SO2 Gas Camera Information

Introduction

The SO2 gas camera uses a CCD detector to create a 2D concentration map of a target (volcano, stack etc.) SO2 is the focus of the current design however other gases may be detected by swapping a few components.

The technique uses a cell containing a gas that is to be detected, an empty reference cell, and narrow bandpass filters to isolate the strong spectral absorption bands for the gas in question. Looking at a plume or area of interest with a potential concentration of the gas in question, images are captured with various bandpass and gas cell filters inserted in the optical paths. These images are then analyzed and compared to each other on a pixel-by-pixel basis using correlation algorithms developed by W.H.Morrow [1]. A false-colour 2D image is then rendered which displays gas concentration in the field of view.

This second generation camera evolved from our earlier design which used a single optical path and a servo to alternate between the empty reference cell and the known concentration cell. Therefore, for every rendered 2D image there were two CCD acquisitions and two mechanical transitions which limited the framerate to approximately 1 fps. The second generation design avoids any moving parts (besides the initial calibration routine) by using two optical paths incident on one CCD. The two paths are side-by-side to each other and therefore two separate images are formed on the CCD. The filters / gas cells can then be permanently fixed in the optical paths. Each acquisition results in a data array containing both images, which is simply split in software and processed to create the resulting false-colour gas concentration map.

Advantages

- <u>2-Dimensional</u>
  Gas is not merely detected, but mapped across the entire field of view.

- <u>Real-time Results</u>
  Data is acquired and processed in real-time to produce the false-colour representation at a framerate greater than 1 fps.

- Two Optical Paths
  This allows two COSPEC calibration cells to remain in the optical paths after calibration has been performed to eliminate the need for a chopper to switch cells in and out of the optical path. Therefore no moving parts are required for operation after calibration has been performed.

- Flexible
  LabVIEW software can be designed to meet any requirements.

- Portable
  The camera can be hand-held and uses only a single USB cable to interface with a laptop of choice running the LabVIEW interface.

- Rugged
  No moving parts combined with a mechanical cage design protects the optics and CCD from jarring or harsh movements / impacts. The system can also be hermetically sealed for more challenging environments.

- Low-Maintenance
  No moving parts and no optical adjustments means all calibration is done in software. There are no mechanical degrees of freedom to fiddle with.

- Flexible CCD Options
  Options include no CCD cooling, air-cooled (-20 to -90 C), and different CCD resolutions according to which Hamamatsu chip chosen. All options change the price and therefore provide a convenient selection between performance and price that suits the application.

- LabVIEW Software
  Powerful, customized, and intuitive user interface provides a multitude of options for data manipulation that can be added to meet any requirement. Pixel averaging, moving averages, automated acquisition, advanced file saving and data output, custom algorithms, and remote access/control, are but a few features easily integrated into the software.

- Price
  This instrument is offered at a price unmatched in today’s market. There is no other complete package that can remotely detect and measure the concentration of SO_2 and map it two-dimensionally in real-time.

Specifications

- Back-thinned Full-Frame Transfer CCD
  - 1044 x 256 or 2048 x 512 resolution
  - 24.576 x 6 mm active area
  - 47 - 66% quantum efficiency @ 300 nm depending on CCD & cooling
  - 10 ms – 520 s integration time (Tec5 electronics)
  - Air cooled -20 up to +90 C
  - 200 – 1100 nm spectral response

