CUAVA InGaAs-based, Short Wavelength InfraRed (SWIR) Instrument for Atmospheric Reconnaissance—Preliminary Design

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ABSTRACT

We report the preliminary design of a new small-size remote sensing instrument operating in the Short Wavelength Infrared (SWIR) domain of the spectrum (1.588µm to 1.673µm) to monitor, detect, and measure atmospheric constituents such as Carbon Dioxide (CO_2) and Methane (CH_4) concentrations. We highlight the instrument features, technical specifications (including a relatively high spectral resolution of approximately 0.4 nm), optical design, and components. The instrument's synthetic spectral response is also explored using NASA's Planetary Spectrum Generator (PSG), a Line-by-law radiative transfer code. The instrument is currently under development at the ARC Training Centre for CubeSats, UAVs & Their Applications (CUAVA), and Sydney Astrophotonic Instrumentation Laboratory (SAIL) at the University of Sydney. Once built, it will conduct an atmospheric reconnaissance from an Unmanned Aerial Vehicle (UAV) and will be tested to qualify for future space flights on one of CUAVA's CubeSats.

INTRODUCTION

There have been various instruments designed and developed to enable air- and space-based measurements of atmospheric gases. They can be summarized in two categories: 1) Large instruments with super high spectral resolution and 2) Small instrument with coarse spectral resolutions.

- Large space missions such as (OCO-2)[1], (GOSAT)[2], (SCIAMACHY)[3], and (TanSat)[4] offer ultra-high spectral resolutions (0.08nm – 0.16nm) from space-based platforms.
- Small instruments on Nano-satellites such as Argus 1000 micro-spectrometer onboard (CanX-2)[5] enables miniaturization concept but comes with coarse spectral resolution (5nm) compared to large space-based instruments. The GHGSat, however, is another NanoSat that carries a passive spectrometer with a relatively high spectral resolution (0.1 nm)[6] but is tuned to only detect the atmospheric Methane (CH_4) concentration in the narrow spectral channel 1630 –1675 nm[7].

We report a new small instrument with commercial off-the-shelf components (COTS) that offers a relatively higher spectral resolution and covers two absorption bands, CH_4 and CO_2.

INSTRUMENT OPTICAL DESIGN

- The instrument is a passive spectrometer operating in the Short Wavelength Infrared (SWIR) part of the spectrum from 1.588 µm to 1.673 µm.
- The Instrument optical design, mainly, consists of five optical elements, slit, collimator, diffraction grating, camera (focusing unit), and detector. Figure 1 shows the instrument preliminary optical layout produced by Zemax.

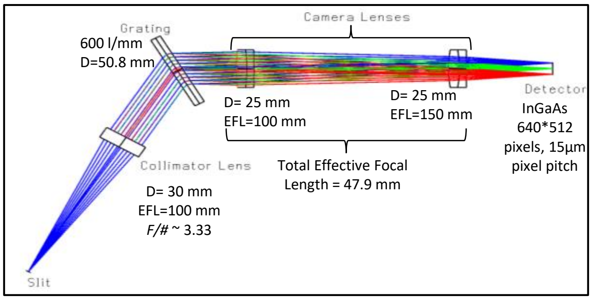

Figure 1: Instrument Optical Layout. Colors represent the wavelengths where blue is the minimum of 1.588 µm, green is the central wavelength 1.6305 µm, and red is the maximum wavelength of 1.673 µm.

