ARMS CONTROL VERIFICATION OCCASIONAL PAPERS No. 6

Overhead Imaging for Verification and Peacekeeping: Three Studies

by Allen V. Banner

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Arms Control Verification

prepared for The Arms Control and Disarmament Division
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Canada

External Affairs and
International Trade Canada

The cover graphic is based on an ancient Egyptian hieroglyph representing the all-seeing eye of the powerful sky god, Horus. Segments of this "eye in the sky" became hieroglyphic signs for measuring fractions in ancient Egypt. Intriguingly, however, the sum of the physical segments adds up to only 63/64 and, thus, never reaches the equivalent of the whole, or perfection. Similarly, verification is unlikely to be perfect.

Today, a core element in the multilateral arms control verification process is likely to be the unintrusive "eye in the sky," or space-based remote sensing system. These space-based techniques will have to be supplemented by a package of other methods of verification such as airborne and ground-based sensors as well as some form of on-site inspection and observations. All these physical techniques add together, just as the fractions of the eye of Horus do, to form the "eye" of verification. Physical verification, however, will not necessarily be conclusive, and there is likely to remain a degree of uncertainty in the process. Adequate and effective verification, therefore, will still require the additional, non-physical, element of judgement, represented by the unseen fraction of the eye of Horus.

Arms Control Verification Occasional Papers

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External Affairs and International Trade Canada
Cat. No. E54-8/6-1990E
ISBN 0-662-18200-6
ISSN 0840-772X

March 1991

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Ottawa, Ontario, Canada

Canadian Cataloguing in Publication Data

Banner, Allen V. (Allen Vernon), 1955-
Overhead imaging for verification and peacekeeping : three studies

(Arms control verification occasional papers ; no. 6)
Includes bibliographical references.
ISBN 0-662-18200-6
DSS cat. no. E54-8/6-1990E

1. Artificial satellites in remote sensing. 2. Aerial reconnaissance. 3. Arms control — Verification — Remote sensing. 4. Security, International — Remote sensing. I. Canada. Arms Control and Disarmament Division. II. Title

UA12.5.B36 1990 621.36'78 C90-090552-2

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Abstract

This paper examines commercially available overhead remote sensing systems and the ways they might be usefully employed for applications related to international security. An introduction is provided on commercially available satellite and aerial remote sensing systems to explain their basic operating characteristics and features. Two case studies are used to examine potential applications of commercial satellite imagery. In the first, imagery acquired during the Soviet withdrawal from Afghanistan in 1988 and 1989 is used to assess whether commercially available satellite imagery would be useful for monitoring large-scale withdrawals of conventionally armed forces. In the second case study, imagery of selected sites in Namibia and Angola is used to examine whether such imagery could have supported United Nations peacekeeping operations in those countries. Potential applications of airborne remote sensing systems are also demonstrated using previously acquired imagery to show the kinds of results which could be obtained using commercially available systems.

The results outlined in this paper clearly demonstrate that commercial remote sensing systems can provide valuable information for certain applications related to international security. They show equally that the applications must be chosen carefully to ensure that the required data can be provided by current commercial remote sensing systems.

Résumé

Le présent document porte sur les systèmes aérospatiaux civils existants de télédétection et sur les façons dont on pourrait s'en servir à des fins reliées à la sécurité internationale. Il fournit des renseignements sur les systèmes aériens et montés sur satellite, pour en expliquer en gros le fonctionnement et les caractéristiques. L'auteur recourt à deux études de cas pour examiner les applications possibles des images obtenues par les satellites commerciaux. Dans la première, il se sert des images recueillies pendant le retrait des troupes soviétiques de l'Afghanistan, en 1988 et 1989, pour poser la question de savoir si les images saisies par les satellites commerciaux aideraient à contrôler les retraits de grande envergure opérés par des forces armées conventionnelles. Dans la deuxième, l'auteur présente des images de certains endroits en Namibie et se demande si de tels clichés auraient été utiles aux Nations Unies dans le cadre des opérations de maintien de la paix qu'elles ont menées là-bas. Il s'interroge aussi sur des applications possibles des systèmes aéroportés de télédétection et se sert d'images recueillies antérieurement pour montrer les genres de résultats que des systèmes commerciaux existants permettraient d'obtenir.