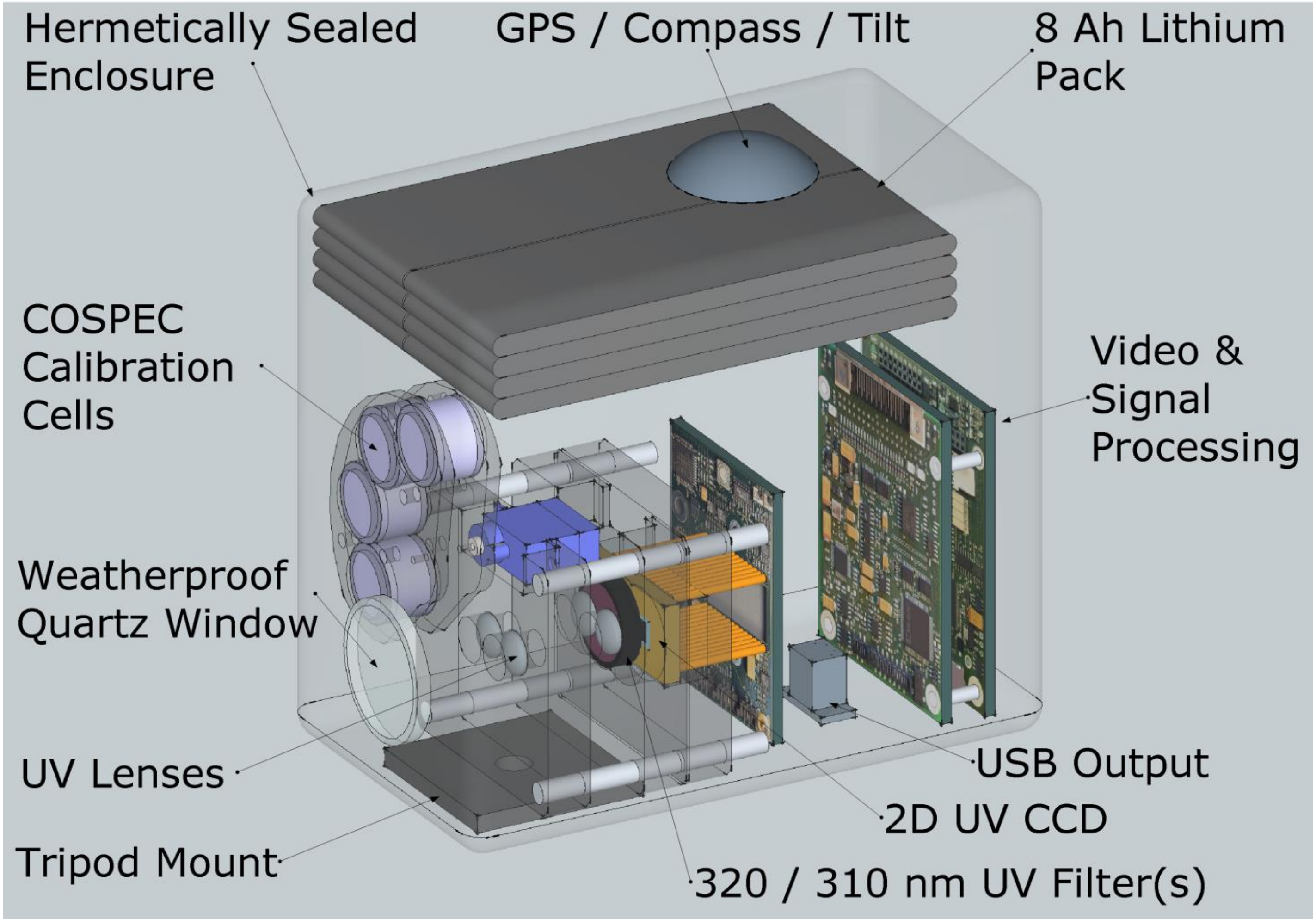
- ~300nm Bandpass Filter(s)
  - 10 nm FWHM
  - Blocks longer wavelengths up to 1200 nm
  - > 65% transmittance

