Simulation of a Remote Sensing System for Fire Detection

Carsten Paproth and Anko Börner

Optical Information Systems, German Aerospace Center (DLR), Berlin, Germany

Abstract—We want to create a simulation of a remote fire detection sensor. The simulated sensor data could help to improve the fire retrieval algorithm. The simulation will be built by using a more general tool for simulations of remote sensing systems. The simulation tool consists of a geometric, a radiometric, and a sensory component. Artificial fire maps will serve as input to the simulation and will be created by using fractional Brownian motion.

Keywords: sensor simulation, remote sensing, fire detection, fractional Brownian motion

1. Introduction

Simulated sensor output can often be used to support the development procedure of a remote sensing system. For example, estimations of the sensor performance or testing of retrieval algorithms could be made with simulated data before real sensor data is available. We want to adapt a simulation concept for remote sensing systems [1], [2] to a remote fire detection system [3]. The goal is to study the influence of the atmosphere on the already existing fire detection algorithm and maybe to improve this algorithm or the fire sensor parameters. The scope of this paper is the description of the main steps necessary to create the simulation of the remote fire detection sensor.

2. Simulation of remote sensing systems

The simulation of a remote sensing system consists of three main components [1]. The first component is the simulation of the geometry. With a ray tracing approach, this component calculates what every sensor pixel can see and what is shadowed or not. The second component is the simulation of the radiometry. This is the radiative transfer from the observed surface to the sensor which results in the at-sensor radiance. The final component is the sensor component which converts the at-sensor radiance into a digital output in dependence on the sensor optics and detector.

SENSOR++ [2] is an enhancement of this simulation concept. One of the improvements is the extension of the spectral range to the thermal infrared which is also needed to simulate the fire sensor. According to [4], the at-sensor radiance can be calculated with

$$L = E_{sun}\rho\tau s BRDF(\boldsymbol{\omega}_i, \boldsymbol{\omega}_o)(\boldsymbol{\omega}_i \cdot \boldsymbol{n}) + B(T)(1-\rho)\tau + L_{atm}.$$
(1)

Eq. (1) uses the following definitions:

 $E_{\rm sun} =$ irradiance of the sun below atmosphere

 $\rho = \text{reflectance of the surface, } 0 \le \rho \le 1$

- $\tau = {\rm transmittance}~{\rm of}$ the atmosphere, $0 \leq \tau \leq 1$
- s = 0 if surface is shadowed
- s = 1 if surface is not shadowed
- BRDF = bidirectional reflectance distribution function
 - ω_i = unit vector from the surface to the sun
 - $\boldsymbol{\omega}_o =$ unit vector from the surface to the sensor
 - n =surface normal vector
- B(T) = radiance of a blackbody at temperature T

 $L_{\rm atm} =$ atmospheric radiance.

The values of E_{sun} , τ , and L_{atm} are calculated with MOD-TRAN [5] which calculates the radiative transfer through the atmosphere of the earth. The atmospheric radiance L_{atm} includes the indirect reflected, solar scattered, and thermal path radiances. The values of s, ω_i , ω_o , and n are gotten from the geometry simulation. Only physically reasonable BRDFs are used by SENSOR++. Except for the geometric quantities, all terms of Eq. (1) depend on the wavelength. To get the digital output of the sensor, one has to calculate the electron number or radiant flux according to the used detector. Both calculations are mainly the integral of the atsensor radiance over the bandwidth. An example output of the sensor simulation is shown in Fig. 1.



Fig. 1: Simulated camera image with the maximum occurring at-sensor radiance. This camera simulation was created with SENSOR++ and is part of a simulation of a moon lander [2]. The thin atmosphere of the moon is ignored in this simulation, thus $\tau = 1$ and $L_{\text{atm}} = 0$.

3. Simulation of the fire detection sensor

For the simulation, we have to consider the following characteristics of the fire detection sensor [3]. The sensor is a multispectral sensor with near (790 nm to 930 nm), mid L_m (3.4 µm to 4.2 µm), and thermal L_t (8.5 µm to 9.3 µm) infrared channels. It consists of line cameras with two staggered lines. The scanning is done according to the pushbroom principle. The fire detection algorithm is sensitive to sub-pixel fires, so we have to sample the fire scene with appropriate high resolution and model the point spread function accordingly.

