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SATELLITE SURVEILLANCE AND CANADIAN CAPABILITIES

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HISTORY OF REMOTE SENSING AND SURVEILLANCE

In 1959, the US satellite Explorer-6 transmitted the first known photograph of the earth taken from space. A year later, in April 1960, the first of the TIROS weather satellites was launched into space and began feeding meteorological data to the earth. Its circular orbit was at an altitude of 830 kilometres, which is typical for a remote sensing mission. TIROS-1 lasted only 89 days, and the image resolution from its two TV cameras was only one kilometre, but it confirmed that earth observation by satellite had great potential. With succeeding spacecraft, each with better instrumentation, the public soon became familiar with satellite weather reporting.

In the US manned space programme, the Mercury astronauts had taken intriguing pictures with hand-held cameras and subsequently, in June 1965, the first systematic photography of the earth's surface was begun by Gemini astronauts J.A. McDivitt and E.H. White. The usefulness of their initial 39 overlapping area colour photographs prompted a continuing Gemini, and later Apollo and Skylab, remote sensing programme.[1]

During that time the US and USSR had also been developing national security satellite surveillance technology ("Surveillance" is the military's equivalent to the scientific community's "remote sensing".) Airborne surveillance had its start in 1859 when aerial photographs were taken from a balloon, near Paris. The new technology was first applied just a few years later, in the US civil war. Photo-reconnaissance became a sophisticated craft in subsequent wars and significantly, for the yet-to-come satellite era, imaging radar and colour infrared photography were developed during World War II.[1] In 1956 the US began U-2 photo-reconnaissance overflights of the USSR and these continued until May 1960 when Francis Gary Powers was shot down by a Soviet missile at 70,000 feet. While this was a headline event, the fact is that over forty other US and allied reconnaissance aircraft had been shot down since the late 1940's.[2] The cessation of the U-2 flights coincided with the maturation of satellite technology, which was believed to be more useful for three reasons: satellites were then invulnerable to attack, they could cover larger areas, and they were not as provocative as manned aircraft overflights. In March 1955—two years before Sputnik—the US had embarked on a CIA-sponsored programme to develop satellite surveillance technology. The first reentry film package was recovered from the Discoverer 13 satellite on 11 August 1960. As John Kennedy began his presidency the alleged "missile gap" between the US and USSR was proven untrue by surveillance. By 1963, both "area surveillance" photos and "close look" photos were being obtained. The USSR's Kosmos programme began during that same era, and we can speculate that the quality of information was similar to that of the US. American and Soviet technological capabilities in surveillance gave both nations the confidence to enter the Strategic Arms Limitation Treaty (SALT) negotiations in 1969.[3]

The parallel development of surveillance and remote sensing technology continued. In the US, information on the technology was shared, subject to security classification, between NASA and the Air Force. The USSR does not divide its space efforts into civilian and military agencies.

By 1971 the US was flying 20,000-pound "Big Bird" surveillance satellites in near-polar orbits, typically with apogees (the highest point of the orbit) at 290 kilometres and perigees (the lowest point of the orbit) at 180 kilometres. At these low altitudes such large objects reenter the atmosphere quickly due to air drag; the lifetimes of the first three "Big Birds" were 52, 40 and 68 days respectively, while the USSR's equivalent spacecraft lasted an average of two weeks each! Consequently the USSR launched 395 surveillance satellites between 1960 and 1977, while the US launched 227.[2] It was after the July 1966 launch of the KEYHOLE-8 (KH-8) "close-look" inspection satellite, that the US reportedly believed its photographic images were sharp enough to consider the possibility of monitoring arms agreements. In December 1976 the US's first electronic-imaging photo-reconnaissance satellite, KH-11, was launched. It was also the first to transmit its images to earth by digital telemetry and its orbit could be adjusted using an on-board propulsion system. Consequently the satellite's lifetime was dramatically improved, with some KH-11's lasting for over two years.