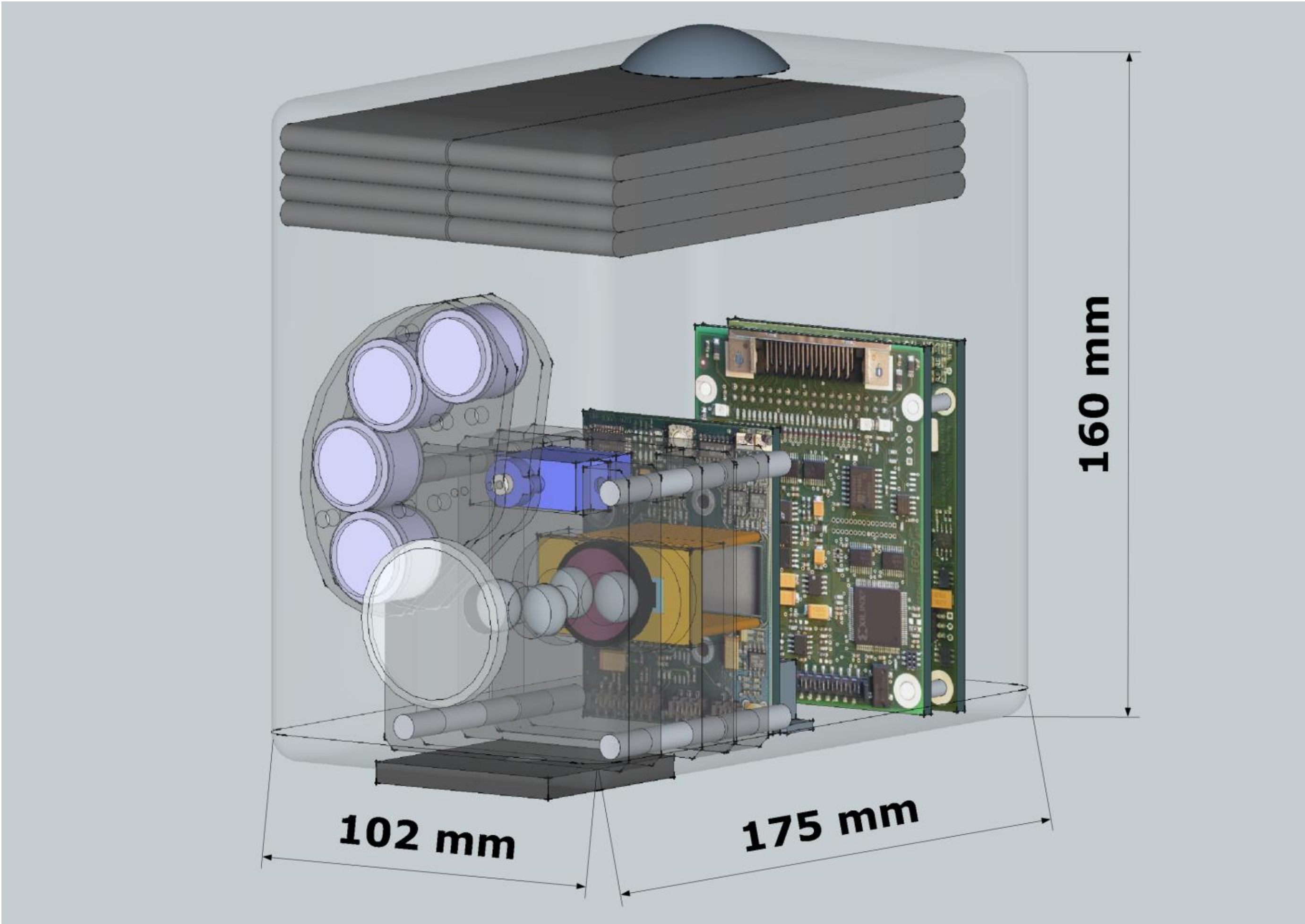
- Embedded Instruments
  - Full file saving
  - GPS
  - Compass with tilt sensor for azimuth
  - Expandable to accommodate any type of sensors

