Integration of Satellite Imagery and Other Tools in Safeguards Information Analysis

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Abstract:

This paper reviews the strengths and multi-dimensional nature of remote sensing, using examples taken from safeguards analyses of panchromatic, multispectral, hyperspectral and radar imagery carried out under the Canadian Safeguards Support Program (CSSP) in support of the International Atomic Energy of Agency (IAEA). A discussion of an integrated approach for information analysis, recent developments in imagery search capability, and strategy for leveraging of funding, information and talent is also included.

Keywords: remote sensing, Earth Observation, safeguards, imagery,

1. Introduction

In the last 3 decades, satellite remote sensing (technically Earth Observation, or EO) has come into its own as an essential data gathering technique in many disciplines. It is now becoming an important tool for the IAEA - particularly since the advent of open-source high spatial resolution imagery in 1999. There are several characteristics of EO data that have combined to make it indispensable for the IAEA. EO provides:

- Wide area synoptic coverage of any location on the globe
- Access to remote or inaccessible areas and trans-boundary analysis (often the only practical way of gathering information)
- Temporal monitoring and change analysis
- GIS compatible image maps of varying scales

The Canadian Safeguards Support Program has carried out many case studies to investigate the application of commercial satellite imagery for international safeguards. The main focus of our work has been on the detection capability of optical and radar satellite sensors.

2. EO data for Safeguards

EO data are provided by a host of different sensors, operating at a variety of scales and sensing many different phenomena. In an attempt to simplify, we will describe EO data as having three relevant "dimensions":

2.1. The spatial dimension of EO

Cues such as shape, size, pattern, texture, shadow, tone and association are used by image interpreters to ***identify objects and phenomena*** in imagery, via the technology of 'image interpretation'. For the image interpreter, the higher the spatial resolution of the imagery, the easier it is to interpret. High-resolution black and white photography, and more recently digital imagery have been the main data source for military and IAEA image interpreters for many years.

Figure 1. A high resolution EOS satellite image of the sarcophagus encasing the damaged nuclear reactor at Cherobyl, Ukraine [1].

2.2. The temporal dimension of EO

Image analysts make use of sequences of images taken at different times, thus permitting ***change detection***. Of course, change detection analyses do not always have to be carried out with high-resolution imagery. Figure 2 illustrates large changes at Ranger mine, in northern Australia between 1989 and 2001, using 30m 'false-colour' Landsat imagery.

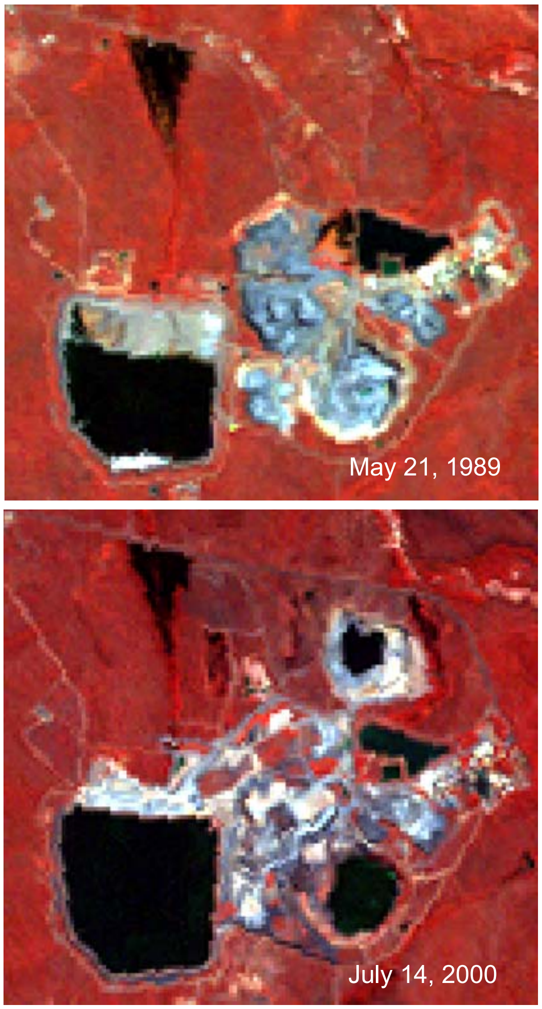

Figure 2. A pair of Landsat images illustrating many changes at Ranger mine, Northern Australia, between May 1989 and July 2000.

2.3. The spectral dimension of EO

There is a growing family of satellite sensors operating in different parts of the electro-magnetic spectrum, providing many very different and complementary types of information (figure 3).

