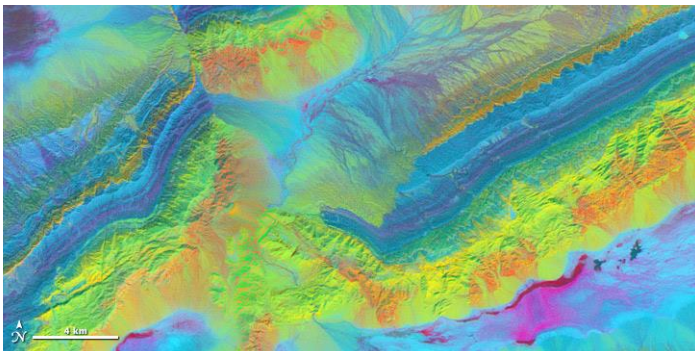
Opportunities and Challenges in Emerging Applications for UV, Visible & IR Remote Sensing

IR Imaging Used by Space Archaeologists to Find New Viking Site at Point Rosee, North America[i]

Remote sensing first developed in the 1880s when Sir Walther Noel Hartley described the strong UV absorptions between 200 and 300 nm in the atmosphere due to ozone. Developing steadily since then, with particular surges of progress during the two World Wars, remote sensing techniques now contribute to many aspects of life and utilize several regions of the electromagnetic spectrum. The major ones are the UV / Vis / IR (ultraviolet, visible, and near-infrared) region (< 3 µm wavelength) which measure reflected solar energy, and the mid-infrared, thermal-infrared, and microwave regions (> 3 µm wavelength) which measure emitted radiation from the Earth's surface and atmosphere.

In the 1960s, early in the space-age, remote sensing started to be deployed from space, causing the next revolution in the technologies, capabilities and applications. There were two drivers behind the space revolution. The obvious one is the ability to remotely sense large spatial areas, transforming our ability to measure and understand the planet we live on, the oceans and its atmosphere. Secondly, in the UV / Vis / IR region, thermal emissions can be neglected, enabling the observed spectral signatures to be directly related to absorption spectra of atmospheric constituents or reflective surfaces, making spectral analysis in this region of the electromagnetic spectrum relatively straight forward.

Originally developed for environmental research, remote sensing from space is now used in a wide and growing number of other applications. The well-known ones are agriculture, forestry and land use /cover: water resources: marine resources and coastal studies: and geology / mineral resources. However, there is a far wider and more eclectic mix of applications than is normally discussed in conferences or the press. Some more off-beat applications include:



Decorrelated 3-band shortwave-infrared image of the Piquiang Fault, China. Image Credit: NASA

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- Catching tax-evaders red-handed by locating new construction and building alterations
- Predicting retail earnings and market share by counting cars in car parks
- Collecting evidence on fraudulent crop insurance claims
- Watching algae grow as an indicator of environmental health
- Detecting land cover/use types for urban planning decision making
- Unearthing ancient archaeological sites like the Mayans and ancient Egypt
- Preventing the spread of diseases in epidemiology
- Mapping regional economic activity at night
- Predicting the occurrence of dinosaur tracks for palaeontologists
- Monitoring oil reserves by looking at floating oil roof tanks

Economic Activity at Night. Image Credit: NASA

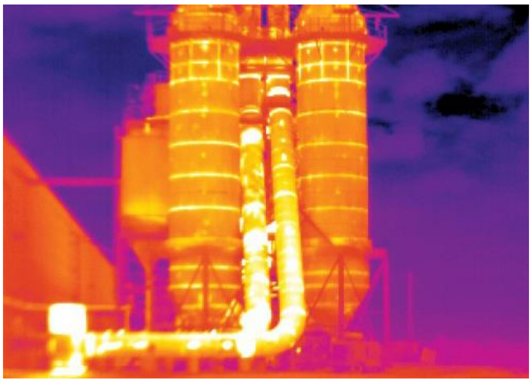
Back on Earth, remote sensing has also continued to develop new applications, especially in the military, security and construction sectors. Interest is now spreading to a wide range of new terrestrial applications which are emerging daily. Examples include:

