EPJ Web of Conferences **238**, 12018 (2020) https://doi.org/10.1051/epjconf/202023812018
EOSAM 2020

Optical Simulation and Design of Spatial Heterodyne Spectrometers for Remote Sensing Applications

C.-A. Stöckling[1,*], *W.* Pöschel[2,**], and *S. A.* Schulz[1,***]

[1]Hamburg University of Applied Sciences, Faculty of Engineering and Computer Science, Berliner Tor 5, 20099 Hamburg
[2]SIOS Meßtechnik GmbH, Am Vogelherd 46, 98693 Ilmenau

Abstract. We present the optical simulation and design concept of a spatial heterodyne spectrometer (SHS) for mobile applications. A framework using Python and Zemax OpticStudio was developed for the optical system design and automated tolerance analysis from the incoming light, the spectrometer and the imaging lens system to the 2D detector. The spectrometer design and the fabrication methods were validated using a test setup in the VIS spectral range for a future SHS fabrication in the LWIR spectral band operating on small unmanned aerial vehicles (SUAV) for remote sensing applications.

1 Introduction

In recent years, the demand for small and robust sensors for mobile applications has increased due to the further development of field robotics. Spectrometers will be an important part of these future solutions. Simple spectroscopic measurements can be solved by the usage of transmission filters for specific wavelength ranges or by systems based on continuously variable filters. Higher spectral resolution in the IR spectral bands usually requires interferometers like Michelson-type sensors or Fourier-Transform-Spectrometers (FTS). For hyperspectral imaging applications these systems combine spatial data with spectral signatures. The miniaturization of hyperspectral sensors enables the integration on small autonomous robotic systems and allows new applications in remote sensing.

For applications in field robotics and processing industry, optical spectrometers will operate in harsh environments under extreme environmental conditions. Rapid change in temperature, high vibration levels and alternating radiant flux are caused by the exploration and investigation of dangerous areas, i.e. in the oil and mining industry. The reliable operation on mobile robots demands small, lightweight and ruggedized hyperspectral sensors. At present, filter-based spectral cameras fulfill many criteria, but with the lack of spectral fingerprint capability because of their low spectral resolution, robust spectrometer designs are required. A spectrometer with no moving parts is essential for such applications. A stationary Fourier-Transform Spectrometer design in a push-broom configuration combines high optomechanical stability, large entrance aperture and high spectral resolution for mobile remote sensing applications.

*e-mail: christian.stoeckling@haw-hamburg.de
**e-mail: poeschel@sios.de
***e-mail: stephan.schulz@haw-hamburg.de

2 Fundamentals of a SHS spectrometer

A SHS with a focal plane array (FPA) to record an entire Fizeau fringe pattern at once in the LWIR spectral range was presented by Harlander and Roesler in 1990 [1], although the first designs of these spectrometers called SISAM were realized by Connes in the late 1950's. The SHS adapts a Michelson configuration with the two end mirrors replaced by diffraction gratings which are identical tilted about the angle Θ to the optical axis which is known as Littrow configuration [3].

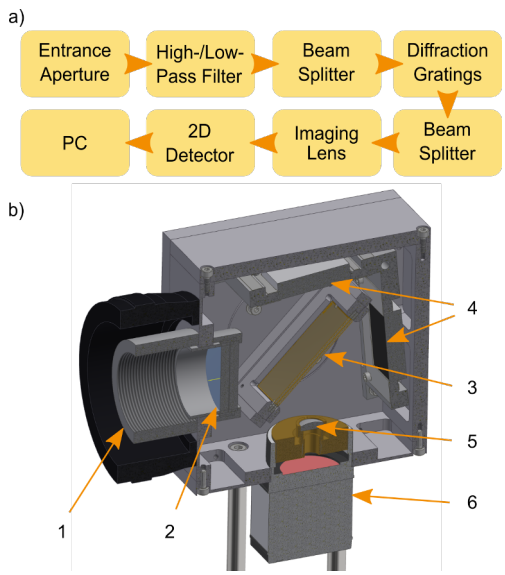

Figure 1: (a) Configuration of the SHS and (b) 3D assembly view: entrance aperture (1), filter (2), beam splitter (3), gratings (4), imaging lens (5), and detector (6).