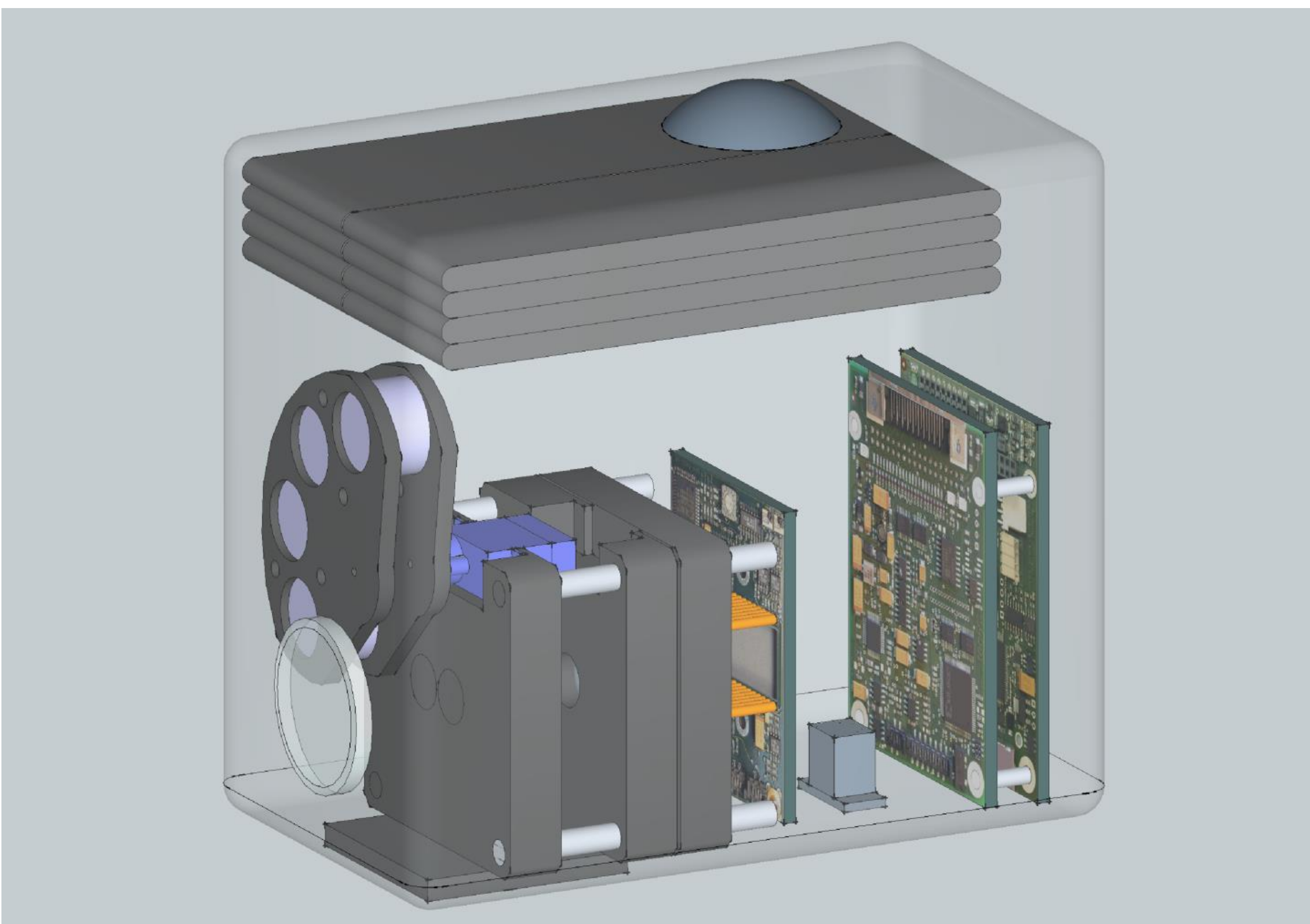
- LabVIEW Software
  - Full file saving
  - Averaging, calibration routines, image thresholding and any custom image manipulation easily programmed