Throughout the 1970's and up until the recent Shuttle and Titan losses, the US continued launching Big Bird and KH-11 satellites. During the same period the "Rhyolite" and "Chalet" series of geostationary satellites for intercepting communications also became operational.[4] The US may currently be flying spacecraft with high-resolution imaging radars, as part of the "Clipper Bow" programme, which was reported to have begun in 1983[5], although this has not been confirmed.[4] The next generation surveillance satellite is KH-12, which is so large it will fill the entire Space Shuttle. It will have both close-look and area-surveillance capabilities, and it will also carry infrared imaging instruments.[4]

During the 1970's the USSR reportedly used surveillance satellites which returned film to the earth, however they are currently using electronic imaging with signals that are digitally transmitted to earth. In addition, the USSR has two constellations of communications-interception satellites, operating in near-earth orbits.[4]

For civilian applications, the US developed the Earth Resources Technology Satellite (ERTS) in the late 1960's, and in 1972 the first ERTS satellite, renamed "Landsat", was launched.[1,6] This was the beginning of a very successful programme that today provides information to subscribers in many countries. Seasat, launched in 1978, demonstrated the potential for oceanographic imaging radar. The USSR's nuclear powered Kosmos 954, which broke up over Canada in January 1978, was also equipped with an ocean-imaging radar.[5] The most recent remote sensing system is France's "Système Probatoire d'Observation de la Terre" (SPOT) which was launched in February 1986 and is now providing the highest resolution imagery available commercially.[6,7]

CANADIAN SPACE TECHNOLOGY

On 28 September 1962, a US Thor-Agena rocket launched a Canadian satellite from Vandenberg, California. Canada became the third nation into space, after the USSR and the US. The first four Alouette and ISIS satellites were used for scientific research. They featured radar-like instruments called "topside sounders" to study the physics of the radio ionosphere. Canadian capability in space technology subsequently flourished through the 1970's and 80's, within both government and a maturing private sector high-tech industry. Preceded by work under the Department of National Defence (DND), the Department of Communications (DOC) developed communications satellite technology and Canada became a world leader. Telesat Canada began operating the world's first domestic system in January 1973 with the launch of ANIK A. During this same period, Canada's National Research Council (NRC) fostered the development of Canadian space science instruments, the Canadarm, our astronaut programme and our current role in the US Space station.[8] Canadian universities, such as York, Calgary and Saskatchewan developed space science excellence, but, as part of NATO and NORAD, Canada relied on US satellites for surveillance and early warning.

An active Canadian remote sensing community also developed during this time, spawned by the needs of a large land, rich in resources. In May 1971 Canada and the US began a cooperative programme using aircraft, and subsequently spacecraft, for remote sensing. Within government, the Canada Centre for Remote Sensing (CCRS)—part of the Department of Energy, Mines and Resources—fostered the development of remote sensing technology and promoted the growth of the industry in four areas: instrument development, surveying, ground processing of data and application of remote sensing to diverse economic sectors. Today Canadian products, particularly image processing systems, are sold throughout the world and the Canadian Remote Sensing Society is an internationally recognized organization with over 600 members.

There is no inherent difference between national security surveillance technology and remote sensing technology. The types of instruments, the design principles and many of the components are identical. The differences are of degree: surveillance programmes generally require higher resolution, the instruments are often physically larger and they require more electrical power and larger launch vehicles. For surveillance missions the ground processing and data analysis can require more labour and equipment, and the required "turn-around" time between the acquisition of the data and its analysis on the ground is likely to be shorter. For both sectors, earth observation satellites can be divided into six categories based on their function:

- remote sensing of the earth and oceans for scientific and commercial uses
- national security (military) surveillance
- early warning
- meteorology
- navigation, positioning and surveying
- treaty verification surveillance

VERIFICATION

> *"Verification with regard to weapons that are destroyed or limited would be carried out by both national technical means and through on-site inspections. The USSR is ready to reach agreement on any other additional verification measures."*
>
> —Mikhail Gorbachev
> 16 January 1986[4]

Verification has been an underlying—and possibly the most important—issue in negotiating arms limitation, test ban, non-proliferation and other types of treaties. The signing of the Limited Test Ban treaty in 1963 demonstrated that "National Technical Means" (NTM) had been developed to such a degree that both the US and USSR felt confident that they could detect non-compliance with the treaty. The Non-Proliferation Treaty (NPT) was signed in 1968 and by 1985 there were 130 signatories, including Canada and three of the nations possessing nuclear weapons: the US, the USSR, and the UK. The two other nuclear states, China and France, have not signed the treaty. Nor have many "near-nuclear" states such as Israel, India and Pakistan.[9]

At the same time as the signing of the NPT, the US and USSR agreed to begin negotiating a Strategic Arms Limitation Treaty (SALT). In 1972 the Antiballistic Missile (ABM) Treaty and the Interim Agreement on Offensive Arms were signed.[2] The successor treaty, SALT II, became effective in June 1979, although the US Congress never ratified it. SALT II formally expired on 31 December 1985, but both countries agreed to continue adhering to its general terms. Under SALT II the US and USSR agreed to ceilings on specific weapons types based on the 1974 Vladivostok understanding between President Carter and Chairman Brezhnev. Strategic nuclear delivery systems such as heavy bombers, intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and air-to-surface missiles were limited by number.[2,3,10]

Technical means of verification include surveillance satellites, aircraft surveillance, listening posts and terrestrial instruments such as seismic sensors and radars. Non-technical means include on-site inspection plus methods such as economic analysis, content analysis of documents and speeches, interviews with travellers and emigrés and clandestine activities. The most reliable approach is to obtain data from multiple sources.