- Assessing rural road conditions (using UAVs)
- Guiding autonomous vehicles
- Keeping an inventory on cemeteries (using UAVs)
- Assisting cities to manage assets and ensuring safety standards
- Planning spine-jarring black diamond ski runs with aspect data
- Narrowing down a search for a missing body

UV / Vis / IR sensors are amongst the most widely used detection technologies and find extensive applications across the medical, defence, security, process, aerospace, environmental, energy, and research sectors. These sectors have common technical challenges in exploiting this part of the EM spectrum and their application needs are often similar enough for solutions from one sector to be migrated to another.

A recent workshop held by the Centre for Earth Observation Instrumentation & Space Technology (CEOI-ST) brought together technical experts from several sectors to discuss these emerging terrestrial applications for UV / Vis / IR remote sensing and explore the opportunities for adoption of new technologies being developed for remote sensing in space. Markets and applications currently considering remote sensing solutions include:

Flammable / Hazardous Areas - Remote sensing of flammable areas is of big interest as it removes the necessity for intrinsically safe instrumentation. Any technologies not requiring electrical power are of interest in these types of applications.



Infrared Inspection of Petrochemical Plant

Security and Health & Safety - There are a range of applications for trace gas measurement in these two sectors. In the security sector, the determination of whom or what is in a building and what is happening inside is of major interest. This could be achieved by remotely measuring NO_2, CO_2, O_2 and other species to provide data on human activity, presence of explosives, and other undesirable activities. The same approach could be used to monitor employees for health and safety. Lone workers

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in remote or hazardous areas are always of concern and being able to monitor their status in facilities and buildings remotely would add an additional layer of safe operation.

Cubesats and UAV Cross-over - There is a rapidly growing interest in terrestrial applications of miniaturised, low mass, and low power sensing technologies for CubeSat missions. These can easily cross-over into the UAV domain for similar sized systems and applications. UV / Vis / IR systems developed for CubeSats can easily be deployed on UAVs, enabling new applications in precision agriculture and forestry. Ultra-low power and processing capabilities, e.g. mobile phone technology, is being adapted for CubeSats, and this may have a wide range of applications on UAVs.

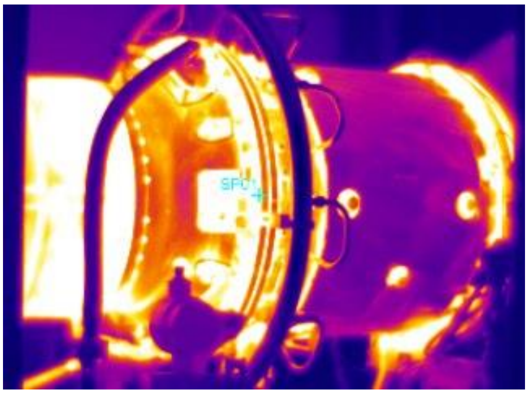
Unmanned Aerial Vehicle (Drone)

Pollution Monitoring - Technologies such as DOAS (differential optical absorption spectroscopy), originally developed for researching atmospheric chemistry from space, are now being deployed to remotely monitor pollution sources over complete cities from one central location.

However, despite the high levels of research and development being undertaken on improved remote sensing for space applications, there is still a wide range of technical challenges to be addressed for both domains.

Trace gas measurement of NOx, SOx, and CO_2 using IR measurements is of major interest. New developments in sources (thermal sources and lasers), detectors (pyrotechnic detectors, bolometers) and photonic detectors in the near IR region with high sensitivity and with no special cooling requirements are of greatest interest.

Gas turbine operating temperatures are increasing to improve efficiency, which results in the need to use ceramic coatings on turbine blades. The coatings appear transparent using observations at 1-2 micron wavelengths. There is a need to increase temperature measurement sensors to wavelengths of 10 microns to enable comparable temperature measurements.



