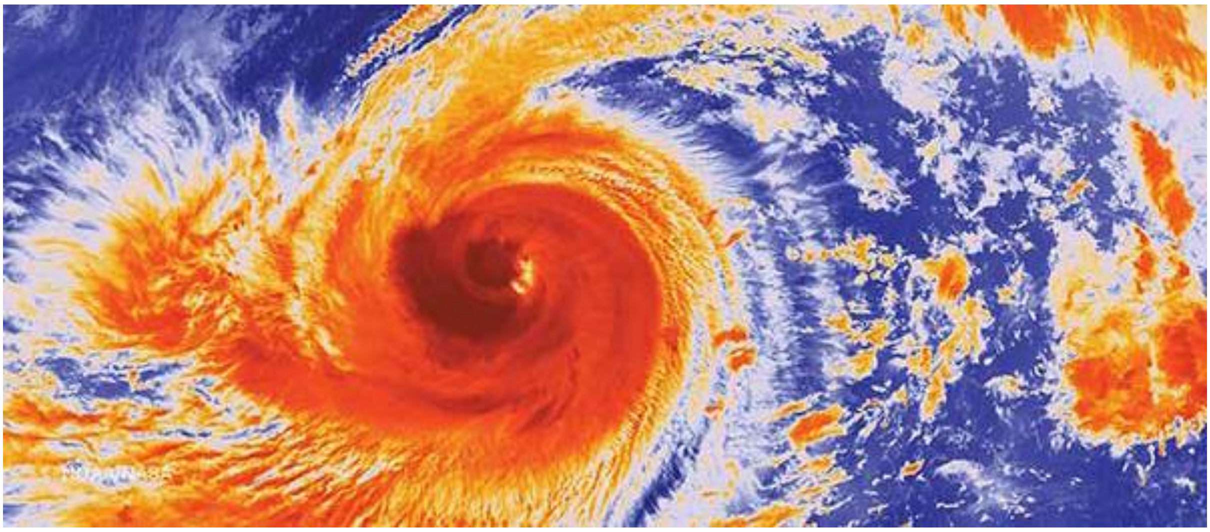
Autonomous Remote Sensing – A Tale of Evolving, Emerging and Converging Technologies



Remote Infrared Image of *Typhoon Phanfone – Source: Photonics.com*

Traditionally, remote sensing has been defined as the acquisition of information about an object or phenomenon without making physical contact. However, the emergence of new sensing techniques, miniaturisation of electronics, more powerful software, and an ever-increasing range of applications has led to this definition being expanded to include terrestrial based remote sensing and remote embedded sensing. At the same time, the emergence of technologies and applications for autonomy have led to a dramatic expansion in the use of remote sensing technologies in these autonomous systems and to the development of remote sensing systems that are themselves autonomous. Autonomous remote sensing systems (ARS) are the culmination of long-term development of existing technologies, emergence of disruptive new technical capabilities, and convergence of sensors, optics, electronics, and communications technologies.

The term remote sensing when applied to space based or aerial sensor technologies refers to the detection and classification of processes and objects on Earth (atmosphere, oceans, surface) by means of propagated signals (e.g. electromagnetic radiation). It is split into active remote sensing, when a signal is first emitted from aircraft or satellites (e.g. radar or lidar) or passive remote sensing when naturally occurring signals are recorded (e.g. from reflected or scattered sunlight). However, in recent years the definition has been extended significantly to new sensing modalities as the range of applications has developed. These include:

- Terrestrial Based Remote Sensing – instruments traditionally deployed on spacecraft or aircraft are being deployed in ground based applications, e.g. for continuous monitoring of urban air quality or security threats.
- New Applications of Remote Sensing – there are growing requirements to analyse and monitor different structures. Examples include the monitoring of tunnels or viaducts using remote sensing techniques to efficiently manage their construction and operation.

CityScan Air Quality Monitor - Source: University of Leicester

• Remote embedded Sensing – while remote sensing has traditionally been completely stand-off, the definition is now evolving to include the use of embedded sensors to remotely monitor structures and environments which are hazardous or difficult to access. Sensors are embedded at the point of interest and the data is transmitted to a central point for processing, analysis, and action, e.g. aero engine combustion chambers, rail track, and nuclear reactors. The challenge being addressed is sensing / monitoring from a distance of environments which are difficult to access with conventional sensors / instruments due to distance, scale (1000 km), environment (temperature / radiation / pressure), etc.