There are four problems associated with technical verification: the physical limitations of the technology, the capability to detect purposely hidden activities, protection if one party tries to confound or destroy the other's surveillance system, and finally—and perhaps most difficult—the objective interpretation of the data.

A good case can be made for the creation of an impartial surveillance programme, administered and staffed by people from countries other than the two superpowers. There have been several calls for such an organization. For example during the UN Special Session on Disarmament in 1978, France proposed the establishment of an International Satellite Monitoring Agency (ISMA), to operate under UN jurisdiction.[11] Similarly, in 1985, (US) Admiral Stansfield Turner—a former director of the CIA—proposed that the United States' technical surveillance information be made more widely available. He suggested the creation of an "Open Skies Agency", taking its name from President Eisenhower's 1955 proposal.[12] Even without such an agency, we are now aware of the existence and general capabilities of some of the US surveillance satellites, which up until a few years ago were totally classified. A group of six nations—Argentina, Sweden, Mexico, India, Tanzania and Greece—has offered to jointly administer an international monitoring programme.[4] In Canada the Department of External Affairs is sponsoring a study on a potential ground and space verification satellite system named PAXSAT. While not yet completed, the study will probably recommend a Canadian satellite equipped with a high resolution radar and imaging instruments, supported by a sophisticated ground system.[13]

WHAT AND WHO SHOULD BE OBSERVED?

Because the SALT treaties concerned strategic threats, "targets" such as ICBMs, strategic aircraft, SLBMs and launch facilities were the main subjects for verification. ("Target" is used, without innuendo, to denote the object being observed.) A more comprehensive verification programme would include observation of naval vessels, radar sites, chemical and biological weapons production, stockpiling, military installations, military land vehicles, and weapons facility construction. It would also be important to identify changes from one observation pass to the next, in order to identify a process or motion. Cruise missiles should also be observed. Current remote sensing technology is capable of observing them on the ground, but, because of their mobility and small size, they can easily be hidden in conventional-looking buildings. Furthermore, they require a much smaller "logistics trail" than ICBMs. Thus the cruise missile verification issue is controversial and probably cannot be addressed solely by technical means.[4,10] A number of other targets have been recommended; for example, nuclear reactors and uranium enrichment facilities could be observed to ascertain compliance with production limits of fissile material for nuclear weapons.[14]

Satellites with sensitive receivers that are able to cover large portions of the communications spectrum and large, high-gain antennas can intercept or "eavesdrop on" ground-to-ground and ground-to-space communications. While an international verification organization could technically do this, unless all parties—including the two superpowers—agreed to such monitoring it would not be practial diplomatically. In addition, there would be severe technical challenges due to the sophistication of equipment and the resources required to process and decode the data.

Any surveillance system for the late 1980's and 90's must be designed with the recognition that the environment which led to the treaties of the 1960's and 70's has changed. Monitoring strategic arms limitations and test bans between the US and USSR is still vital, but other targets must also be covered. Many nations and groups have increased their potential for initiating world crisis through limited military action, weapons build-up, guerrilla activity and terrorism. Consequently the system would have to be capable of observing all areas of the world, and objective presentation, interpretation and distribution of the data would be crucial.

WHAT DATA AND RESOLUTION ARE REQUIRED?

For some surveillance tasks it is adequate to detect merely the presence of an object or activity, while others require identification or even assessment of the target's dimensions. Table 1 shows the ground resolution (in metres) required for various targets, considering different tasks.[2]

Observing troop movements, especially in small groups, requires more precise resolution than for vehicles. For many targets "spectral" resolution (the ability to differentiate between particular wavelengths of light or other electromagnetic radiation) is as important as "spatial" ground resolution. Infrared detectors must be able to distinguish differences in temperature levels which are meaningful to the process under observation, and this usually requires resolution on the order of a few degrees.