PERFORMANCE

- Slit is modelled to have 9 positions (fields), 3 in the middle, 3 in the right and 3 in the left.
- The initial system performance was tested by ray tracing and generating the Spot Diagram of each field position for a range of wavelength, as shown in Figure 2

The spot diagram shows that all rays are confined within the Airy disk with a radius of 12.14 µm. It is also noteworthy that the spot diagram illustrates a relatively consistent and uniform performance of the system on and off-axis. The system's spectral resolution was tested in ZEMAX by generating the Geometric Image Analysis (GIA) feature, which we use to show the wavelengths separated by the required spectral step can be resolved. Figure 3, left panel, shows the central wavelength 1630.5 nm with two adjacent wavelengths, 1630.9 nm, and 1631.3 nm, separated by 0.4 nm spectral step. The normalized radiance profiles of these wavelengths' peaks are shown in the right panel of Figure 3. The Full-Width-at-Half-Maximum (FWHM) value in the right panel indicates that slit image is sampled by at least 2 pixels on the detector.

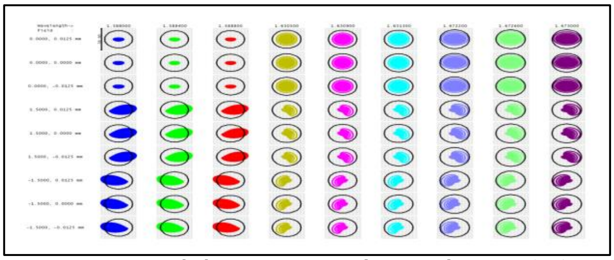

Figure 2: Matrix Spot The box size is 30 µm and Numerical Aperture (NA) is 0.1.

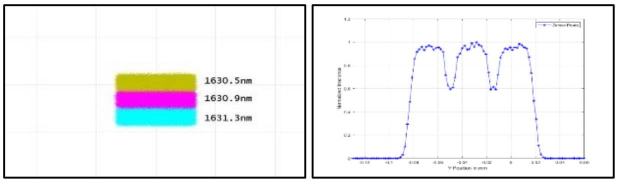

Figure 3: Central wavelength 1630.5 nm with two nearby wavelengths, 1630.9 nm and 1631.3 nm, separated by 0.4 nm (Left Panel). Right Panel, Normalized Radiance profile of the wavelengths' peaks in left panel.

SPECTRAL ANALYSIS

- The Planetary Spectrum Generator (PSG)[8] has been used to simulate the spectral range of our instrument where data is stored and processed in MATLAB.
- Figure 4, left panel, shows the instrument spectral range that includes absorption bands of CO_2 and CH_4. Right panel of Figure 4 shows the gases transmittance in the instrument spectral window.

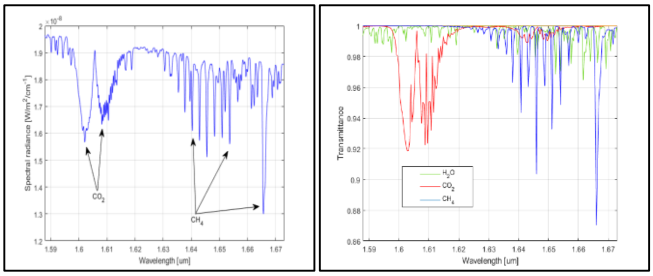

Figure 4: Right Panel shows Instrument spectral interval generated by NASA's Planetary Spectrum Generator (PSG). The lines resolution is set to 0.4 nm to simulate the instrument spectral resolution. Left Panels is the CO_2 and CH_4 transmission profiles in the atmosphere.

CONCLUSION

We have reported a new small size, passive remote sensing instrument operating in the Short Wavelength Infrared (SWIR) with a relatively high spectral resolution of approximately 0.4 nm to monitor, detect and measure CH_4 and CO_2 concentration in the lower atmosphere. We have shown the instrument preliminary optical design and performance in ZEMAX and simulated its spectral responsivity utilizing the Planetary Spectrum Generator (PSG) which is a line-by-line radiative transfer code developed by NASA. The filed lens, which determines the field of view (FOV), will be selected and the whole system will be tested again in ZEMAX. The instrument will, initially, conduct its first reconnaissance from a UAV platform and collect data over various targets on the ground. It will, then, be tested to qualify for a space mission onboard one of CUAVA's future CubeSats.

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