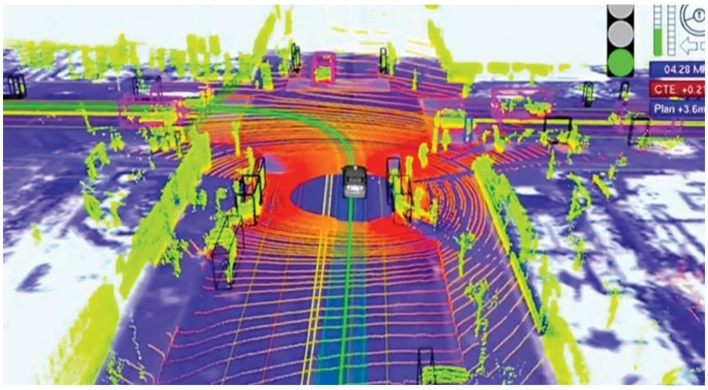
Autonomous Manufacturing - Source: Politforums

While remote sensing technologies have been evolving over several decades, capabilities in Autonomy have emerged rapidly over the last few years. Autonomous systems technologies are truly transformational with benefits in cost / risk reduction and can enable entirely new capabilities in applications where direct human control is not possible due to inaccessibility, speed of decision making, or other human limiting factors. They have traditionally been used in situations where great precision and accurate repetition is important such as manufacturing and assembly. Autonomous systems are finding new applications in hazardous or challenging environments and areas where human lives may be exposed to greater risk. Examples include autonomous submarine vehicles for deep sea exploration and maintenance in oil and gas facilities, or remote systems conducting maintenance and repair in nuclear contaminated areas and lunar and space exploration. But the disruptive future applications of autonomous systems will be in “systems of systems” such as intelligent transport systems across an entire region or cost-effective management of integrated healthcare systems, from tele-diagnostics through stratified medicine and hospital admission to aftercare.

Sensor Web Project – Source: NASA

Applications for ARS systems already exist, for example in monitoring volcanoes and other terrestrial features (where embedded sensor networks trigger satellite sensing as necessary), and autonomous remote water level gauges for tide and wave heights. Maintenance and monitoring of assets in challenging and extreme environments is of great interest and the energy sector has a particular interest in the application of this technology in oil and gas, off shore, nuclear and subsea systems. Extreme environments include those dangerous and unsafe for human access, remote or difficult to access locations, and environments that are particularly challenging such as extreme temperature, chemical conditions, pressure or radiation.

At the same time, there is a convergence of ARS systems and autonomous vehicles, both in the use of ARS to provide situational awareness to the autonomous vehicles (Lidar, Radar, IR, optical, sensing) and for autonomous vehicles (cubesats, UAVs, vehicles, ships) to provide mobility platforms for ARS systems. Applications include precision farming, forestry, monitoring of critical infrastructure, fire detection and flood monitoring, bio-security, and security /law enforcement.



Lidar ARS in Autonomous Vehicle – Source: Velodyne

A recent Centre for EO Instrumentation (CEOI) workshop discussed future applications of autonomous remote sensing in a wide range of sectors and found opportunities that will take the technology into major new markets. In aerospace, services are becoming increasingly important to engine manufacturers wishing to maximise revenues while maintaining functionality and quality. To do this, real-time remote sensing of all parts of the airframe and engine are required (condition monitoring) to optimise operation and maintenance.

There is a movement away from man-heavy to man-light operations in the defence and security sector with an increasing need for remote sensing to monitor situations / environments on a continuous basis to provide situational awareness. However, this often requires a rapid refresh or continuous temporal monitoring due to the nature of the threats, which makes it difficult for satellites to be used. Remote sensing from satellites and aircraft can be used to spot things like clandestine laboratories as they are relatively slow to appear but other approaches are needed for rapidly evolving situations.