TABLE 1 Resolution (in metres) Required for Different Verification Tasks

	TASK		
TARGET	*Detection*	*General Identification*	*Description*
Radar	3	1	0.15
Aircraft	5	1.5	0.15
Surface ships	8	5	0.3
Vehicles	1.5	0.6	.06
Roads	9	6	0.6
Submarines	30	6	0.6
ICBMs	3	1.5	0.3
SLBMs	30	6	1
Cruise missiles (estimated)	1.5	0.6	.06

FUNDAMENTALS OF A SATELLITE VERIFICATION SYSTEM

There are six key elements of a verification system:

- satellites
- satellite control and tracking station
- data receiving station
- data processing centre
- analysis and interpretation group
- information distribution network

The number of satellites and orbit selection is a trade-off among coverage requirements, resolution requirements, system lifetime and cost. Polar orbits have been used most often for surveillance missions because they allow coverage of the entire earth. Depending on the instruments' field(s)-of-view and the orbit altitude it usually takes several days, or even weeks, to observe everything. Other orbits such as equatorial and inclined elliptical orbits are useful for specific requirements. For example the USSR frequently uses "Molniya" orbits which are elliptical, inclined at sixty-five degrees or so, and have their apogees in the Northern hemisphere; they allow a good view of the North. As more satellites are added to the system, the time between repeated viewings of targets decreases and, depending on the orbits chosen, the global coverage can improve. With any orbit, instrument resolution improves if the altitude is lower; however the coverage area—or "swath width" per satellite pass—decreases, as does lifetime. As noted earlier, photo-reconnaissance satellites have very low orbits and short lives but they can produce pictures with resolution of less than ten centimetres. At the other extreme, geostationary satellites with orbits of 36,000 kilometres—used for meteorology, early warning, navigation and communications—provide coverage of almost the entire earth, but picture resolution is on the order of one kilometre.

A simple satellite with ordinary instruments can cost fifty to a hundred million dollars and the launch cost can be in the same range. Satellites with complex instruments (such as large radar antennas) can cost many times more. The price of a KH-11, for example, is reportedly five hundred million US dollars per satellite.[4] Electrical power requirements strongly affect a satellite's size and cost. Large instruments can require thousands of watts of power, usually derived from large solar arrays or nuclear reactors. A surveillance spacecraft must be stabilized very precisely, because stability affects its instruments' resolution. Therefore complex and expensive attitude control systems are often needed for large spacecraft.

Surveillance missions provide a large amount of raw data. For example, SPOT has a telemetry stream of 50 megabits per second. Once on the ground, this data is processed into a useful format using specialized software. Depending on the application, the computing equipment needed can range from a personal computer to a high speed mainframe with array processing capability. For many surveillance tasks it is not necessary to process the data in "near real time", as it is for an early warning satellite system.

Analysis and interpretation are critical, and the techniques developed for remote sensing are applicable for surveillance and verification missions as well. As mentioned previously the use of multiple instruments, multiple modes of operation of these instruments and multiple means of technical and nontechnical verification, leads to the most objective and accurate interpretation. After processing the data, it has to be efficiently transmitted, or made available on demand, to individuals and organizations who need it. Scientific projects, such as NRC's CANOPUS, have shown that dedicated computer networking works well. A dedicated communications satellite (such as Anik) channel can be utilized to transmit this computer-to-computer data.

FUNDAMENTALS OF EARTH OBSERVATION INSTRUMENTS

Satellite and airborne instruments are similar to those used on earth. The differences are chiefly in the design details and materials chosen, not the operational principles. Almost all remote sensing instruments operate by sensing some form of electromagnetic radiation, such as visible light, infrared heat, or telecommunications signals. These energy-bearing electromagnetic waves all travel at the same velocity in the vacuum of space—the speed of light (3×10^8 metres per second). A wave therefore can be pictured as travelling through space while oscillating sinusoidally.

There is a simple relationship between a wave's frequency* and wavelength:**

$$\text{wavelength} = \frac{\text{speed of light}}{\text{frequency}}$$

Consequently, since the speed of light remains the same, a particular electromagnetic wave—for example a radio signal—can be described equally unambiguously by stating either its wavelength or its frequency.

