Determination of the Angular Sensitivity of a Multispectral Line Scanner from Image data

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ABSTRACT

The DAEDALUS AADS 1268 is a multispectral line scanner with 11 spectral channels and 716 pixels per line. This paper presents a post-flight calibration method to correct the data for dependence of the detector sensitivity on the scanning angle. An area has to be found where only neglegible BRDF effects are expected across the principle plane for zenith angles smaller than the maximum scanning angle. The area does not need to be homogenous, but it must extend over a whole scan line. In our case the runway of the Nuremberg airport was chosen. The pixels of the scan line acquired when crossing the runway at right angles were divided by the respective pixels of the perpendicular overflight after georegistration. The resulting angular sensitivity functions show variations up to 15 % (depending on channel), similar to findings from a laboratory experiment done 3 years earlier. A comparison with laboratory data from a DAEDALUS operated in Australia shows similar results, except for channels 2 and 8.

DESCRIPTION OF THE DETECTOR

A scan line from the DAEDALUS line scanner AADS 1268 contains 716 pixels for each of the 11 spectral channels. The maximum scan angle is $\theta_r = 43°$ to both sides. The scan starts at the right (when looking into direction of flight heading), so pixel number 0 correponds to a scanning direction to the right as seen from the sensor. Each pixel covers an angular range of $2 \times 43°/716 = 0.12°$, ground resolution at a flight height of 300 m is about 0.7 m for nadir.

ANGULAR SENSITIVITY FUNCTION ASF

The angular sensitivity function ASF(θ_r) is the ratio of the measured radiance at the viewing angle θ_r to the measured radiance at nadir ($\theta_r = 0°$). The biggest obstacle in determining the ASF is providing a homogenous illumination source. If the ASF is constant and if the radiance reaching the detector is independent of scanning direction θ_r, all pixels will give the same value. The DLR has performed such a test in the laboratory in 1994, pointing the DAEDALUS into an integrating sphere with a diameter of 2 m. For channels 2 to 9 the difference between maximum and minimum measurement was about 5 %, but almost 20 % for channel 1, see fig. 1. However, it remains questionable to what extent these measurements are influenced by inhomogenities of the integrating sphere. There has been no determination of the ASF immediately prior to the 1997 flight campaign over Nuremberg. Because BRDF (bidirectional reflectance distribution function, see e.g. [1]) effects deduced from the data crucially depend on the ASF, we present a method to derive the ASF from our image data. As the instrument was reconditioned since 1994, the ASF as determined by the DLR is significantly different from the 1997 ASF for some channels. In principle, the ASF can simply be determined from a scan line over a spatially homogeneous target. In practice, it is almost impossible to find targets with the required homogenity. Especially urban areas are characterized by a high spatial variance of reflectance. In order to accomodate for this effect, we divided a scanning line that was obtained crossing the runway of the Nuremberg airport by the georegistered data of an overflight along the runway. For a lambertian surface and a constant ASF, the expected result is 1 for all pixels. This procedure is only possible when there is at least one pair of flight tracks perpendicular to each other and the calibration area is seen from both tracks. In case the BRDF of the calibration area chosen is not known, it is furthermore necessary to use scans perpendicular to the sun azimuth, in order to avoid specular or hot spot effects. But even across the principal plane BRDF effects are possible. However, these effects are symmetric with respect to nadir ($\theta_r = 0°$) if the calibration area is rotationally symmetric. Symmetric ASF effects cannot be detected by our procedure if the BRDF of the surface is unknown.

APPLICATION

The method was tested on a set of airborne DAEDALUS data acquired in 1997 over Nuremberg, Germany. The best suited calibration surface in our data is the runway of the airport of Nuremberg for the following reasons: 1.: BRDF effects of the surface (asphalt) across the principle plane in the angular range covered by DAEDALUS (maximum scan angle: $43°$) are small. The sun angle of $\theta_i = 40°$ ensures that there are neither effects from a broad hot spot or a broad specular peak that might be expected for a sun positioned in nadir, nor will there be any strong BRDF effects that typically occur for zenith angles larger than $60°$. The relative angle of the scan direction to the sun azimuth is $68.5°$ for the scan to the left and $111.5°$

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for the scan to the right. So the relative angle is only $21.5°$ smaller resp. bigger than $90°$ corresponding to the direction across the principal plane. 2.: The area stretches from the very left of the DAEDALUS scan to the very right, so that almost all pixels can be included in the investigation. 3.: The reflectance profile of the area is quite homogeneous, although deviations of up to 20 % occur. 4.: The width of the runway is about 50 pixels. Thus averaging over the width will dismiss random sensor noise to a large amount. Small scale inhomogenities will also be smoothed after averaging. 5.: Small landmarks on the side of the runway allow a very exact registration of the along-runway scan onto the cross-runway scan. The registration accuracy is estimated to be about one pixel. 6.: A change in reflectance that occured between the cross-runway scan and the along-runway scan is highly unlikely, in contrast to e.g. streets highly frequented by cars.

