Ultra-Violet Multispectral Imaging Cameras for Validation of SO_2 Emissions

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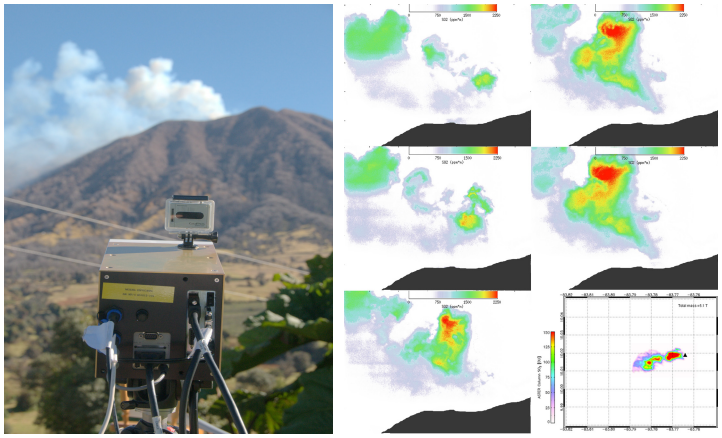
Introduction

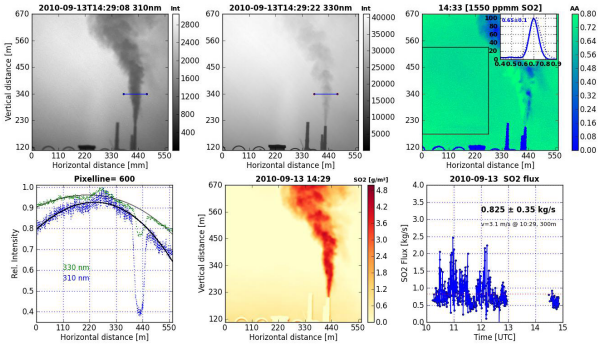
The ultra-violet region of the electromagnetic spectrum can be exploited to measure several important polluting gases, including SO_2, NO_2, O_3, BrO among others. Low-cost, highly-portable grating spectrometers are commonly used to detect these gases and provide measures of emission rates and atmospheric loadings. These instruments have proved very successful, but suffer from the drawback that they can only provide line-of-sight measurements within a single field-of-view, or along a line if used together with a scanning mechanism. The imaging camera can overcome these spatial sampling deficiencies, but there are several problems to address, not least the loss of spectral resolution. We describe the development of a new multispectral UV imaging camera and show results which suggest that recovering SO_2 from UV imagery is practical and has some advantages over UV line-of-sight spectrometers. The results are illustrated from three different applications: low emission rates from sea-going ships, medium emission rates from industrial stacks, and the high emission rates from passively degassing volcanoes.

Volcanic SO_2 Emissions



Envicam-2 monitoring SO_2 emissions from Turrialba volcano, Costa Rica. The sequence of five images on the right show SO_2 path concentrations (ppm*m) taken at intervals between 0.1 and 5s. The last panel shows an SO_2 retrieval using ASTER satellite data. Work is in progress to utilise the camera data to validate satellite retrievals.

Stack Emission Measurements



The images illustrate results from the data analysis of UV-camera observations of SO_2 emissions at the Rovinari power plant (44°54' N, 23°8' E, SW of Romania) made during a field campaign in September 2010.