Table 2 shows the regions of the electromagnetic spectrum, categorized according to wavelength, and the types of instruments which are used for surveillance and remote sensing:

TABLE 2 The Electromagnetic Spectrum and Typical Instruments

Wave Type	*Wavelength*	*Instrument Types*
radio	10 km-20 cm	receivers, sounders
microwave	20 cm-0.1 cm	receivers, radars, sounders, radiometers, scatterometers
infrared	1 cm-0.75 μm	imagers, detectors, radiometers
visible	0.75 μm-0.4 μm	optics, lasers, lidars
ultraviolet	0.4 μm-3 nm	imagers, spectrometers
X-Rays	3 nm-.03 nm	detectors, spectrometers
gamma rays	1 nm and shorter	detectors, spectrometers

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*Frequency is the number of cycles of wave oscillation in a given time, and one cycle per second is defined as one "Hertz." The prefixes kilo-, mega-, and giga- refer to one thousand (10^3), one million (10^6) and one billion (10^9) Hertz respectively.

**Wavelength is the physical length of a complete propagating wave cycle and it is usually expressed in metric units, such as metres, centimetres (cm.) and kilometres (km.). A millimetre (mm.) is one thousandth (10^{-3}) of a metre, a micrometre (μm.) is one millionth (10^{-6}) of a metre and a nanometre (nm.) is one billionth (10^{-9}) of a metre.

In physical terms, instruments utilizing wavelengths larger than a tenth of a centimetre or so are primarily "electronic" and they intercept and emit signals using antennas; in the range below a tenth of a centimetre down to fifty nanometres or so, instruments are primarily "optical" utilizing both geometric and diffraction optics techniques; and as wavelengths become even shorter, instruments rely on particle physics, recording the interaction of discrete waves/particles with the sensor material. Only those waves not absorbed by the earth's atmosphere can be utilized to observe the earth's surface from a satellite. These regions of the spectrum are sometimes called "windows". Visible light, thermal infrared waves (with a wavelength centred around ten micrometres), most microwaves, and the longer ultraviolet waves pass through these "windows".[15]

Instruments can be categorized as:

- detectors or imagers
- active or passive

A *detector* indicates the presence of some intensity of electromagnetic radiation at some wavelength(s), but it doesn't explicitly give spatial information. The motion of the satellite or aircraft can however be used to create low resolution detector images, and for many surveillance applications this is adequate. Radiometers are examples of detectors. An *imager* can be thought of as a detector which also explicitly obtains information about the target's spatial features which can subsequently be processed into a picture. An example of an imager would be a camera.

Passive instruments intercept waves that originate independently from the target. Examples are cameras, telescopes, radiometers and spectrometers. An *active* instrument, on the other hand, first emits a wave toward the target and then consequently receives a returning wave which contains the desired information. Radars, lidars and electromagnetic sounders are examples of active sensors.

SPACEBORNE INSTRUMENTS AND CANADIAN CAPABILITIES

Visible region optical instruments

This category includes telescopes, cameras, spectrometers and interferometers. Picture resolution is defined as the smallest interval on the ground that can be distinguished by the instrument. It is usually limited by the imaging surface's ability to differentiate detail—no matter how precise the optical components may be. For electronic imagery, Charge Coupled Devices (CCDs) or similar solid state microchips are used. A CCD is retina-like and its imaging surface has on the order of 1000 by 1000 individual facets called "pixels", arranged in a rectangular matrix pattern. The resolution of these instruments is governed by the CCD's pixel size which is generally between five to thirty micrometres. Similarly, in a conventional camera it is the "graininess" of the film which limits the system's resolution.

The spatial resolution (r) of an optical instrument is determined by the distance between the target and the instrument's imaging surface (h), the pixel, or film grain, size (d), and the focal length (f), according to the following geometrical relationship:

$$\mathbf{r} = \frac{\mathbf{h} \times \mathbf{d}}{\mathbf{f}}$$

As an example, if a verification satellite were at a 400 kilometre orbit altitude, and if a CCD with 10 micrometre-sized pixels were used in its instrument, then target resolution of one metre could be obtained if the instrument had a four metre focal length. This is large but feasible, and consistent with the sizes used for spy satellites. If a "folded optics" design were used the overall physical length could be less. Variations in the earth's atmosphere, spectral effects, reflection losses and other phenomena impose practical limits on the resolution which is geometrically possible.