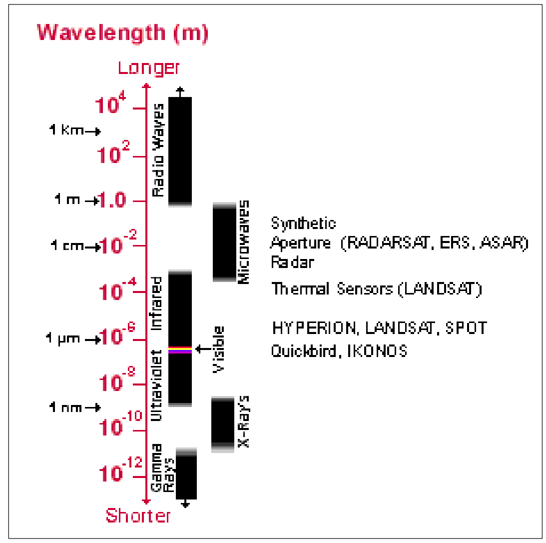

Figure 3. The electro-magnetic spectrum, with regions useful for remote sensing marked, and some representative Earth Observation satellite sensors - modified after CCRS [2]

Colour: Of increasing importance in the past few years, multispectral and hyperspectral imagery permits ***identification of materials or physical/chemical properties***. Spectral bands carry information to enhance visual interpretation and permit multispectral and hyperspectral analysis.

Colour adds greatly to the interpretability of an image. More spectral bands allow more detailed analysis. In Figure 3, the addition of false colour (centre) greatly accentuates the presence of vegetation and other materials, even though the spatial resolution has been reduced from 1m to 4m. The bottom panel illustrates the results of a analysis with 30m hyperspectral imagery in which the ore dust is differentiated from the fertilizer dust on the basis of their spectral signatures. Both dusts are bright and cannot be differentiated on the basis of brightness alone.

Multispectral sensors, as their name implies, provide imagery in several, usually 3 to 10, wide spectral bands or colours – not necessarily within the same spectral range as the human eye. 'False colour' imagery implies that the spectral bands are depicted in a way that is not natural, most often referring to images in which a near-infrared band (in which vegetation is very bright) is depicted as red. In such false colour images, vegetation is clearly differentiated from other materials by its red colour.

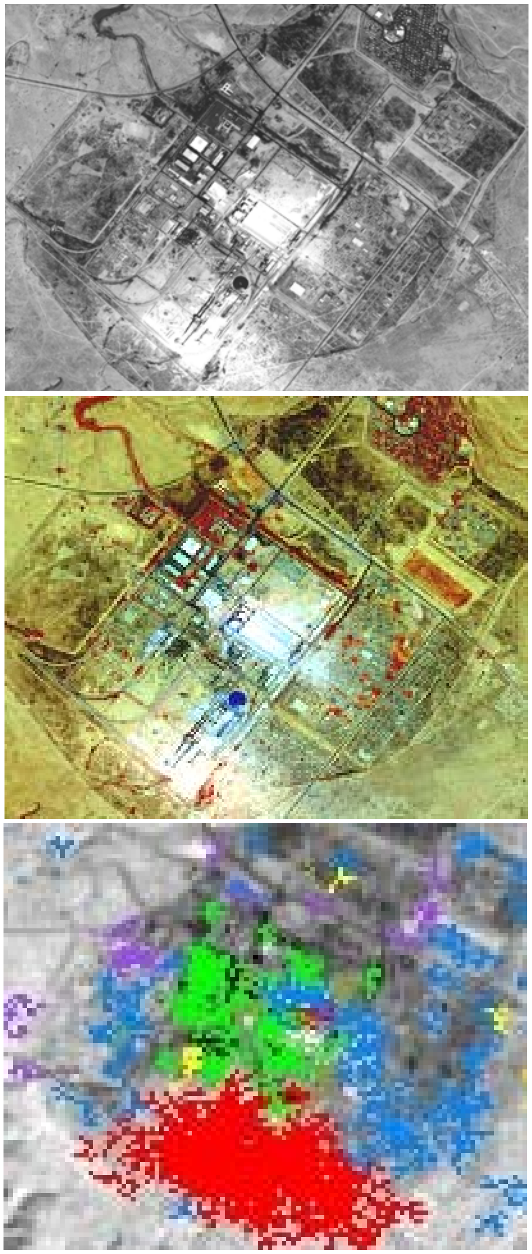

Figure 4. Top: 1m panchromatic image of a fertilizer plant in the Middle East. Centre: 4m false-colour image showing vegetated areas as shades of red; Bottom: 30m hyperspectral classification differentiating raw ore (red) from fertilizer (green) on the basis of their spectral signatures.