To obtain the ASF, the steps described below were performed. As image data, we did not use the raw data but the reflectance images, because the reflectance images have been processed [2] with MODTRAN to eliminate atmospheric effects .

1. Correct the images for panoramic distortion. Register the along-runway image to the cross-runway image.
2. Average the values over the width of the runway for both images (correct for BRDF if possible).
3. Divide the cross-runway scan by the along-runway scan. The ratio gives the ASF and is shown in fig. 1 for all channels after normalization to nadir (solid line).

DISCUSSION

For a lambertian surface, the average of the ratio should be equal to 1. But in the principal plane, the surface is not lambertian, as can be seen from a cross-runway scan acquired in the morning (not shown). This means, that the average of the ratio will depend on the scan angle of the runway in the along-runway scan. However, this is not a problem here because we are not determining an absolute ASF but a relative ASF, therefore we can normalize our results without loosing information.

A possible reason for a non-uniformity of the ASF is a slight misadjustement of the scanner optics. If the ray alignment between rotating mirror and primary paraboloid is not perfect, a non-uniform ASF is possible.

There is a uniform characteristic of channels 2 to 7: at angles about $-40°$ the ASF is about 12 % higher than at nadir, for positive scan angles it is quite constant. The rise with negative zenith angles looks very linear. Channel 1 shows a rise (about 10 %) with both positive and negative angles. The same behaviour can be seen in channel 8, but at $\pm 40°$ the rise is only 7 % above the nadir value. The sensitivity of channel 9 rises a little towards increasing zenith angles, of channel 10 for negative zenith angles (each about 5 %).

An ASF laboratory measurement (directing the DAEDALUS FOV into an integrating sphere) performed by the DLR in 1994 shows similar results, but the angular deviations are only about 5 % (exception: channel 1 with 20 %), see dashed line in fig. 1. The spectral behaviour looks very similar for channels 3 to 7. But channel 2 rises for positive angles, channel 8 does not rise for negative angles, channel 9 rises with negative zenith angles and channel 10 rises symmetrically about nadir, in contrary to our findings. We do expect changes between the 1994 DLR data and our results from August 1997, because the scanner was overhauled and readjusted in early 1997.

ASF measurements for another DAEDALUS AADS 1268 were made in Australia for channels 1 to 8. The DAEDALUS was placed in front of a light source and turned to obtain different look angles. Channels 3 to 6 are quite similar in shape to our measurements, there is a rise for negative angles of about 10 to 20 %. Channel 2 shows a rise of 40 % for negative zenith angles, for channel 8 the value at $40°$ is almost twice as high as the value at $-40°$. The shape of the ASF for channel 1 is similar to the ASF from the DAEDALUS operated by DLR, but the rise for negative zenith angles is twice as strong. Except for channel 2, these results are confirmed by flight data over a desert area from the previous year (not shown).

This shows that the results derived from the Nuremberg image data are of the same order of magnitude as results from other groups, obtained by different methods. Our method has the advantage of being performed after takeoff right after (or before) the actual image data are acquired, so that vibrations during takeoff or landing won't change the ray alignement in the DAEDALUS and thus the ASF. Furthermore there is not the problem of providing a constant light source in the laboratory.

There are several possible error sources for our method: imprecise atmospheric correction, sensor noise, registration errors, rapid illumination variations during data take and surface BRDF effects. Varying the atmosphere parameters within reasonable limits, we estimate the first error source to be about 2 %. Registration errors can be neglected due to the easy registration of the runway and the averaging over an area of 2000 pixels, the same is true for sensor noise. Across the principal plane, BRDF effects are usually small for man made surfaces for viewing zenith angles less than 45 degrees [1], so we estimate the error from the lambertian assumption to 3 %. Assuming the illumination variations to be 2 %, error propagation leads to an overall error of about 4 %.

The results of our method can be confirmed (or improved) if immediately after the cross-runway scan of the test area another cross-runway scan heading into the reverse direction is performed (in our case heading north instead of heading south). Unfortunately, during our campaign no such flights were performed.

