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Remote Gas Sensing of SO_2 on a 2D CCD (Gas Camera)

Sulphur dioxide (SO_2) is a colourless gas and is of interest scientifically due to its relevance with regards to environmental effects such as climate change, damage to plants and wildlife, as well as causing respiratory problems. [4]

Sulphur dioxide is emitted through industrial processes, the smelting of raw materials, burning fossil fuels - including vehicles - as well as through natural processes such as volcanic vents. Active volcanoes, emitting smoke and gasses, one of which is SO_2, have a direct correlation to the amount of magma flow underneath the volcano and can be used to measure and potentially predict future volcanic activity. [1] Sulphur dioxide is a precursor to acid rain, killing plants and wildlife as well as causing increased erosion of buildings and bedrock. SO_2 also causes breathing difficulty and respiratory problems. [4]

The proposed project will expand upon the principles of remote gas sensing, and the development of an inexpensive camera capable of real-time detection and concentration of gases. Sulphur Dioxide (SO_2) is the chosen gas for the scope of this project; however, the system will have the capability to be adapted for the detection and measurement of other gases such as Nitrogen Dioxide or Carbon Dioxide as well as a variety of greenhouse gasses.

Sulphur dioxide, as do all gasses, has absorption and emission lines at specific wavelengths. The collective absorption or emission lines from a gas can be compared to the human fingerprint; with each gas having a unique signature. Neon gas for example, has a majority of these lines in the reddish orange region which gives us that familiar glow of neon signs everywhere. SO_2, as shown in Figure 2 below, has these lines concentrated in the ultra violet region. This gas ‘fingerprint’ leads to the principle of remote gas detection in which the background light is compared to the same light passing through the sample, either in a chamber in a laboratory, or in a gas plume in the atmosphere. The difference between the light itself and the light passing through the gas (in which the gas absorbs its particular ‘fingerprint’ of lines) allows the type of gas, and its concentration, to be known.

Existing portable gas sensors fall into one of two categories: spectrometer based instruments and filtered camera based instruments.[5] A spectrometer allows for greater sensitivity and accuracy because the entire light spectrum is recorded. However, it is limited to a single point, it can not take an image of an area, but it can give you a measurement for the area as a whole. Spectrometer based instruments also require the operator to “hunt” for the gas; making it possible to miss an auxiliary source or even an area of maximum concentration if it is in an unanticipated location. The system can be mechanically scanned across a region to build up an image, however this takes time - upwards of half an hour depending on resolution. And due to this increased time of scanning, changing wind conditions adversely affects the image.

Existing camera based instruments make use of selective filters to take two images of the area, one in the range in which SO_2 absorbs light, and another in a range where SO_2 does not absorb. A computer then finds the difference in the images and correlates it to the amount of SO_2 in the image [2]. A drawback to current camera based instruments is decreased sensitivity and potential for noise; as other gases can potentially also absorb in the same region for the filters which are used.

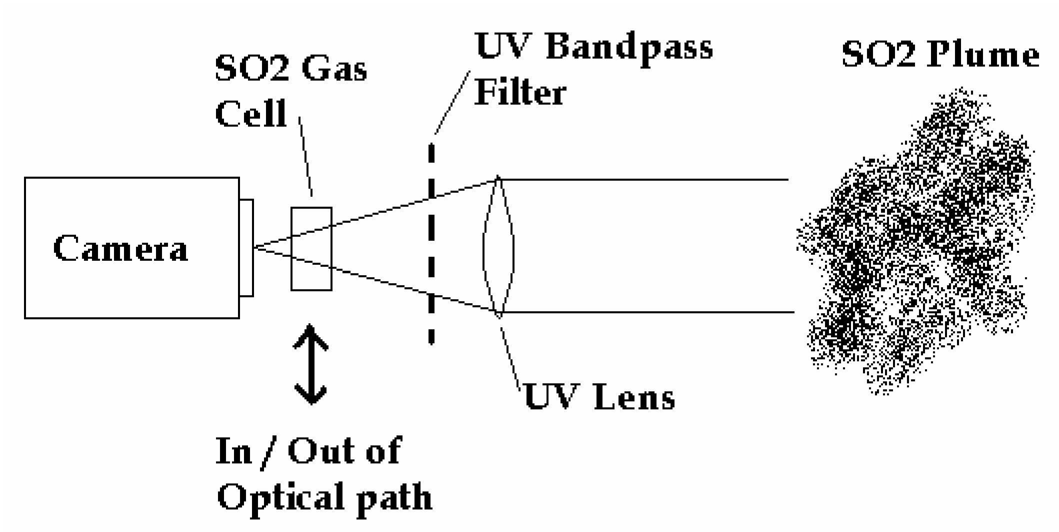

Figure 1: Proposed System

The system we are proposing, as shown in Figure 1 above, will use a gas cell filled with SO_2 which will act as an extremely selective filter. This system will do the rough equivalent of fingerprint matching in which we use the gas itself, in a known concentration, to filter the light to be measured. The SO_2 in the gas cell will absorb specific wavelengths of UV light which have not already been absorbed by the SO_2 in the plume. By recording two images in rapid succession, one with the gas cell in, another with an empty reference cell, we will be able to determine the concentration in a plume with the speed of a camera-based system and the accuracy and sensitivity approaching that of a spectrometer-based system. A UV band-pass filter will be used to limit the incident light to the region of interest for SO_2, and this narrow region of interest will be passed through the SO_2 cell, and then the empty cell. The greater the difference between the two images with and without the SO_2 cell indicates that there wasn't a high concentration of SO_2 in the atmosphere to absorb those wavelengths before it reached the camera. The smaller the difference in intensity, the greater the concentration of SO_2 in the atmosphere - up to the point in which the light is fully absorbed prior to the camera and swapping the SO_2 gas cell in and out would not make a difference. For this reason, the SO_2 cell used should contain a concentration of SO_2 much higher than what you expect to find.