Canada has industrial, academic and government research capabilities in optics. For example a number of private companies build precision optics components, and several universities, such as Laval (Quebec), are well known for optics research. The NRC's Dominion Observatory (Victoria) is one of several institutions that has developed complex land-based optical systems, including a laser system targeted at the moon, a portable astronomy system for Saudi Arabia and participation in the 3.6 metre Canada-France-USA telescope located on Hawaii's Mauna Kea. Under contract to NRC, an Ottawa firm has developed an advanced ultraviolet (UV) imaging CCD camera system for Sweden's Viking spacecraft which, launched in February 1986, is now yielding the most detailed ultraviolet pictures yet obtained of the Aurora Borealis. At present a Western Canadian firm is developing a Wide Angle Michaelson Doppler Imaging Interferometer (WAMDII) scheduled for a Shuttle science mission. Two Ontario firms, in collaboration with France, are teamed to develop a large Wind-Imaging Interferometer (WINDII) for flight on NASA's Upper Atmosphere Research Satellite (UARS), which is scheduled for a Shuttle, or Titan, launch in the late 1980's.[6] Numerous Canadian companies market ground and airborne optics instruments.

Synthetic Aperture Radar (SAR)

An imaging radar differs from a detection-only type radar in that the transmitted beam is relatively narrow, and the wave reflected from the target is received by the antenna in such a way that a picture of the target is obtained. A conventional imaging radar's resolution depends on the wavelength of the energy emitted, the length of its antenna, and the distance of the antenna from the target. Side Looking Airborne Radars (SLARs) have been used extensively in airborne remote sensing. However this type of imaging radar is not practical for a satellite because the antennas would have to be kilometres long in order to identify targets consistent with surveillance requirements. Synthetic Aperture Radar overcomes this problem by utilizing a clever signal processing procedure whereby the Doppler shift of the returning radar wave is used in conjuction with the velocity and orbit position data of the spacecraft, and consequently the effective length, or aperture size, of the antenna appears to be orders of magnitude larger than its physical dimension. A SAR-equipped surveillance spacecraft with an antenna ten to twenty metres long would be able to perform many surveillance tasks because it could provide resolution on the order of one to five metres.[4]

Radar waves penetrate clouds, and the instruments can be used night or day. The first SAR to confirm the potential of imaging the earth from a satellite was SEASAT A, which in its short lifetime gave us a wealth of data on ocean characteristics. Right now Japan and Europe are both developing SAR equipped space missions for commercial remote sensing.

Table 3 summarizes several noteworthy SAR missions:[1,6]

TABLE 3 Satellites with Synthetic Aperture Radars

Mission	*Radar Characteristics*
NASA's SEASAT, launched in June 1978 into an 800 kilometre orbit; it mapped 95% of the world's ocean every 36 hours	L-band*** SAR with a 2.1 by 10.7-metre antenna, yielding resolution of 25 metres by 6 metres along a 100-metre wide swath
Shuttle Imaging Radar (SIR-A), flown in 1981	Modified SEASAT SAR with a 9.4-metre antenna, yielding resolution of 40 metres
European Space Agency's ERS-1, to be launched in 1989 into a 777-kilometre orbit, to provide 36-hour full-earth coverage	C-band SAR with a 1.0 by 10-metre antenna, requiring 4.8 kilowatts of peak power, to yield 30 metre resolution
Japan's ERS-1 (same name) to be launched in 1991 into a 570-kilometre circular orbit	L-band SAR with a 2.4 by 12 metre antenna, requiring 1.0 kilowatt of power, to yield 25 metre resolution

Over the past ten years Canada has been planning Radarsat which was to be a SAR-equipped remote sensing satellite. Generally, the studies recommended a high inclination circular orbit at an altitude between 800 to 1000 kilometres, SAR operation at 5.3 Gigahertz (C band), and ground resolution around 25 metres with a ground swath of approximately 200 kilometres, multiple beams, and a steerable antenna.[6] In May 1986 the Minister of Science and Technology announced that the programme was losing government financial support and industry was challenged to develop a strategy to finance it from the private sector. This activity is now underway. On the other hand, the designs and technology which were developed will also be useful for any derivative programme, including that of a verification mission. Aside from Radarsat, Canada is participating in the European Space Agency's (ESA) ERS-1 program by providing the SAR's ground processing system.

On the airborne side, CCRS contracted a British Columbia firm to develop one of Canada's first SAR systems and it is now being used on CCRS's Convair 580 research aircraft.[16] Side Looking Airborne Radars (SLAR's) have been used extensively in Canada and a number of commercial organizations have developed applications methodology and provide airborne remote sensing services. Other Canadian companies design and build world leading, high performance SLARs.

