGOS setup in conjunction with an upward looking spectroradiometer placed

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on a separate tripod which was manually adjusted to the corresponding observation angles. (Schopfer, 2006). The currently final setup consists of two FieldSpec-3 spectroradiometers pointing in opposite directions, mounted onto the goniometer system FIGOS. The dual view capability and the performance of the dual FOV FIGOS were evaluated in summer 2006 during an extensive field campaign in Gilching, Germany. The dual FOV FIGOS is currently the only system in operation which is capable of simultaneous measurements of the reflected and incident radiances at the same high angular and spectral resolution. A characterisation of the system and results from the first dual-view measurements are presented here along with the BRDF retrieval concept proposed by Martonchik et al. (Martonchik, 1994).

2. DUAL FIELD-OF-VIEW GONIOMETER FIGOS

2.1 Characteristics

The dual FOV goniometer system FIGOS is based on the proven field goniometer system FIGOS (Sandmeier, 1999). It is used either in the field as dual FOV FIGOS or in the laboratory as LAGOS (not dual view). In the field case the reflected and incoming radiances are collected simultaneously at high spectral and at an equal angular resolution. Two wirelessly computer controlled ASD FieldSpec-3 spectroradiometers are used to cover the spectral range from 350nm to 2500nm. Data is sampled at intervals of 1.4nm (350 – 1050nm) and 2nm (1000 – 2500nm) with a spectral resolution of 3nm at 700nm and 10nm at 1400/2100nm, respectively (Analytical Spectral Devices Inc., 1999). Both spectroradiometers are operated with a 3° FOV foreoptic which is connected to the sensor using a 1.4m fibre optic. The idea of having both instruments being moved while taking directional measurements evolved from various considerations. The design of the U-base plate (Fig. 2) supports the attachment of both spectroradiometers as closely as possible to the zenith arc. Therefore, and since the zenith arc is eccentrically positioned, no cast shadow is generated on the target area (except for the dual optic holder at the hotspot direction), even though a large volume is moved along the zenith arc. Additionally, fibre optics of standard length can be used and a sufficient signal to noise ratio (SNR) is obtained. In contrast, having only the optics moved (and the spectroradiometers placed outside the goniometer) would create the need of having very long fibre optics (> 4m) and consequently a lower SNR.

The goniometer itself consists of three major parts: a zenith arc and an azimuth rail, each of 2m radius, and a motorized sled, onto which the two sensors are mounted on a U-base plate. All parts are made of black-coated aluminum in order to minimize adjacency effects. The zenith arc is tightly fixed to four wagons which allow a manual 360° rotation on the azimuth rail. The sled with the two spectroradiometers is driven by a braking motor at a velocity of 2.5°/s. Fully adjustable labels on the zenith arc allow for an automated positioning of the spectroradiometers at desired steps. Currently, measurements are taken at azimuth steps of 30° and zenith steps of 15° (-75° to 75°). A full dual view hemisphere is completed in about 25 minutes. Figure 1 shows the dual FOV goniometer FIGOS being used for data collection over an artificial target.

Figure 1. Dual field-of-view goniometer system FIGOS

To allow measurements in the principal plane the zenith arc is positioned eccentrically on the azimuth arc and only the two optics are moving in the principal plane. By using a dual optic holder both optics are exactly aligned while pointing in opposite directions. Figure 2 shows the U-base plate carrying both spectroradiometers and the dual optic holder. Furthermore, the generated shadow at the hotspot direction is minimized to the optic's size, which is about 1cm in diameter. Since the instantaneous field-of-view is 3° and always pointing to the centre of the hemisphere (downward looking optic), the corresponding ground instant field-of-view (GIFOV) is circular with 10.5cm (diameter) in nadir direction. However, for large off-nadir observation angles the sensor's footprint becomes elliptical with a maximum longitudinal extent of 41cm. It is therefore essential to consider the correct target reference height, especially when measuring a target with limited size.