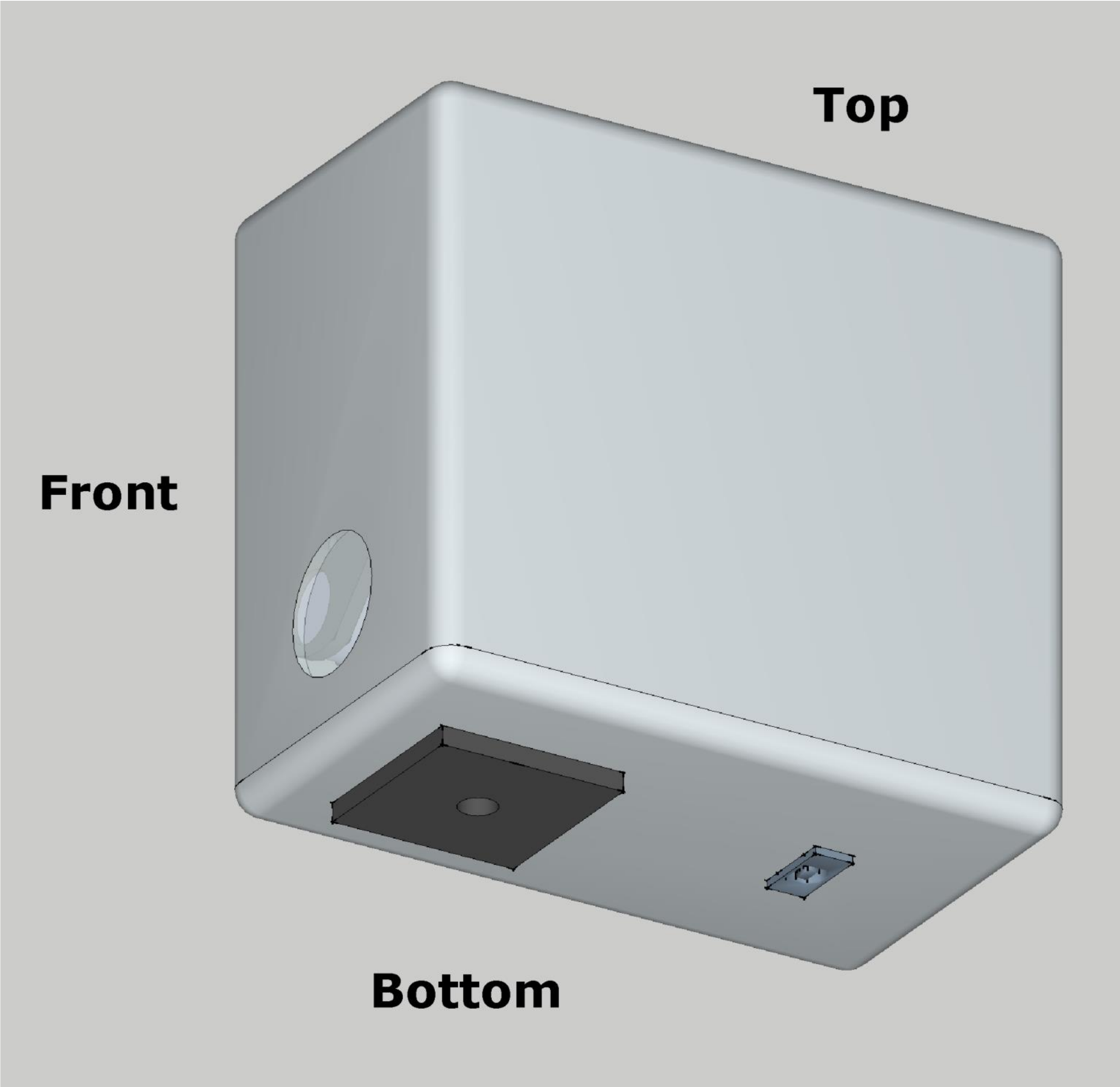
- Rugged Container
  - Hermetically Sealed
  - Optics, CCD, bandpass filter(s), and COSPEC cell changer all mounted on a sturdy cage to guard against jarring and impacts

Prototype Design – 2nd Generation




160 mm
102 mm
175 mm




Top
Front
Bottom

Bandpass Filter Performance

The following two figures display parameters of the bandpass filters used for the prototype. The first figure is from the manufacturer's website and was for the 310 nm filter. It shows that its peak transmission is guaranteed to be at least 65% and that it blocks longer wavelengths at least up to 1200 nm. Anything beyond 1200 can be ignored since the sensitivity of the CCD diminishes at this point.