Hyperspectral sensors like HYPERION on the American EO-1 satellite provide up to 200 narrow spectral channels (usually in the 400 to 2500nm spectral range) permitting extremely detailed geological and other analysis. Figure 5 illustrates why hyperspectral analysis can easily overcome the difficulty in differentiating fertilizer, cement, phosphate ore concentrate, limestone and fertilizer stockpiles at the site in figure 4. These materials all look similar in the range 500 to 1000nm, but are quite different in the near short wave infrared region above about 1250nm.

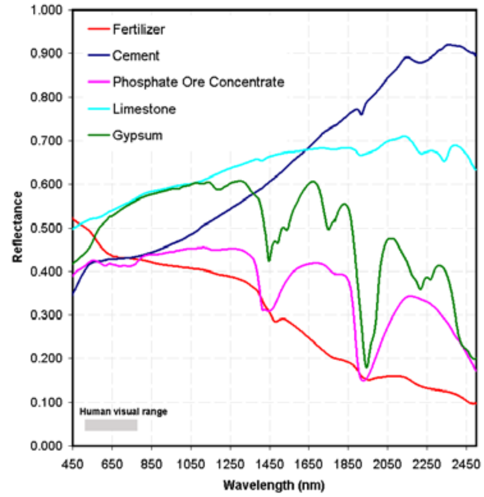

Figure 5. Reflectance spectra of several materials found stockpiled at the industrial facility in figure 4.

Temperature: Sensors operating in the thermal infrared region around 10 to 12 μm, can image heat. While it is difficult to measure temperature over land targets unless the emissivity of the surface is known, water is a different case. The emissivity of water is close to unity, and the surface temperature of water bodies can be estimated with good accuracy if an atmospheric correction can be made. Even in the absence of an accurate atmospheric correction, relative temperature variations can be mapped. Thermal and colour signatures of water bodies provide important clues to activities in the vicinity of industrial facilities such as the Bruce Nuclear Power Plant, (Ontario, Canada) in Figure 6. At this time Bruce A was operating, but Bruce B was shut down.

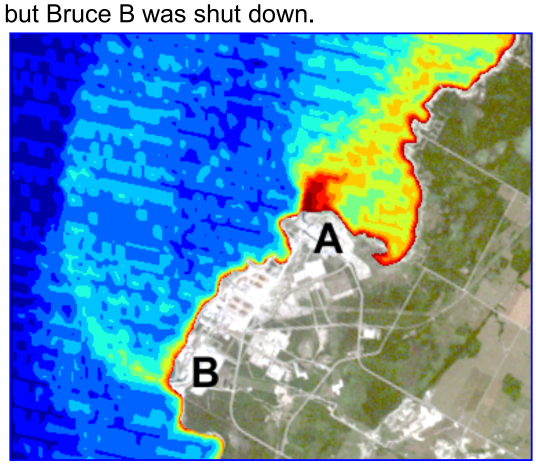

Figure 6. Relative thermal Discharges indicate operational status of the Bruce Nuclear Power Plant August 2, 1988. Red = hot, blue = cold.

Radar: While it does not replace high-resolution optical imagery, Synthetic Aperture Radar (SAR) imagery is a very important safeguards tool for three reasons:

- SAR can penetrate clouds and night.
- SAR imagery provides information on objects and structures, complementary to that from optical imagery.
- The radar phase can be exploited to reveal otherwise invisible phenomena such as surface subsidence or disturbance.

Persistent cloud cover is a fact of life in many parts of the world, and at high latitudes, night or low sun angles prevail for much the year, preventing optical surveillance for long periods and making covert activities difficult to detect. Figure 7 shows two radar images of a Canadian hydroelectric reservoir acquired in the evening and on the following morning. The change in water area was due to discharge of the reservoir through the day and recharge of the reservoir overnight. Parts of the bottom of the reservoir are visible at low water, but are submerged at high water.