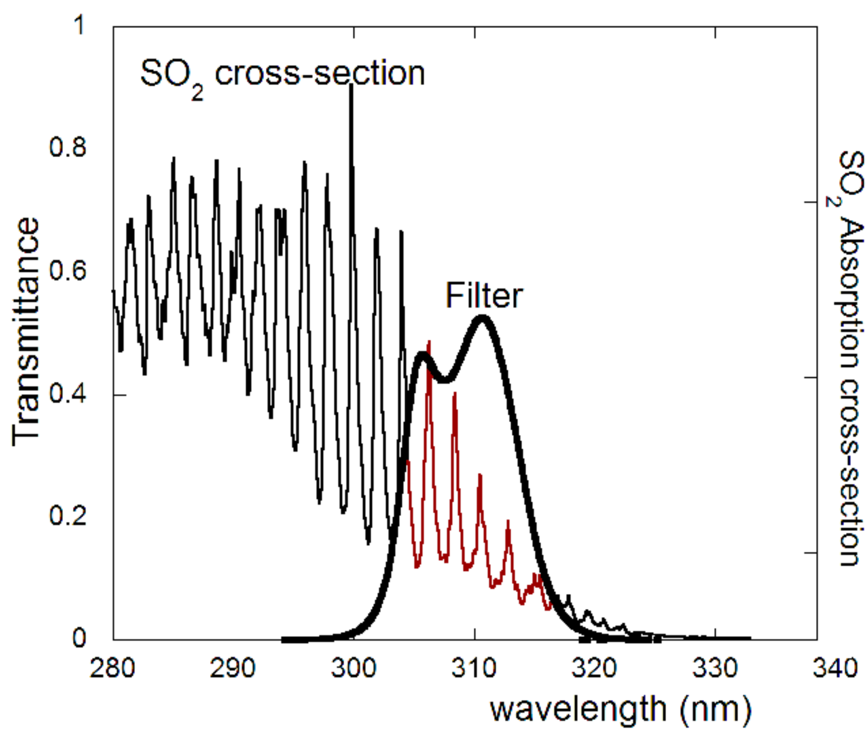

Figure 2: SO_2 Absorption with respect to wavelength filter [2]

Existing systems - while accurate and sensitive - are still quite expensive due to the precision required of the discrete components. Recent developments in the design of gas sensing cameras [2] have sought to lower the cost of such a system down to $10,000 using a visible light camera and discrete filters, however this presents a decrease both in dynamic range and sensitivity.

High precision instruments using gas cells [1] have both greater range and sensitivity, however they are not designed to image an area, but to take incident light from a specific path, which can be very narrow, spanning only one or two degrees. As stated earlier, to process an image or a path with such a device, the instrument is required to be transported along a path, or mechanically scanned. [5]

Although this system will have the capability to detect and measure other gases using a similar process simply by replacing the gas cells, or adding a new gas cell to the system, for the purposes of this proposal we are limiting the scope to the detection and measurement of SO_2 only.

The system will be low cost, between $1,000 and $3,000, significantly lower in price than for similar systems already developed, but without an associated decrease in sensitivity. This system is expected to be comparable to, or outperform existing gas cameras - approaching spectrometer-based systems with regards to sensitivity.

Portability for field use is a must, both in simplicity of operation and power requirements. Rugged design to facilitate operation near a volcano as well as for eventual installation into an unmanned aerial vehicle (UAV) is also required.

Real-time imaging allows the operator, while in the field, to view the SO_2 plume and direct further measurements without requiring post-analysis of the data.[5] It should be noted that the option for post-processing of the data along with a calibration source to achieve greater resolution than supplied by real-time imaging is also offered for this device.

A key component to the system is the development of an inexpensive UV-sensitive camera. Commercial UV cameras cost $1000 and up, depending on sensitivity. Alternative techniques will be investigated to facilitate the use of a low cost visible light camera. One such method will be the use of a fluorescent material applied to the camera sensor which will emit visible light in response to ultraviolet light[3][6].

Next, prototyping and development of the optics assembly is required to determine the optimal configuration of lenses and filters with respect to the gas cell and camera. Design of an appropriate filter wheel for both the band pass filter and the gas cells is also required. This filter wheel will be motorized and computer controlled.

Laboratory testing and software design will be performed in parallel determine the limits and capabilities of the optical system and to determine noise levels and subsequent error.

Mathematical processing of the image pairs will be developed to correlate the differences in intensity with SO_2 concentration. Additional SO_2 gas cells of varying concentration will be used to calibrate the system in the laboratory prior to field trials. Processed images will be displayed through the use of false-colour imagery as well as with the use of isometric contour mapping.

Works Cited

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