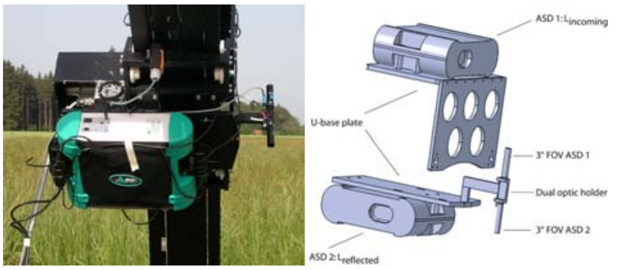

Figure 2. Dual field-of view combination

In order to monitor the pointing accuracy of the downward looking optic, a small laser is integrated into the dual optic holder. The geometric precision of the zenith arc is then referenced while moving the sled over the zenith arc in the principal and in the orthogonal plane. Maximal deviation of the laser spot, representing the centre of the sensor GIFOV, is recorded at a view angle of -75° and is about 4cm (Figure 3). A possible cause for this deviation might be a slight deformation of the respective part of the zenith arc due to extensive usage (assembly/disassembly) over time. However, this is not a limiting factor since the target under observation is usually assumed to be homogeneous and of satisfying spatial extent.

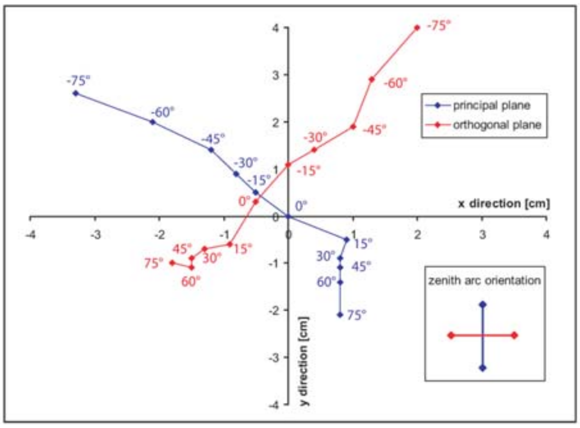

Figure 3. Pointing accuracy over zenith arc. The coordinate system is aligned to the centre of the azimuth circle.

2.2 Measurement Setup and Procedure

The two spectroradiometers which are used to simultaneously collect the reflected and incoming diffuse radiances are usually operated in radiance mode. For further processing, the intercalibration coefficients have to be known for both instruments. For this study the intercalibration was performed at the German Aerospace Center (DLR) using an integrating sphere.

Spectrodirectional measurements with the dual FOV FIGOS usually start in the principal plane at a forward scattering direction of 75°. Following a predefined sequence the whole hemisphere is scanned at zenith steps of 15° and azimuth steps of 30°. Spectralon references are collected in the beginning and in the end of each hemisphere as well as at every nadir bypass with the downward looking sensor. This provides a) the potential of calculating reflectances, if wished at a later date, and b) of monitoring atmospheric changes or instrument drifts. In total 140 measurements are taken for one dual view hemisphere (8 reference measurements plus 66 directional measurements for reflected and incoming radiances, respectively). Figure 4 shows the measurement sequence for goniometric measurements with the dual FOV FIGOS.

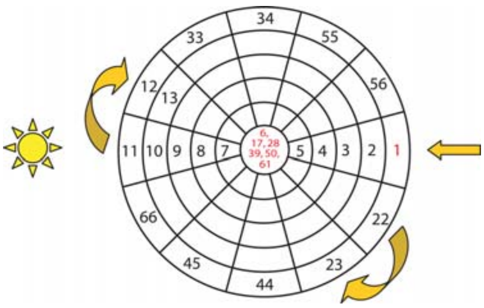

Figure 4. Measurement procedure for dual FOV FIGOS. Red coloured numbers represent reference measurement positions.

Even though shadowing is minimized it might occur anyway when the sun zenith angle equals one of the (downward looking) sensor view angle steps (e.g. at 15°, 30°, 45°, 60°, 75°). If this is the case, the corresponding measurements are either omitted, interpolated, or modelled by fitting to a BRF model.