EnviCam-2 Technical Specifications

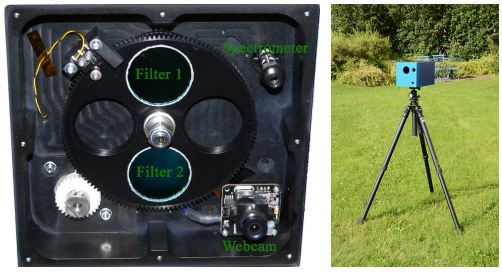
	Camera	Spectrometer	Webcam
Total field-of-view	∼6°	∼1° (adjustable)	160 °
Optics	50 mm C-mount lens F/3.5	5 mm diameter F/2	
Image size	1344 x 1024 pixels	1024 pixels	640 x 512 pixels
Spectral resolution	4 filters, narrowband ∼10 nm	∼0.3 nm (FWHM)	RGB
Number of fllters	up to 4	–	–
Filter 1	307 nm	–	–
Filter 2	325 nm	–	–
Filter 3	Optional–user specified	–	–
Filter 4	Optional–user specified	–	–
Sampling rate (max)	35.7 Hz (4x4 binning)	1000 Hz	25 Hz
Exposure setting	1μs–1 s	1 ms–10 s	–
Detector	Progressive scan in-line CCD	Sony ILX511B CCD	CCD
Digitization	12 bits	16 bits	16 bits
Accuracy (SO_2)	±0.2 gm^{-2}		
Operating range	–10 °C to +50 °C	–30 °C to +70 °C	–10 °C to +50 °C
Interfaces	PCI/CameraLink	USB 2.0	USB 2.0
Power requirements	12 V, 3 A, 40 W peak		
Total weight	9 kg		
Total dimensions	300 mm x 200 mm x 90 mm (LxWxH)		

Measurement Principles

UV radiation is measured using a high quantum efficiency CCD after passing through special narrowband filters that select radiation where certain gases strongly scatter or absorb radiation. The region between 280–320 nm can be used to estimate SO_2 path concentrations, while other gases, for example NO_2 can be measured between 400–500 nm.

Envicam-2

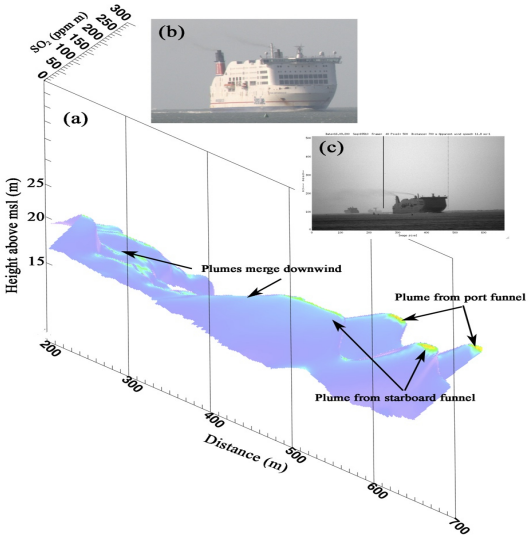
integrates the Hamamatsu C8484 UV camera with a UV spectrometer and webcam to provide a complete set of measurement data for quantifying fugitive emissions rapidly and accurately. The camera provides 1344x1024 pixels and by using Envicam-2's four-position filter wheel, spectral selection can be achieved. The spectrometer is co-aligned with the camera axis to provide a ∼0.3 nm resolution spectrum within the field-of-view of the camera. The webcam allows the user to view the scene in real-time using visible light and maintain a visual record of the data capture.



Front part of the Envicam-2 UV camera showing filters, spectrometer and webcam (left). Envicam-2 on tripod (right).

Ship Emission Measurements

Envicam-2 is highly suitable for measuring SO_2 emissions (and particulates) from ships. Quite low concentrations can be detected and by sampling the plume rapidly (∼10 Hz) the emission rate can be estimated. There is no requirement for wind speed measurement and provided there is sufficient sunlight, emission rates of g s^{-1} to kg s^{-1} are easily determined. Emission rates from various ships in Rotterdam harbour (Hoek van Holland) were estimated in this way giving emission rates of 5–150 g s^{-1}.



Ship emission measurements in the Rotterdam channel, Hoek van Holland. Emissions can be identified from individual ships and even from individual funnels at distances of several kilometres, depending on ambient visibility. (a) A three-dimensional rendition of the SO_2 path concentration (ppm*m) as a function of height and distance. (b) A visible image showing a large ferry approaching the channel. (c) The same ferry shown in UV light.