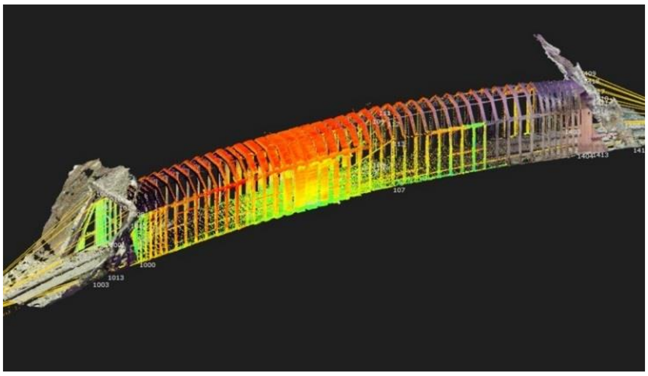
A major challenge for the defence and security forces in using ARS is finding rare events in very large data sets. Improved data processing, fusion, analysis and interpretation techniques are needed before remote sensing will become really useful.

In the maritime world, there is a growing interest in autonomous operation and swarms of vessels. This change in operation will give rise to a number of challenges, especially navigation of autonomous ships in contended and chaotic areas such as the Solent.

Autonomous Cargo Ship – Source: Rolls Royce

There are three major areas in the Oil & Gas sector where improvements in ARS are needed. First is sensors & intelligence in the drill head; intelligent drill bits can enable better control of the drilling process, and on-board data processing can reduce the amount of data to be transmitted to the surface. Second, communications are an issue as data transfer has low bit rates due to sonic modulation, and electrical connections are not reliable. The ability to transfer much larger amounts of data to the surface from intelligent drill bits will significantly improve drilling operations. The big prize is to avoid withdrawing the drill bit. Third is autonomous processing of seismic survey data which currently requires human intensive pre-processing.

In the rail sector, embedded ARS systems are increasingly needed for asset management, where fixed assets typically have a 120-year lifetime. Trains could check their own infrastructure with data capture while on the move. The technology exists but it is hard to retrofit, leading to adoption only in new projects such as HS2 and HS3. Communications is a big issue for these applications, as data download is a challenge when travelling at 100m / sec. Another application is autonomous remote monitoring of tunnels under construction, a dangerous environment. Maintenance of tunnels over long periods whilst in operation are also a challenge. Ideas under consideration include computer vision to monitor change, and 3D mapping with defect analysis to monitor tunnels at a larger scale.



Rail Tunnel Scan – Source: Leica

"Data as a service" is also beginning to emerge as an alternative to traditional approaches where organisations run their own ARS systems or buy datasets from such systems. ARS could be as service in its own right (e.g. topographic data / pollution monitoring) or to enable another service offering, e.g. condition monitoring as part of an equipment maintenance service. The challenge will be to acquire appropriate data with sufficient "value add" to enable a viable business model.

While these future applications provide great potential for ARS systems, there are many technical challenges still to be overcome if they are to be practical. Airborne and space borne remote sensing platforms often incorporate in-scene ground truth measurements as a means of calibration and increasing the robustness of the model used to extract information from the imaged scene. In many of these future applications, it will often be impractical to utilize human observers for ground truth measurements due to temporal and physical restrictions. An in-situ sensor network may be needed to replace human observers, which could also provide a rich stream of data autonomously. This can enhance the product produced from the ARS platform.

Chicago Wireless Sensor Networks – Source: Autodesk

Fusion of data from satellite, UAV and ground sensors to give high quality data and information is a major challenge. Other major data challenges include management and analysis in real-time monitoring, and security to ensure sensor systems are resilient in the face of cybersecurity threats

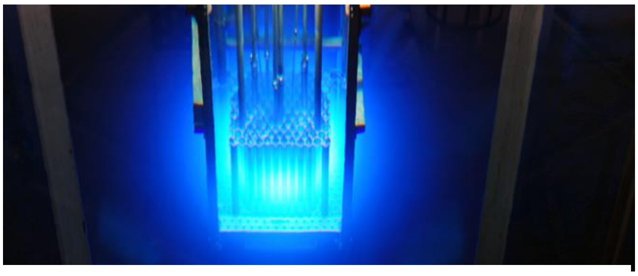
Power harvesting / scavenging will become increasingly important as autonomous remote sensing systems are deployed into a wider range of applications. Remote locations without power have obvious issues, but the bigger challenge is for wearable systems developed to aid

Armed UK Police Officers on Duty – Source: Commons Wikimedia

police, soldiers or workers whilst operational. Such systems could provide critical information but the power issues will need resolving before effective widespread adoption can take place.