Simultaneous sunphotometer measurements are still necessary for a number of reasons: 1) monitoring the state of the atmosphere during the whole measurement time; 2) the direct sun radiance is required as an input parameter to the BRDF retrieval algorithm (refer to Fig. 5). Currently, the dual FOV FIGOS is not yet able to directly measure this quantity, mainly due to the following reasons:

- The upward looking sensor is saturating when directly aligned with the sun view direction. However, this problem might be solved by reducing the integration time of the spectroradiometer.
- Using a 3° FOV accurately pointing at the sun disk is challenging and time consuming. The time for measuring one hemisphere is a critical factor and desired to be as short as possible.

For this study an MFR-7 shadowband sunphotometer has been used which directly records the total and diffuse irradiance in 7 bands (broadband, 415, 500, 615, 673, 870 and 940nm). The direct sun radiance is then calculated as a difference of the two, taking the respective sun zenith angle into account.

3. RETRIEVAL CONCEPT

As mentioned above, field goniometer system measurements are affected by changing atmospheric conditions. By retrieving the BRDF from field measurements such influencing factors are corrected. Ideally, the incoming diffuse illumination has to be known at the same angular resolution as the reflected radiation from the target area. The most accurate BRDF retrieval for field measurements can be performed by following the procedure proposed by Martonchik et al. (Martonchik, 1994). It is based on the idea of splitting up the total incident radiance into its direct and diffuse part L_{dir} and L_{diff}, respectively. The reflected radiance $L_{reflected}$ is then calculated as

$$L_{reflected}(-\mu,\mu_0,\varphi-\varphi_0) = \pi^{-1}R(-\mu,\mu_0,\varphi-\varphi_0)*L_{dir}(\mu_0)+L_{diff}(-\mu,\mu_0,\varphi-\varphi_0) \quad (1),$$

where $-\mu,\mu_0$ = cosines of the view and solar angles
$\varphi-\varphi_0$ = is the view azimuthal angle with respect to the solar principal plane and
R = bidirectional reflectance factor (BRF) of the target.

L_{dir} is obtained from sunphotometer measurements and the dual FOV FIGOS directly provides spectrodirectional measurements of $L_{reflected}$ and the incident diffuse radiance L_{diff}^{inc}. L_{diff} is the upward diffuse radiance which is calculated as

$$L_{diff}(-\mu,\mu_0,\varphi-\varphi_0) = \pi^{-1}\int_0^1\int_0^{2\pi} R(-\mu,\mu',\varphi-\varphi')*L_{diff}^{inc}(\mu',\mu_0,\varphi'-\varphi_0)\ \mu' d\mu' d\varphi' \quad (2).$$

The notation $-\mu$ and μ is used for upwelling and downwelling radiation, respectively. The integral equation (1) is then iteratively solved for R. As an initial estimate of the BRF, R(0) is used where the diffuse incident radiance is neglected and atmosphere-surface reflections are ignored ($L_{reflected}/\pi^{-1}*L_{dir}$).

For each iteration, the reflected radiance $L_{reflected}$ is calculated on the basis of the current iteration estimate of R. The iteration is ended when the difference between the calculated and measured reflected radiances, $L_{reflected}^{calculated}$ and $L_{reflected}^{measured}$, respectively, becomes smaller than a previously defined threshold. Figure 5 shows an overview of the field BRDF retrieval concept. Highlighted boxes represent measured quantities obtained by the sunphotometer and the dual FOV FIGOS.

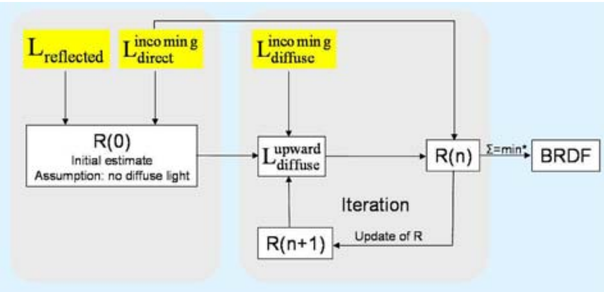

Figure 5. BRDF retrieval concept. Yellow boxes represent measured quantities.

The retrieval accuracy of R is increased by using multiple datasets of the same target area obtained at different sun zenith angles. For this study, an artificial target was used in order to a) minimize effects due to intrinsic changes of the target, b) guarantee the reproducibility of the measurements and c) to perform validation measurements in the laboratory.