Multispectral Scanners (MSSs)

These instruments are the mainstay of present remote sensing satellite technology. They are basically electronic cameras which operate in the visible light to near-infrared region, utilizing a number of discrete spectral bands. The motion of the satellite or aircraft is used to sweep the field of view of the MSS over the target. A scanning mirror can also be used. The target is viewed simultaneously in each band, and after data processing, an effective "colour" image is produced. Very often false colours are used to aid interpretation.

Commercial multispectral scanning from satellites began with Landsat A. Landsat's imagery is familiar because of its beauty; Landsat pictures appear frequently in magazines such as *National Geographic*. The programme was transferred from NASA to the National Oceanic and Atmospheric Administration (NOAA) and within the past year was taken over by EOSAT, a private sector corporation. Landsat D, the most recent in the series, has a

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*** "L-Band" designates microwaves with wavelengths in the neighborhood of 20 centimetres and "C-Band" designates wavelengths in the neighborhood of 5 centimetres.

four band multispectral scanner covering the visible light regions plus a newer type of MSS instrument, called a "Thematic Mapper" which is specifically designed to highlight particular classes of target, such as crops, forests, etc. Landsat's MSS resolution reportedly could have been better, but the Pentagon imposed restrictions on NASA.[4]

France's SPOT was conceived as a commercial venture from its start, following an initial non-recoverable investment from the government.[7] SPOT provides higher ground resolution than Landsat and its two MSSs are able to pivot to point sideways. SPOT can therefore produce stereoscopic images of targets, but it lacks Landsat-D's spectral range. Planning is underway for improved SPOT satellites, and depending on the commercial success of the venture, these spacecraft should be in orbit in the early 1990's. For verification purposes, it is significant that SPOT and Landsat data are available to anyone in the world.

Table 4 details the characteristics of the instruments on these two satellites:[1,6]

TABLE 4 Satellites with Multispectral Scanners

Mission	*Instrument Characteristics*
EOSAT's Landsat D in a 700 kilometre, circular, near-polar orbit; launched in March 1984 (two instruments)	Four band MSS, covering 0.5 micrometres to 1.1 micrometres, with a ground resolution of 80 metres; and Thematic Mapper, which is a seven-band MSS ranging from 0.45 micrometres to 2.35 micrometres, with a ground resolution of 30 metres
France's SPOT in an 832 kilometre, near-polar orbit; launched in Feb. 1986	Three band instrument covering the visible light regions from 0.51 to 0.89 micrometres, two MSSs, 20 metre resolution for multi-spectral imagery and 10 metre resolution for black/white imagery

Canada has developed a number of airborne scanners. For example, CCRS contracted development of the Multidetector Electro-optical Imaging Scanner (MEIS) which, using 1728 discrete detector elements, each with its own lens, has provided one metre resolution over a range of eight spectral bands.[15] Furthermore, the Department of Fisheries and Oceanography contracted the design and construction of a Fluorescent Line Imager (FLI) which is currently being used to determine plankton concentrations. The airborne FLI is planned to be a forerunner of a space borne version.

Laser Instruments

Lasers are active instruments which produce a narrow beam of coherent light, usually in the visible region, though there are ultraviolet and infrared lasers. One of the advantages is that laser light has minimum dispersion, so an emitted beam remains thin throughout its journey. LIDARs ("Light Detection and Ranging") are laser instruments used for depth profiling and altimetry.[6]

Canadian industry is world class in certain areas, particularly commercial and research CO_2 lasers and airborne Lidars. A Canadian firm developed a laser bathymeter, which is currently being used to map the precise depths of our inland and coastal waters. Laser altimeters have also been developed. Laser research has been done by Canadian government research laboratories such as NRC and the Department of National Defence (DND) laboratories.

Infrared (IR) Region Instruments

Infrared detectors and imagers have wide application in verification. They can be used day or night. The US (and presumably the USSR) use them for military surveillance since, more than any other sensor, they identify a process as well as an object. Thus an aircraft or missile in flight, a moving land vehicle, a moving ship—anything that emits significant heat—may be observed with an infrared sensor. NASA's Heat Capacity Mapping Mission (HCMM) satellite was launched in April 1978, and from a 620 kilometre orbit its (non-imaging) Infrared Mapping Radiometer provided approximately 600 metre resolution, utilizing solely the motion of the spacecraft.[1] Since then spacecraft imaging infrared detectors have been developed which provide much better resolution. One aspect of these instruments is that the detector element has to be maintained at cryogenic temperatures so that it doesn't respond to its own heat instead of the target. Canada has not flown spaceborne infrared instruments, but has used them extensively for airborne surveillance of buildings and processes. Several Canadian firms design and build high quality airborne infrared instruments and one aerospace firm is a major supplier of military infrared sensors for shipboard use.