Artificial Intelligence is seen as vital for ARS, but there are a number of challenges that need to be addressed, including "what needs to be sensed"; "how to handle large data sets"; "monitoring of the sensing system itself"; "identifying complex solutions from large data sets"; and "situational awareness". There is the potential to generate huge volumes of data, but with fewer people affordable to process the data, machine learning paradigms to extract the relevant information will be needed. AI should be able to reduce processing time and level of false positives, undertake auto labelling / auto feature analysis, and flag anomalous events, thus enabling effective automatic learning and decision making tools.

There are several challenges relating to autonomy in ARS systems. Autonomous determination of when to sense, selection of relevant spectral bands, and selection of relevant spatial regions are all of interest. Autonomous management of data processing, communications, self-forming networks, and navigation in difficult environments are enabling capabilities that need further development. Autonomous scene selection is of major interest. When combined with machine vision & photogrammetry for autonomous feature extraction and SLAM (simultaneous localization and mapping) techniques suitable for the built environment, it builds a powerful capability for practical applications of the data.



Breazeale Nuclear Reactor Core– Source: Pen State University

Reliability and robustness of ARS systems over long periods will be an issue, especially in hostile or mobile environments. Equally, the quality of the data acquired over long periods will also need to be validated. Software standards are also required for effective validation and verification of ARS systems. Validation methods and processes for autonomy are not good enough at present. While the automotive and aircraft sectors use utilisation time (just drive/fly for many hours), this is not possible for many applications. Development of an evidence base that could be shared by all sectors would be of great value.

The wider implications of the adoption of ARS systems have yet to be addressed. Small, closed loop systems used in, for example, aero engines have few wider implications, but large, open loop systems have many societal, legal, trust, security and ethical challenges that have yet to be resolved. Bishop's paper in Cultural Politics – *"Smart Dust and Remote Sensing, The Political Subject in Autonomous Systems"* starts to examine these issues and discusses the failures of ARS systems used in the Vietnam war caused by a lack of understanding of the outcomes of autonomy and the vulnerability to manipulation and deception by the enemy. Cyber-attack and warfare are the contemporary manifestations of these challenges.

And ethical considerations of using ARS systems are yet to be addressed. Where do we still need human judgement in the loop and where can humans bow out safely? There is an important distinction between “decision support” and “decision making” in such systems with significant legal and regulatory implications. These issues will need clarifying early in the development of any “decision making” systems.

Self-Organising Autonomous Robots– Source: Phys.org

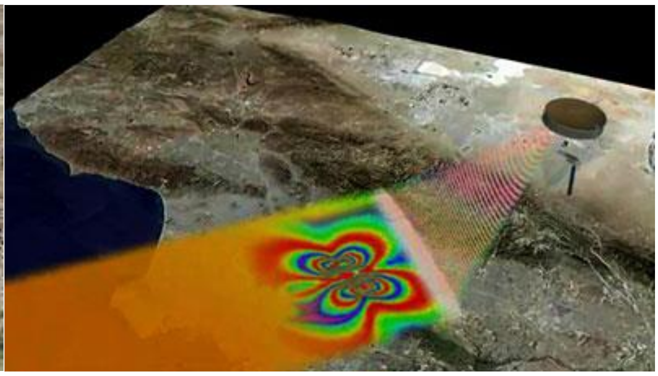
Societal acceptance of these systems cannot be taken for granted either. We have already seen major resistance to the deployment of drones and the public use of Google Glasses. Human interaction with and trust in autonomous systems will become a major issue. How easily humans can interact with ARS systems and the accuracy and reliability of the data produced will determine the level of trust we have in them. Performance evidence for users and regulators will become critical in addition to the normal HMI issues that are likely to arise.

Finally, legal issues resulting from actions or decisions based on the use of autonomous remote sensing analysis have yet to be identified and clarified. Certainly, traceability of the data from sensor to answer and validation of each step from acquisition decision making will be essential.

Autonomous remote sensing systems have the potential to improve the performance of many industries through new products or improved productivity and the effectiveness of significant parts of society. However, more than just technical progress will be needed. Challenges in trust, law, security and ethics must be addressed before the world can fully benefit from this emerging technology.

Further information about the work of the Centre for Earth Observation Instrumentation 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. You can also contact the CEOI Director, Professor Mick Johnson: Tel: +44 (0)1438 774421 or email: mick.johnson@airbus.com.

Autonomous Tractors Spraying Texas Vineyards– Source: Wikipedia



InSAR Mapping Transport Infrastructure – Source: US Dept. of Transportation