Figure 1:

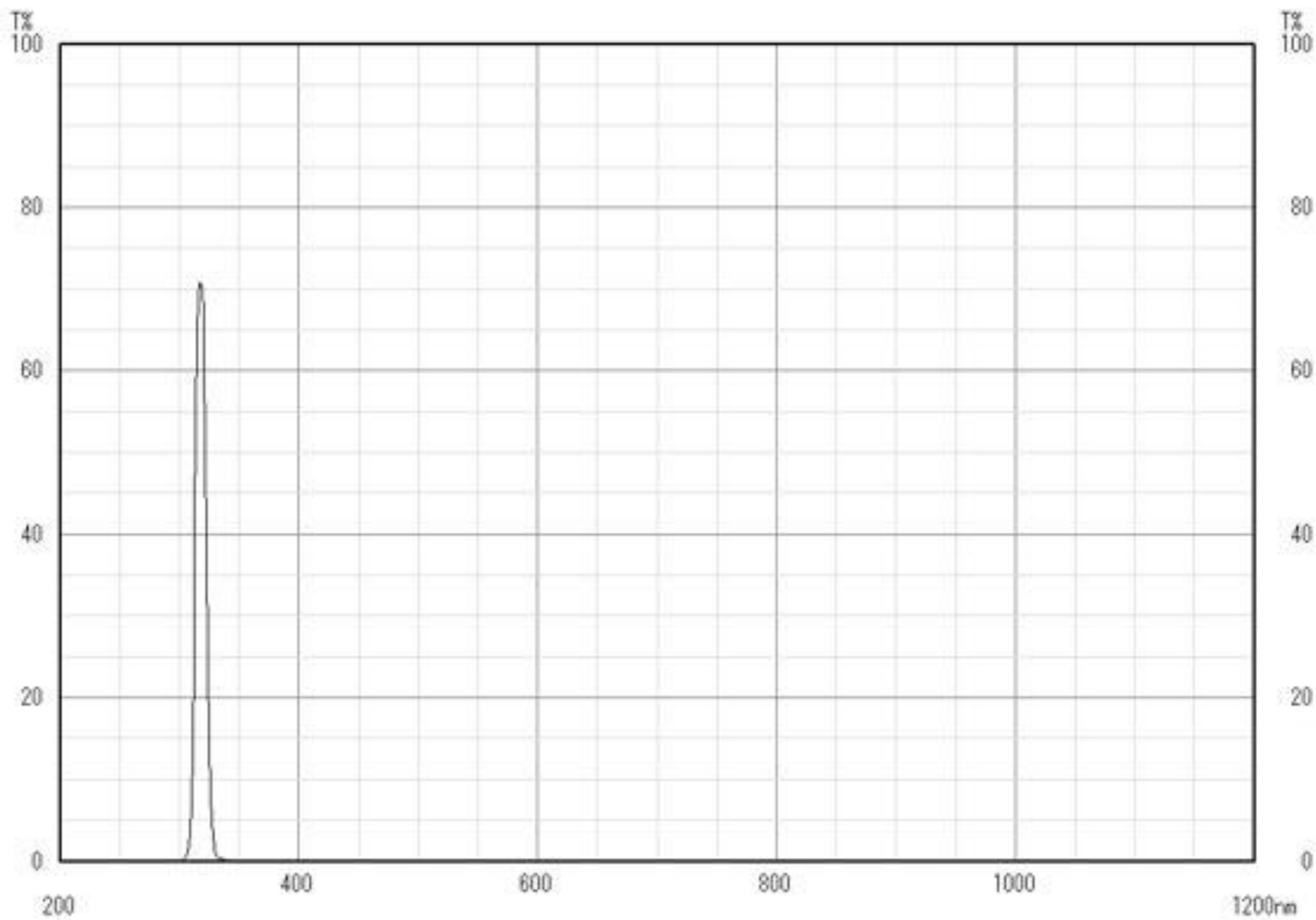