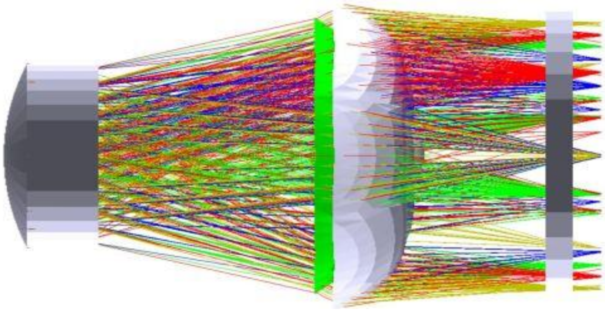
Infrared Thermography of Gas Turbine. Image Credit: Building Response

Implementation of cooled sensors to achieve measurements in the 10-micron range has been demonstrated, often achieved using a liquid nitrogen coolant system, which is only feasible for ground-based turbine applications. For aircraft turbines, a different approach is required, either for cooling or using detector technologies that are low mass, compact and do not require active cooling.

As always, there is significant interest in improved sensor performance, especially accuracy, environment, response time, room temperature operation and cost (this is a big driver). Miniaturisation and low cost expendable systems are also of interest.

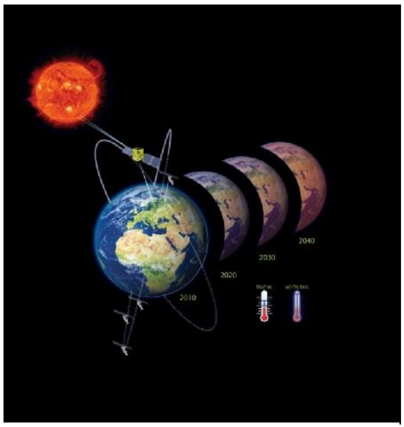
Un-cooled IR bolometers, which may address a number of application and deployment barriers, remain of great interest.

In the signal processing domain, there are many challenges relating to remote sensing. There is significant interest in the progress that has been made in the EO domain in the processing of satellite imagery for change detection, analysis and identification of targets of interest. Another area of significant challenge is how to process, fuse and understand data from different sources – e.g. polarimetry, fluorescence, hyperspectral, in order to enable a decision in a short time frame. Modelling of gases at high temperature is of interest as existing approaches extrapolate low temperature models to high temperatures, e.g. 500°C to 1500°C. Better high temperature models are needed in the detection of oxygen, CO, leaks, etc. Registration between images in formation flying is of interest for terrestrial imaging applications. And there is significant interest in simpler computational imaging systems to correct image distortion.



Computational Imaging. Image Credit: University of Glasgow

Finally, calibration and validation of remote sensors is a big challenge. To verify data quality there are major challenges in calibration and characterisation of the equipment to understand the uncertainties in the system. Better understanding of the processing chain is also needed. Long-term calibration of sensors is a big challenge to correct for any drift in sensitivity over time. It is not only the accuracy of the data that is important. There is a growing interest in whether more knowledge can be extracted from the data with a better understanding of the calibration.



Truths Mission Concept – Calibration of EO instrumentation in orbit, traceable to SI standards. Image Credit: NPL

Addressing the challenges of increased performance and miniaturisation in Earth observation instrumentation requires improvements in a wide range of enabling technologies, which are also directly applicable to terrestrial remote sensing systems. The CEOI-ST programme is always seeking high quality proposals for projects that are aligned with these objectives.

Further information about this and previous Industry Consultation Workshops can be found at www.ceoi.ac.uk. The website also includes information on the wide range of projects and programmes funded by the CEOI-ST. You can also contact the CEOI-ST Director, Professor Mick Johnson: Tel: +44 (0)1438 774421 or email: mick.johnson@airbus.com

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[i] *A CGI representation of the alleged Viking site at Point Rosee. Image credit: WGBH Educational Foundation*

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