Les résultats décrits dans le présent document montrent clairement que les systèmes commerciaux de télédétection peuvent fournir des renseignements précieux aux fins de certaines applications afférentes à la sécurité internationale. Ils révèlent aussi qu'il faut choisir soigneusement les applications, pour s'assurer que les systèmes commerciaux actuels de télédétection pourront effectivement fournir les données voulues.

Acknowledgements

The work described in this publication is based on studies undertaken on behalf of the Verification Research Program of External Affairs and International Trade Canada by two companies specializing in the application of commercial remote sensing systems. The studies were conducted during the period from 1988 to 1990. The ones outlined in Parts 2 and 3 relating to the application of commercially available satellite imagery were completed by Banner and Associates. The study described in Part 4 regarding the use of airborne remote sensing systems was done by Intera Technologies Limited with the participation of Banner and Associates.

The author would like to acknowledge the contributions of Intera Technologies Limited, Major A.G. McMullen, Lieutenant-Colonel R.B. Mitchell (retired) and D. Dorschner, Aviation Resource Management, to this publication. The author would also like to acknowledge the encouragement, patience and support of the Verification Research Unit of External Affairs and International Trade Canada.

List of Abbreviations

CCD	Charge coupled device
CFE	Conventional Forces in Europe
DOMSAT	RCA's domestic communications satellite
EOSAT	Earth Observation Satellite Company
EROS	Earth Resources Observation System
FOV	Field of view
FLIR	Forward looking infrared
HRV	High Resolution Visible
INM	International nautical mile
IR	Infrared
IRLS	Infrared line scanner
MSS	Multispectral scanner
P	Panchromatic image (as identified by SPOT Image)
P + XS	A satellite image product offered by SPOT Image, created by merging simultaneously acquired panchromatic (P) and multispectral (XS) images of a particular site
POL	Petroleum, oil and lubricants
RAR	Real aperture radar
SAR	Synthetic aperture radar
SDRS	SPOT Direct Receiving Stations
SLAR	Side-looking airborne radar

SPOT	Satellite pour l'observation de la terre
TDRS	Tracking Data Relay Satellite System
TM	Thematic Mapper
XS	Multispectral image (as identified by SPOT Image)
UNTAG	United Nations Transition Assistance Group
UNYOM	United Nations Yemen Observer Mission

Introduction

This report summarizes the results of studies completed for the Verification Research Program of External Affairs and International Trade Canada on the potential of commercially available sources of overhead imagery for monitoring related to arms control verification, peacekeeping operations or similar purposes.

The first study investigates whether commercially available satellite imagery would be useful for verification of large-scale withdrawals of conventional forces. The withdrawal of Soviet forces from Afghanistan in 1988 and 1989 is used as a case study. Imagery of Kabul, Afghanistan was acquired before and after the first phase of the Soviet withdrawal. Change detection analysis is used to assess the extent to which the withdrawal of Soviet forces could be confirmed using the imagery.

The second study uses imagery of sites in Namibia and Angola to investigate whether commercial satellite imagery could supply useful information for initial planning of peacekeeping operations. This study focuses on whether civilian satellite imagery could provide useful information regarding military and civilian infrastructure, rather than the actual military forces themselves.