The artificial target (80 x 80cm) is made of sanded duralumin and consists of a regular matrix of cubes with known geometrical characteristics. It is well qualified for BRDF investigations, since it exhibits a high angular anisotropy and is inert over time (Govaerts, 1997). This target (Figure 6) has already been extensively used for field-lab comparison measurements (Dangel, 2005) and for various measurements during a dual FOV configuration test setup (Schopfer, 2006).

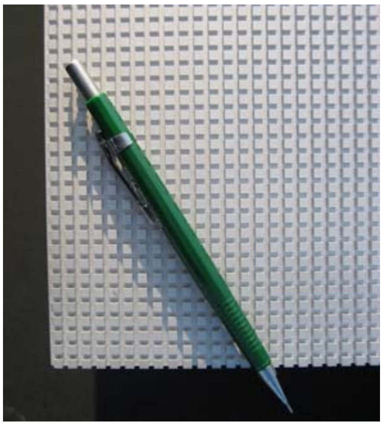

Figure 6. Artificial target

4. EVALUATION RESULTS

During this study the dual FOV goniometer FIGOS was used for the first time in its final configuration. Reflected and incoming diffuse radiances were collected at 20 sun zenith angles ranging from 24.8° to 68° (with respect to nadir) and at varying atmospheric conditions. Due to a sunphotometer malfunction, permanent atmospheric monitoring was only assured for 13 goniometer datasets. Figure 7 reports the ratio of diffuse to total irradiance for the range of sun zenith angles for which spectrodirectional measurements were performed.

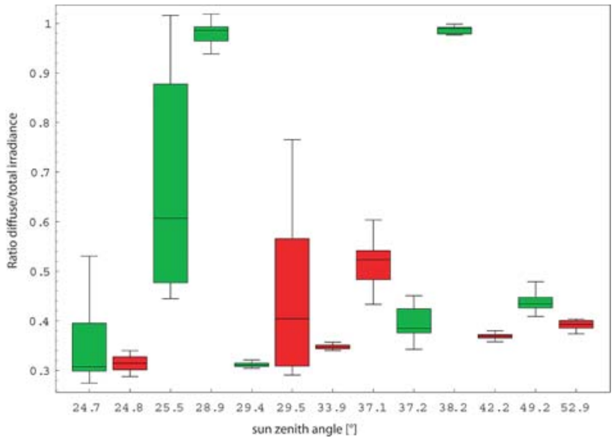

Figure 7. Variability of the ratio of diffuse / total radiation during corresponding goniometer measurements. Data are represented as standard box plots (green for natural target, red for artificial target). The boxes represent 50% of the measurements with the median value and the vertical lines show the total extent of the datasets.

Both the abovementioned artificial target (6 datasets) as well as a natural target (7 datasets) were observed. The natural target consisted of Triticale, a hybrid between rye and wheat, and will not be further analysed in this study.

The dual FOV FIGOS showed a stable and reliable performance during the whole measurement campaign. Despite the additional dual FOV combination, measurement times for almost all hemispheres could be kept at about 30 minutes. The slowest part of the goniometer system is the motorized sled which has to be moved between the zenith angle steps, and not the double measurement triggering (for the upward and downward looking spectroradiometers). Table 1 shows the corresponding illumination angles, sun movement and the time period for every hemisphere of the dataset.

Dataset	Start sun zenith	Δ time	Δ sun azimuth	Δ sun zenith
1	29.5°	32 min.	14.3°	3°
2	24.8°	33 min.	17.2°	1.7°
3	37.1°	23 min.	6.3°	3.4°
4	25.5°	26 min.	13.9°	0.8°
5	28.9°	24 min.	9.4°	2.7°
6	38.2°	23 min.	6.1°	3.6°
7	49.2°	23 min.	5.1°	3.8°
8	37.2°	24 min.	7.5°	3.3°
9	29.4°	31 min.	13.9°	2.9°
10	24.7°	25 min.	13.7°	0.3°
11	33.9°	23 min.	7.1°	3.3°
12	42.2°	51 min.	11.5°	8.2°
13	52.9°	27 min.	5.2°	4.5°

Table 1. Total goniometer dataset with corresponding time period and sun movement in azimuth and zenith directions.