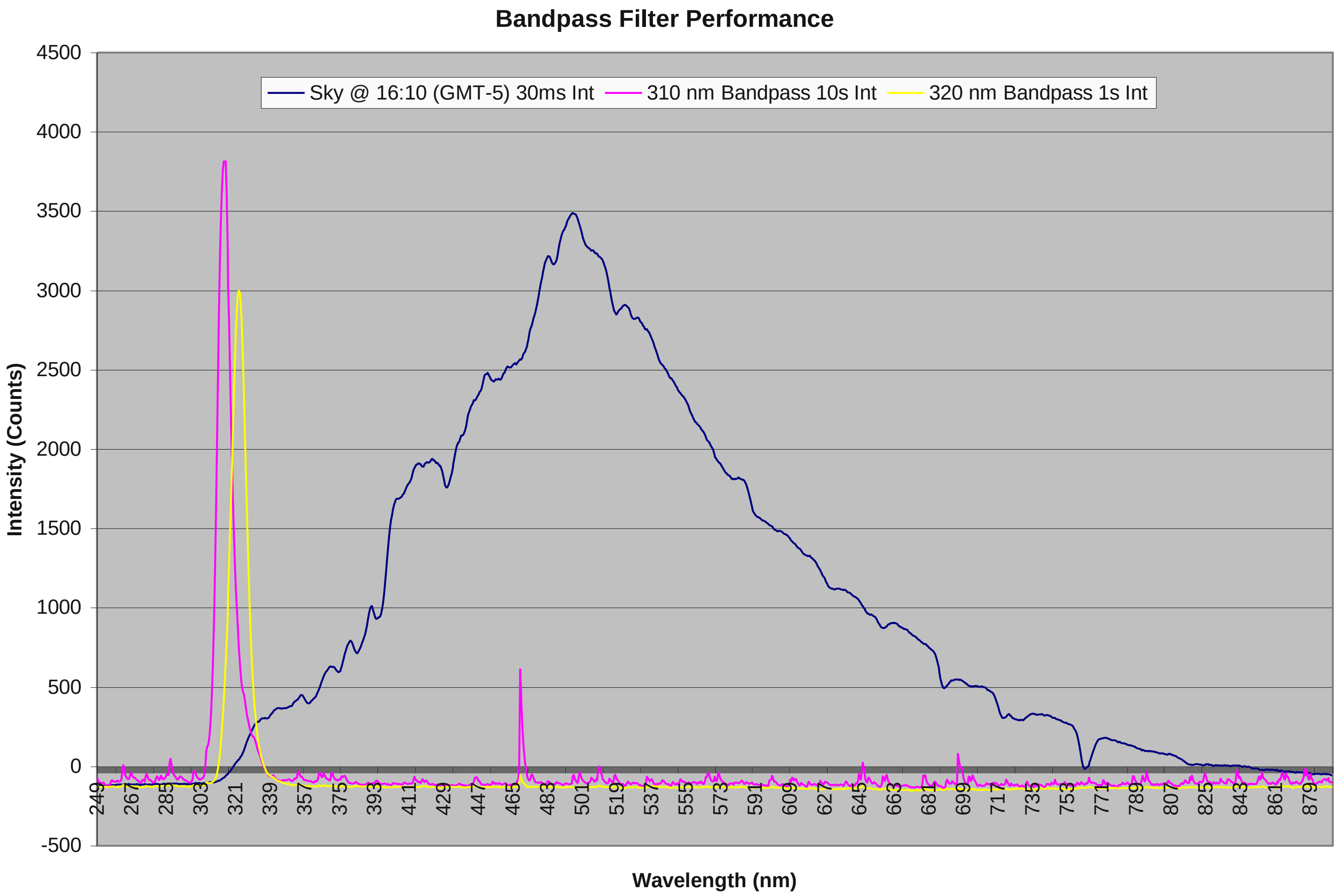