At first, the algorithm searches for potential fire pixels by interpreting the information of the different spectral channels. The final step of the fire detection algorithm determines the fire temperature T_F , fire area A_F , and finally the fire radiative power FRP by solving

$$L_m = A_F B_m(T_F) + (1 - A_F) L_{m,bg}$$
(2)

$$L_t = A_F B_t(T_F) + (1 - A_F) L_{t,bg}$$
(3)

$$FRP = \sigma T_F^4 A_F GSD^2, \qquad (4)$$

with the Stefan-Boltzmann constant σ and the ground sampling distance GSD. The quantities $L_{m,bg}$ and $L_{t,bg}$ are estimations of the background radiances, i.e. the non-fire part of the pixels, in the mid and thermal infrared respectively.

4. Creating artificial fires

One problem is to get input data for the simulation. We want to use artificial data which we can control but which also has some natural features. For this purpose, we want to exploit the self-similarity of a Gaussian process called fractional Brownian motion fBm [6] to create fire maps. With the Fourier filter method, we can create *d*-dimensional fractional Brownian motion corresponding to noise with a power spectrum of $1/f^{\beta}$. For it, the absolute value of the Fourier coefficients is set to

$$|C_{\boldsymbol{f}}| = \frac{1}{|\boldsymbol{f}|^{\frac{\beta+d-1}{2}}} \cdot Z_G,\tag{5}$$

 Z_G are Gaussian distributed random numbers with a mean of 0 and a standard deviation of 1. The phase of the Fourier coefficients $\arg(C_f)$ is set to uniformly distributed random numbers between 0 and 2π . One gets the fractional Brownian motion by an inverse discrete Fourier transform

$$fBm(\boldsymbol{x}) = \sum_{\boldsymbol{f}} e^{\frac{2\pi i}{N} \boldsymbol{x} \cdot \boldsymbol{f}} C_{\boldsymbol{f}}$$
(6)

Furthermore, the coefficients have to fulfill $C_{-f} = \overline{C_f}$ to create only real values with the Fourier filter method. In Fig. 2, a 1-dimensional example of such a random fractal is shown. By additionally applying a threshold, we can create a 2-dimensional fire temperature distribution, see Fig. 3.



Fig. 2: Fractional Brownian motion also contains usual Brownian motion and accordingly Brownian noise. These N = 1000 samples were created with the Fourier filter method with d = 1 and $\beta = 2$.



Fig. 3: An artificial fire map $(N \times N = 500 \times 500 \text{ samples})$ created with the Fourier filter method with d = 2 and $\beta = 2.5$ and applying a threshold.

5. Conclusion

With SENSOR++ and fractional Brownian motion, we have all tools to build the simulation of the remote fire detection sensor. By using simulated sensor data to test the fire detection algorithm, one can ignore calibration problems, non-uniformity problems, and the misalignment between the different spectral channels of the real sensor. This helps us to concentrate on the atmospheric effects we want to study.

References

- [1] A. Börner, L. Wiest, P. Keller, R. Reulke, R. Richter, M. Schaepman, and D. Schläpfer, "SENSOR: a tool for the simulation of hyperspectral remote sensing systems," *ISPRS Journal of Photogrammetry & Remote Sensing*, vol. 55, pp. 299–312, 2001.
- [2] C. Paproth, E. Schlüßler, P. Scherbaum, and A. Börner, "SENSOR++: simulation of remote sensing systems from visible to thermal infrared," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, ser. XXII ISPRS Congress, vol. XXXIX-B1, 2012, pp. 257–260.
- [3] B. Zhukov, E. Lorenz, D. Oertel, M. Wooster, and G. Roberts, "Spaceborne detection and characterization of fires during the bi-spectral infrared detection (BIRD) experimental small satellite mission (2001-2004)," *Remote Sensing of Environment*, vol. 100, pp. 29–51, 2006.
- [4] L. Wiest, "Radiometriesimulation hyperspektraler Sensoren in der Fernerkundung," Ph.D. dissertation, Technische Universität Berlin, 2001.
- [5] A. Berk, L. S. Bernstein, and D. C. Robertson, "MODTRAN: A Moderate Resolution Model for LOWTRAN," Air Force Geophysics Laboratory, Tech. Rep., 1987.
- [6] B. B. Mandelbrot and J. W. van Ness, "Fractional Brownian Motions, Fractional Noises and Applications," *SIAM Review*, vol. 10, no. 4, pp. 422–437, 1968.