As a direct consequence of the rather long measurement time, the illumination direction does not remain constant during the collection of a complete dataset consisting of x view angles. Typically, larger deviations are obtained in azimuth direction, especially around noon when changes in sun zenith angle are minimal. However, this effect is partly assessed in the BRDF retrieval process by using the sunphotometer recordings either in a timely resolved manner (corresponding to the single directional measurements) or by using a mean value for the direct incident radiance.

The first analysis of spectrodirectional goniometer measurements were performed for the 4 datasets of the artificial target which are least influenced by atmospheric conditions (dataset 2, 11, 12 and 13). These were obtained at sun zenith angles of 24.8°, 33.9°, 42.2° and 52.9°, respectively. The reflected radiance distribution is dominated by the strong forward scattering characteristic of the target, which increases at large sun zenith angles. The diffuse incident radiance field shows a more or less opposite tendency with increasing values towards the sun view direction. Irregularities are generally more pronounced in the diffuse incident radiance field and possibly occur due to changing atmospheric conditions and sun movement during the measurement time, especially for dataset no. 12 (zenith = 42.2°, measurement time 51 min.). No data were collected at the exact hotspot direction due to instrument saturation (upward looking spectroradiometer) and cast shadowing (downward looking spectroradiometer). Figure 8 shows the incident diffuse and total reflected radiances as directly measured with the dual FOV goniometer system FIGOS.

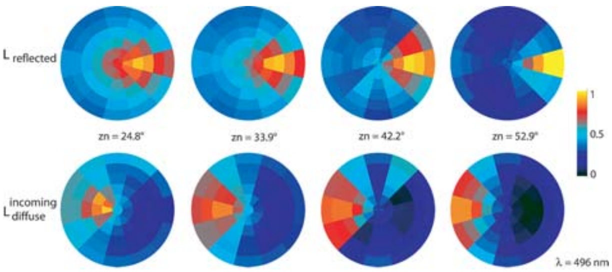

Figure 8. Total reflected and diffuse incoming radiances at various sun zenith angles for 496 nm. The sun position is on the left.

5. CONCLUSIONS

The dual FOV goniometer system FIGOS shows a stable and reliable performance for the simultaneous collection of the reflected and incoming diffuse radiances at high angular and spectral resolution. In its present configuration and in conjunction with a sunphotometer the dual FOV FIGOS may be used to provide the necessary dataset for a full field BRDF retrieval of selected targets. Since measurements in both directions are done simultaneously the critical time to measure a whole hemisphere is not affected by having two instruments and is kept at about 20 to 30 minutes. Illumination changes during that time rather depend on atmospheric instability than on the sun movement.

The dual FOV configuration also supports hotspot studies since only the dual fibre optic holder is moving in the solar principal plane and measurements can be made close to the hotspot direction.

The usage of an artificial target provides the advantage of reducing target related measurement errors. Errors due to inherent system inaccuracies persist but are well known for the dual FOV FIGOS. Since the same goniometer can also be used in a laboratory configuration (without dual view option), direct field-laboratory comparisons are supported as well as direct comparisons to other goniometric systems currently used (Bourgeois, 2006; Painter, 2003; Pegrum, 2006; Peltoniemi, 2005).

Further challenges include the establishment of procedures to reduce sources of uncertainties e.g. intercalibration issues. This can be achieved by collecting all necessary input data for the BRDF retrieval with only one or at least the same type of instruments. However, this requires accurate pointing at the sun disk to collect both the direct irradiance and the diffuse irradiance (shaded sun disk) in the sun view direction. Such pointing accuracy is very time consuming with the existing setup and therefore currently not feasible.

Due to its well known characteristics the dual FOV FIGOS has the potential to be a reference instrument for extensive field and laboratory experiments. The retrieved BRDF of selected targets will be a valuable contribution towards a more accurate validation of air- and spaceborne data as well as BRDF models.

ACKNOWLEDGMENTS

The authors would like to thank the Swiss National Science Foundation (contract no: 200020 – 101517) and all colleagues who participated at the field experiments. Special thanks go to the Physics Institute of the University of Zurich for its support for the construction of the dual field-of-view configuration.

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