Figure 2:

The filters were tested at Resonance Ltd. to confirm the manufacturer specifications. Note the integration times, which are not equal for the two filters. This was changed in order to create two spectra that could be compared on the same y-axis of intensity counts. Both filters exhibited a small leak at approximately 466nm. Since the camera system relies on the total amount of light passing through the filter and incident upon the CCD as opposed to selecting specific absorption peaks such as spectrometer-based detection systems, only the total area under the curve is a concern, and not the peak intensity count of the leak. The total area of the leak is minimal compared to that of the main filter pass and therefore will not significantly impact performance.



Comparison to Other Gas Cameras

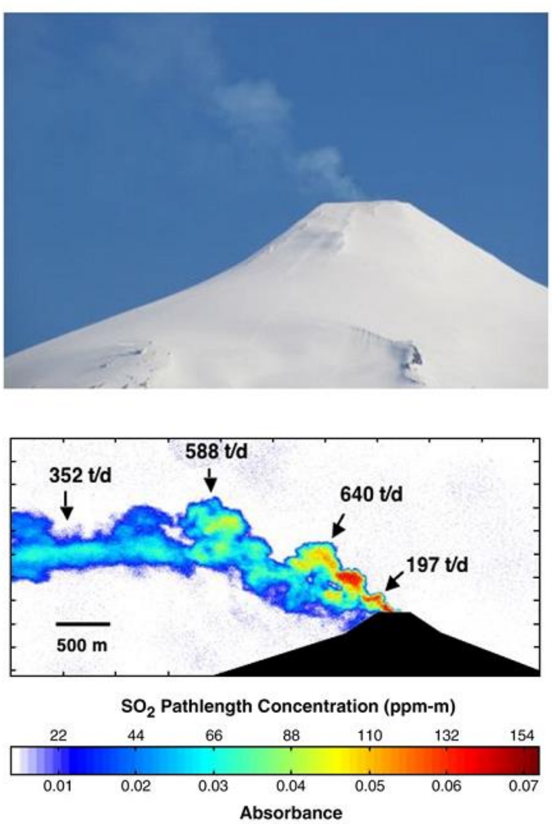
The Resonance Ltd. gas camera prototype is considerably more advanced and refined than similar systems. Two other cameras will be compared to the prototype; one from Toshiya Mori and Mike Burton [2] and one from G.J.S.Bluth (Michigan Tech) [3].

	Resonance Ltd.	**Mori / Burton**	**Michigan Tech**
Cost of Parts	< $10,000	~$10,000	~$18,000
Quantum Efficiency	> 47%	< 10%	< 10%
Automatic Cell Changer	Yes	No	No
Real-time results	Yes	No	No
3rd Party Post-Processing Required?	No	Yes	Yes
Moving Parts After Calibration?	No	Yes	Yes
GPS / Sensors?	Yes	No	No
Custom SO2 Imaging Software?	Yes	No	No
Frame Rate	> 1 FPS	< 1 FPS	0.3 FPS
Two Optical Paths Simultaneously?	Yes	No	No

Expected Results

The following figure was taken from Michigan Tech's [3] paper on their SO2 camera to give an idea of the concentration map that will be obtained in real-time from the Resonance Ltd. system.

Figure 3:



The concentration of SO2 in the plume is designated by a colour gradient relating the arbitrary false colours to a numerical ppm-m concentration value. Figure 3 was generated after collected data was post-processed using 3rd party tools and therefore does not display the SO2 concentrations in real-time.

The Resonance system does not simply utilize a CCD for its 2D capabilities, and acts as a conventional camera would. The LabVIEW interface allows video to be recorded as a sequence of frames acquiring at a rate of at least 1 Hz. In this way sources of SO2 could be immediately identified and even profiled as data is correlated with position and azimuth thanks to the embedded sensors.

References

[1] W. H. Morrow, “Filter Correlation Spectrometers For Remote Sensing Of Tropospheric Gases,” Ph.D. Dissertation, York University, Toronto, ON, Canada, 2002.

[2] T. Mori, M. Burton. 2006. The SO2 camera: A simple, fast and cheap method for ground-based imaging of SO2 in volcanic plumes. Geophysical Research Letters Vol. 33

[3] G.J.S. Bluth, J.M. Shannon, I.M.Watson, A.J.Prata, V.J.Realmuto. 2007. Development of an ultra-violet digital camera for volcanic SO2 imaging. J Volcanology and Geothermal Research 161: 47–56