Ultraviolet (UV) Instruments

These instruments have limited application for a surveillance mission because the shorter UV waves are absorbed by the earth's atmosphere. However certain physical processes emit UV in the longer wavelength "windows" and these can be detected. Canada has built ground based UV instruments, for example at the University of Saskatchewan, and as mentioned Canadian industry developed the highly successful UV cameras for Sweden's Viking spacecraft.

GROUND PROCESSING AND CANADIAN CAPABILITIES

The art of converting data into meaningful, objective pictures or information is perhaps the most crucial element in a surveillance system. Raw data is processed, sometimes thematically, to present an illustration which best conveys the information to the analyst and the end user. Very often these pictures are not photographic replicas because false colours and stereoscopic enhancement are used to clarify meaning. Knowing the characteristics of the spacecraft, the target, and even the noise characteristics of the instrument, today's ground processing technology may use image enhancement and image restoration to produce a picture which, in many ways, overcomes the errors introduced by the sensor. Features can be highlighted to aid the interpreter, and information from different sensors can be analyzed in composite. The current development in this art is that "Artificial Intelligence"(AI) software is being used for advanced remote sensing applications. This software is designed to have human-like decision making abilities, using an "expert" knowledge base which is incorporated in the programme.[1,15]

Several Canadian companies have established worldwide markets for their Landsat image processing systems and are now marketing SPOT compatible systems. One is providing the ground system for ESA's ERS-1 satellite (previously discussed), and their most recently introduced system is at the top end of equipment available from any of the world's suppliers. Another very successful Ontario firm supplies SPOT compatible systems, including sales to China and to Sweden for their SPOT ground station at Kiruna. There are other examples. An advanced "fast" system was developed by an Ottawa firm for CCRS, and recently both a Toronto and a Montreal company introduced low cost systems which operate on a personal computer. And there are over a dozen Canadian companies who specialize in image interpretation for the various natural resource sectors.

SPACECRAFT AND GROUND STATIONS AND CANADIAN CAPABILITIES

Canada has a world class capability to design, build and integrate spacecraft and ground stations. Our largest aerospace firm provided most of the Anik series of satellites as well as Brazilsat, and has been a major contractor on other satellites such as Hermes. Along with a Western Canadian company they have also provided numerous communications satellite ground control and local receiving stations, and they are currently selling world-wide, including to Nigeria and China. And of the fourteen or so Landsat ground stations throughout the world a Canadian company has been a key participant in all but one. As part of the international Search and Rescue Satellite (SARSAT) programme, an Ottawa firm developed and is now selling the world's leading ground processing system.

Canada has been an active partner in Landsat since the programme's beginning; first by providing a ground station at Prince Albert, Saskatchewan and later adding another at Shoe Cove, Newfoundland to support both Landsat and Seasat. In May 1986, a third station was added in Gatineau, Quebec and it supports SPOT as well. The David Florida Laboratory in Ottawa is one of the most modern satellite test facilities in the world, and the Shirley Bay spacecraft control and tracking facility—at the same site—was used for all five of Canada's scientific and technology development satellites.

CONCLUSION

Satellite remote sensing technology is reaching commercial maturity and the data resolution is now close to that required for a surveillance mission.[17] By 1991 a deluge of high quality data will be available from current commercial systems such as Landsat and SPOT, from the soon-to-be launched systems like Europe's ERS-1, from Japan's SAR equipped satellite system, from the SPOT and ERS upgrades currently in planning or development[18], and possibly from selected US or even USSR national security programmes.

Canada has a mature satellite industry, an experienced remote sensing sector, solid airborne and spacecraft instrument capability, and world class ground receiving and remote sensing data processing technology. Canada also has an international reputation as being fair and able to conduct peacekeeping activities. An objective, internationally administered satellite surveillance organization would fulfill a needed world role, and it is logical to consider Canadian participation. A promising systems approach would be for the organization's technical centre to receive data from all available sources, and if necessary to augment this with data from a dedicated surveillance spacecraft system, designed and operated under the jurisdiction of the organization. The satellite's purpose would be threefold: to provide vital information not otherwise available about specific targets, to authenticate data received from other organizations, and to provide "second look" images of targets.

The most challenging task would likely be on the ground. There, all available data could be correlated, processed, analyzed and objectively interpreted.

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The views expressed in this paper are the author's own and should not be taken to represent the views of the Institute and its Board.

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