A SHS is heterodyning the signal, so the spatial frequency of the fringe pattern is the same for every wave-

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

length with the same distance to the Littrow wavelength. A short or long pass filter has to be used to get an unambiguous result and an extended spectral range can be achieved by field widening. In a basic principle of operation (Fig. 1), the input wave front is divided at the beam splitter, and a wavelength dependent wave front phase shift is induced by the gratings. Both opposed phase shifted wave fronts form the Fizeau fringe pattern with a characteristic spatial frequency. This 2D interferogram on the detector (FPA) can be converted via Fourier Transformation (FT) to its equivalent spectrum.

3 Python Framework for SHS Simulation

For the exact and reliable SHS design an object-based Python framework was developed. The framework is capable of simulating the whole chain of generating a interferogram from a single wavelength or given spectrum and transform the interferogram to a spectrum for an ideal SHS (Fig. 2). The SHS parameters are defined in a SHS object to generate the interferogram and also improved spectra. For further improvement methods like apodization with different windowing are implemented.

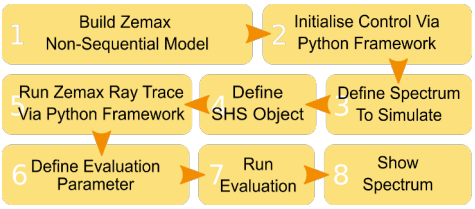

Figure 2: Flow chart of a typical SHS simulation

The python framework simulates a SHS without imperfections. This allows the investigation of SHS parameter variation and its impact of the system performance of an undisturbed system. Disturbation of the system on purpose and simulating coatings, filters and other obstacles in the optical path to study the effects is implemented. To investigate the phenomena induced by more complex elements like lenses to the SHS system, the framework is coupled with Zemax OpticStudio for ray tracing. The python framework controls the operation of Zemax for closed-loop optimization to generate a interferogram, which is evaluated by the framework. Fig. 2 shows a typical simulation run with the framework and Zemax OpticStudio combined.

4 Simulation and Experimental Results

To test the python framework a SHS for the visual spectral range was simulated and built. Figure 3 shows the neon spectra for the simulation and the experimental data with a neon spectral lamp (Oriel 6032) in good agreement. Deviations are caused by the uncollimated light source and due to standard single lens imaging which impose wavefront aberrations.

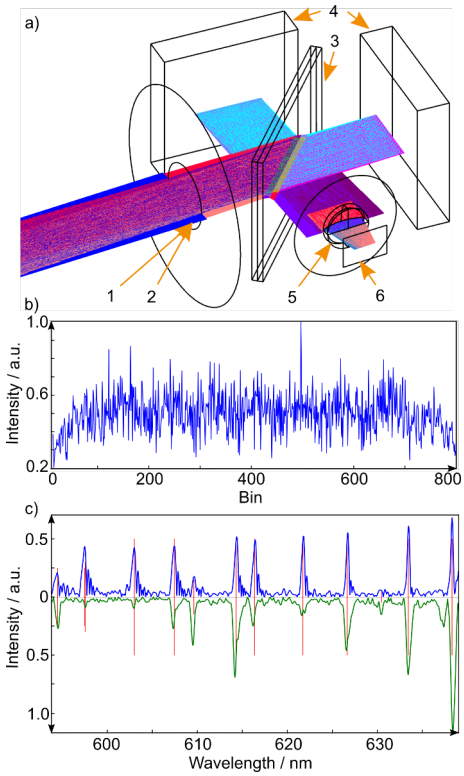

Figure 3: Simulation results: (a) Zemax model of a VIS-SHS, (b) interferogram of a neon spectral lamp, (c) measured (blue) data, simulated (green) data with NIST reference [5] (red).

5 Conclusion and outlook

A SHS for the visible spetral range was designed, simulated and built based on a developed Python simulation framework and combined with the optics simulation ZEMAX software. We have shown that the Python framework is well suited to predict the performance of a SHS by experimental demonstration of the simulation by a reference SHS build and characterization in the visible spectral range. The Python framework allows the closed-loop optimization for future SHS designs in the LWIR spectral range for remote sensing applications.

The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany (BMBF) in the project ATHMOS (13N14762).

References

[1] J. Harlander, F. L. Roesler, SPIE **1344**, 120-131 (1990)

[2] P. Connes, Journal de Physique et le Radium **19**, 215-222 (1958)

[3] C. Palmer, E. Loewin, *Diffraction grating handbook* (Newport Corporation, New York, 2005)

[4] C. R. Englert, D. D. Babcock, J. M. Harlander, Optical Engineering 48 (10), 105602, (2009)

[5] A. Kramida, Y. Ralchenko, J. Reader, NIST ASD Team, *NIST Atomic Spectra Database (ver. 5.7.1).*