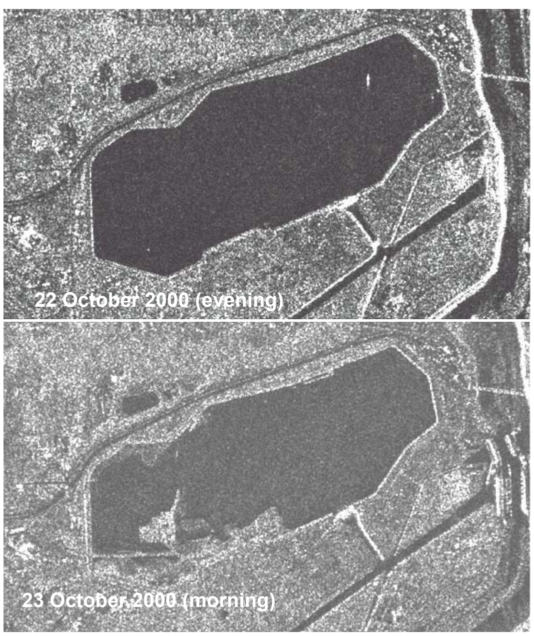

Figure 7. Radar detection of changes in water level of the Sir Adam Beck hydro reservoir (Ontario, Canada).

It is worth noting that detection of ships and marine structures at sea is a major application of SAR, and this may play a role in safeguarding remote sites accessible by sea. Clouds are persistent over most of the world's oceans.

Figure 8 compares an optical image taken by a high-resolution optical satellite with a moderate resolution radar image of the same site in India. While the optical image is very useful and is easier to interpret, some man-made structures such as buildings and metal fence lines show up especially well in the radar image despite the lower resolution.

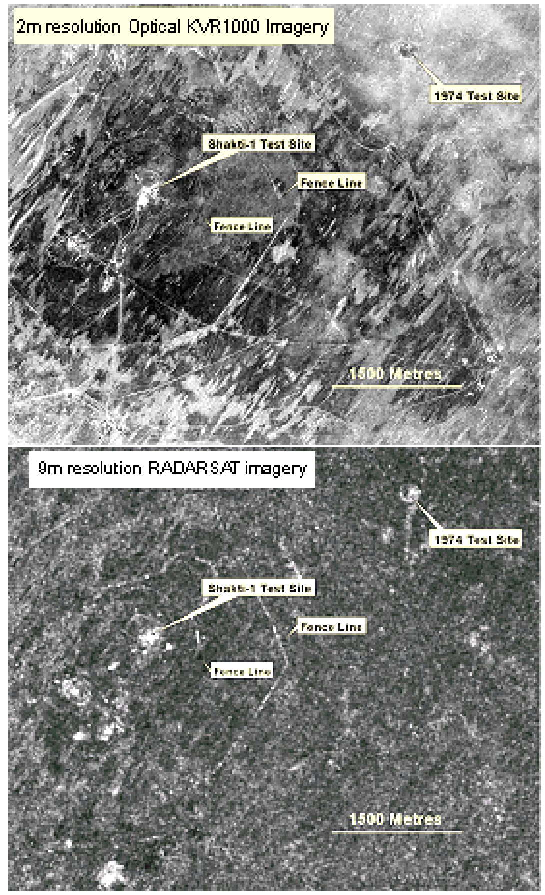

Figure 8: Optical and radar images of the Pokhran test range in India.

Some phenomena that are literally invisible in optical imagery are revealed by SAR imagery by virtue of analysis of a property of the radar image data known as *phase*. Exploitation of the phase information in SAR images is most widely described as part of the field of **interferometry**, in which multiple SAR images taken from slightly different flight paths (ordinarily on different dates) can be used for applications such as:

- Generation of digital elevation models
- Detection of subtle ground subsidence or uplift (for example, related to tunnelling or changes in the size of ore stockpiles)
- Detection of disturbance of the ground surface by passage of vehicles, tillage, excavation etc (Figure 9).

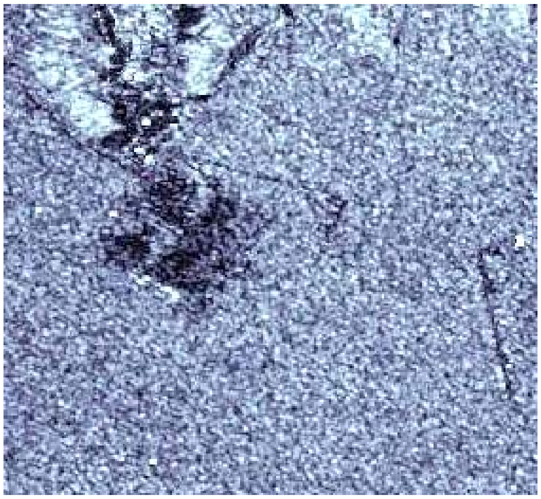

Figure 9. Ground disturbance at the Bullfrog mine, Nevada mapped using RADARSAT fine mode.