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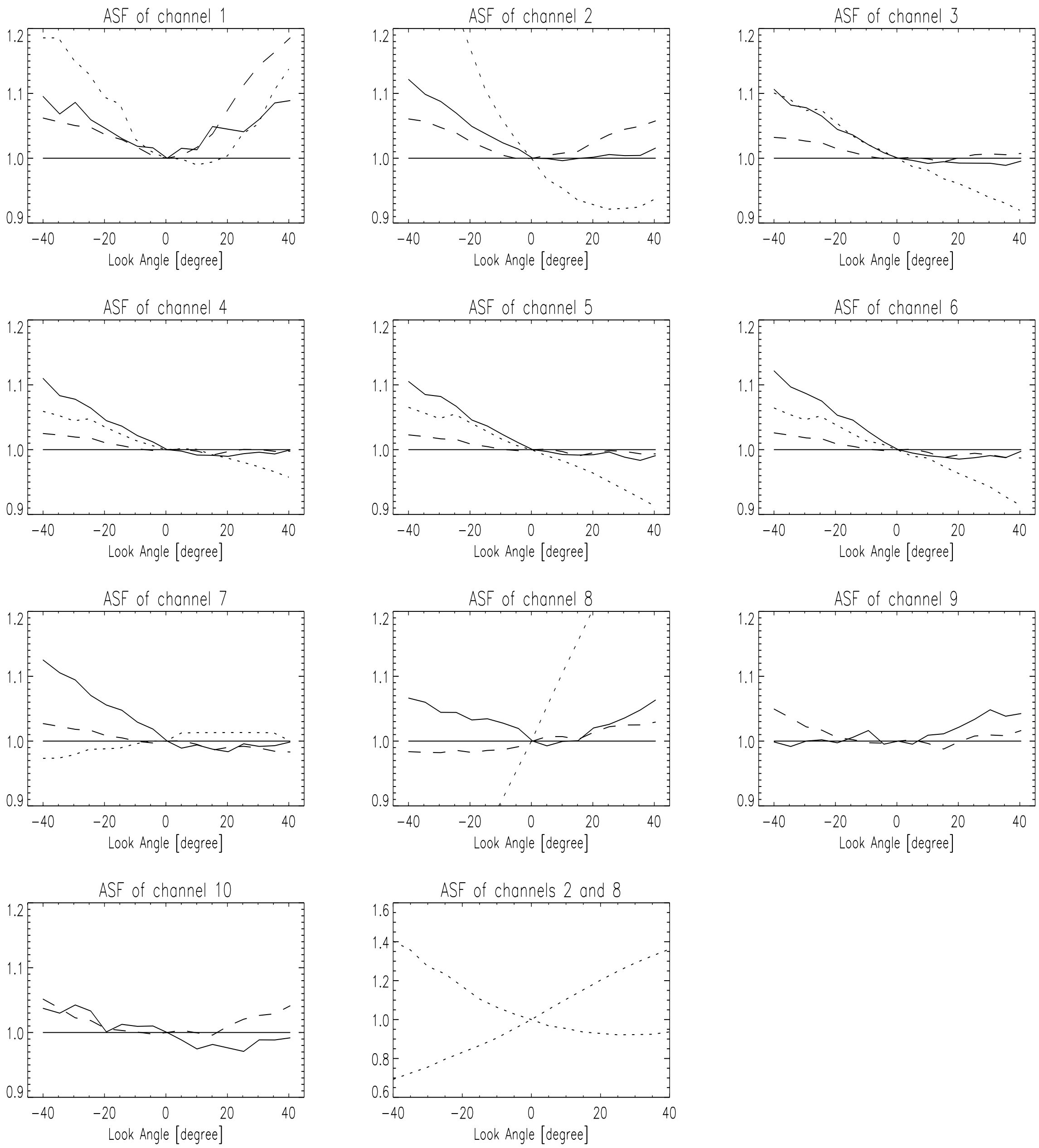

Fig. 1: The ASF for the first 10 DAEDALUS channels as a function of DAEDALUS look angle, normalized to nadir and averaged to intervalls of 5 degrees. Negative look angles correpond to the right direction as seen from the DAEDALUS. Solid line is the ASF determined from the Nuremberg image data, dashed line is the ASF determined by DLR laboratory measurements. Dotted line is the ASF determined by laboratory measurements for the DAEDALUS operated in Australia (available only for channels 1 to 8). The last plot shows the ASF for channels 2 and 8 for the australian DAEDALUS with an enlarged plotting range.