3. Integration with Other Tools

It is self-evident that transformation of data and information into knowledge forms the basis for sound decision-making. However the overall approach is important. Search for imagery and other information should not be carried out in isolation, and analysis of information must be carried out with appropriate tools, and by a team of analysts with complementary skills and expertise. A common platform will be useful to bring together all functions such as search, analysis, visualisation and sharing of results with other analysts and decision makers.

3.1. Recent Developments in Interactive Image Visualisation

Recent developments in freely available interactive software such as **GoogleEarth** [3], **WorldWind** [4] and **VirtualEarth** [5] that allows easy viewing of maps and satellite imagery draped over Digital Elevation Models are also relevant to Safeguards applications. GoogleEarth is fast and has more recent imagery than WorldWind and is neatly linked to image ordering of high resolution Quickbird satellite imagery from Digital Globe Inc. However, upgrades to the basic package (that allow GPS tracking, movie making etc) are licenced for $400/yr. WorldWind is a completely free open source program from NASA, but is slower. MSN VirtualEarth is much more limited. While all three are offered to the public for educational purposes, they are extremely useful for anyone requiring a geographical introduction to a new site. None of them is secure, and should not be used for mission critical work, but offer a new way of viewing the earth to everyone with Windows XP or 2000 personal computers.

Developed by GeoTango International **GlobeView** [6] is a commercial program providing similar search capability with the same look-and-feel as GoogleEarth and WorldWind. However, it is designed with an open architecture and links to various data servers such as USGS, NASA, Space Imaging, etc. It can also be linked with networks of sensors, e.g. surveillance cameras, radiation detectors and various others. GlobeView is capable of working with data sets of unlimited size. Map and image data, 3D models and terrain data can be delivered to a wide variety of clients over distributed networks.

Site analysis requires visualisation of large images, terrain data and 3D models. While 2D methods for displaying such data exist, they are often not suited for displaying complex terrain surfaces. Today's 3D visualisation systems suffer for various reasons. Many are not network based, making it impossible for personel to share and update incoming data to multiple stations or field units. Many 3D systems are not multi-resolution, making analysis of a point of interest at both global and a local scales tedious, if not impossible. Systems currently in use that are both network ready, and multi-resolution suffer some of the greatest flaws, a lack of interoperability. To provide high performance visualisation, these systems must rely on proprietary data storage formats, making their data hard to manage, update, and share with other existing Geographic Information Systems (GIS). GlobeView is one of the key components of the integrated information portal discussed below.

3.2. Integrated Information Portal

The Canadian Safeguards Support Program has been sponsoring development of an Integrated Information Portal (IIP), with the goal of developing an easy-to-use and effective on-line tool to support timely decision-making [7]. The system utilizes state of the art geospatial tools, ESRI ArcIMS Web Services and GeoTango GlobeView.

OpenSource Explorer and GlobeView are used to support enhanced data access to multiple data sources over the Internet, fast data discovery and search and 2D/3D on-the-fly visualization. The prototype implemented has demonstrated many valuable capabilities for nuclear safeguards applications. Additional tools can be linked to the IIP for network and consequence analysis, and their results displayed using appropriate visualisation technology.

4. Concluding Remarks

The satellite image toolbox available to safeguards analysts is growing quickly. While analysts are still focused on visual interpretation of high spatial resolution black and white imagery for identification of objects, the addition of colour, hyperspectral and radar sensors has greatly increased the capability of the analyst to identify surface materials, chemistry and other physical phenomena.

We can expect greatly increased Earth Observation capacity and capability in all three dimensions in the near future. Many companies and national governments are launching mini-satellites with high spatial resolution panchromatic and multispectral sensors that will be of use in safeguards. Several countries, including Canada, are planning operational hyperspectral satellites with higher sensitivity, increased data storage and downlink capability, wider swath and higher spatial resolution than is presently available from the experimental HYPERION sensor. Canada's RADARSAT-2 and the German SAR satellite will have greatly increased spatial resolution as well as multi-polarisation.

Of course, satellite imagery is only one kind of tool, and must be used in conjunction with other on-the-ground sensors, cameras and inspectors. Optimally, it will be integrated with other tools such as Geographic Information Systems (GIS), 3-D viewing, consequence analysis, in a common Information Portal that permits co-ordination, collaboration and sharing of knowledge and feedback between imagery analysts and a network of experts to support on-site verification. Collaboration with others and leveraging of both funding and expertise would greatly assist the IAEA carry out its mandate in an effective and efficient manner.

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