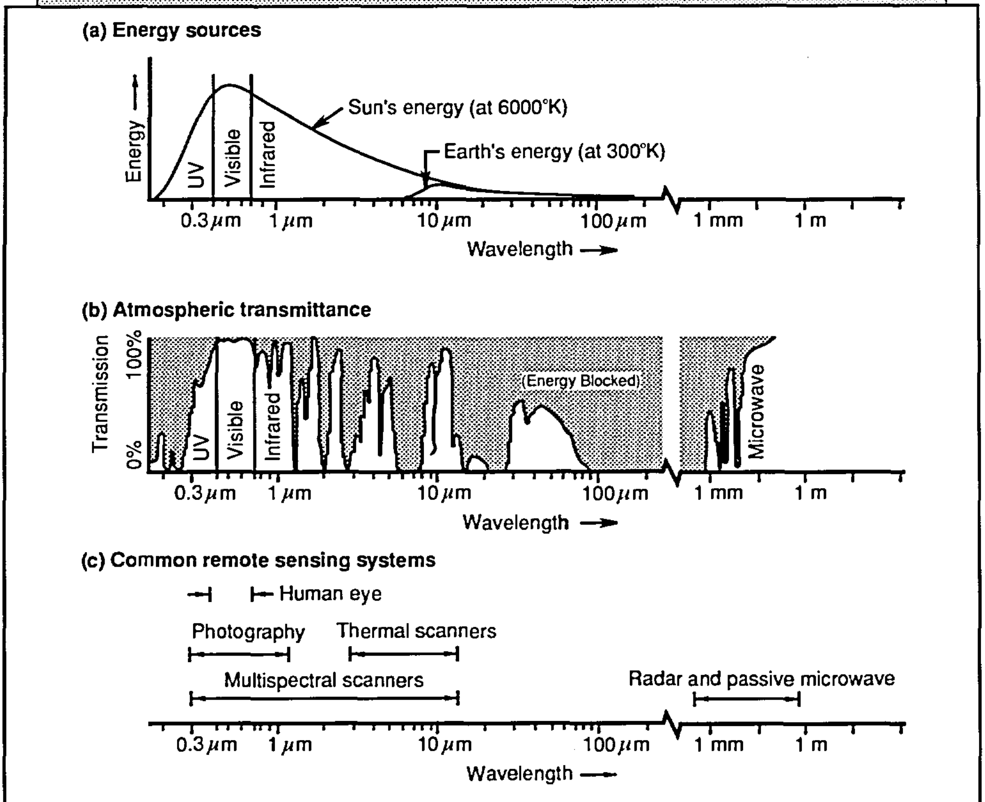
In the third study, commercially available airborne imagery rather than satellite imagery is the focus of attention. This study looks at methods of improving monitoring and reconnaissance for arms control verification or peacekeeping using commercially available aerial remote sensing systems.

Part 1: Commercial Remote Sensing Systems

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.[1]

This report discusses the potential use of commercially available sensors, which create images from electromagnetic energy that is emitted or reflected from various earth surface features. These remote sensors can operate using ultraviolet, visible, reflected infrared, thermal infrared or microwave energy. Figure 1 illustrates the types of electromagnetic energy, the associated

Figure 1 Spectral Characteristics of Energy Sources, Atmospheric Transmission and Common Remote Sensing Systems



Note that the wavelength scale is logarithmic. (From Thomas M. Lillesand and Ralph W. Kiefer, ***Remote Sensing and Image Interpretation*** (New York: John Wiley & Sons, 1979), p. 11. © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., all rights reserved.)

wavelengths and the sensitivity ranges for various sensing systems. The visible light to which our eyes are sensitive includes a small portion, from 0.4 µm to about 0.7 µm, of the full electromagnetic spectrum.

Imaging Satellite Systems

Three potential sources of commercially available satellite imagery might be considered for arms control or peacekeeping applications. The French SPOT Image Corporation markets imagery acquired by the SPOT satellite system. Imagery from the U.S. Landsat satellite system is marketed by EOSAT, the Earth Observation Satellite Company. Imagery acquired by several Soviet imaging satellite systems is being marketed by Soyuzkarta.[2]

SPOT

The French SPOT-1 (Satellite pour l'observation de la terre) satellite has two High Resolution Visible (HRV) sensors, which provide three-channel multispectral images with a resolution of about 20 × 20 m or single-channel panchromatic images with 10 × 10 m approximate resolution on the ground.

Table 1 outlines characteristics of the SPOT HRV sensors. The panchromatic mode is intended for users requiring fine geometric detail. The bands provided in the multispectral mode were optimized for analysis of vegetation, which will typically have a response peak in the green band, strong absorption in the red band and a pronounced response in the near-infrared (IR) band.

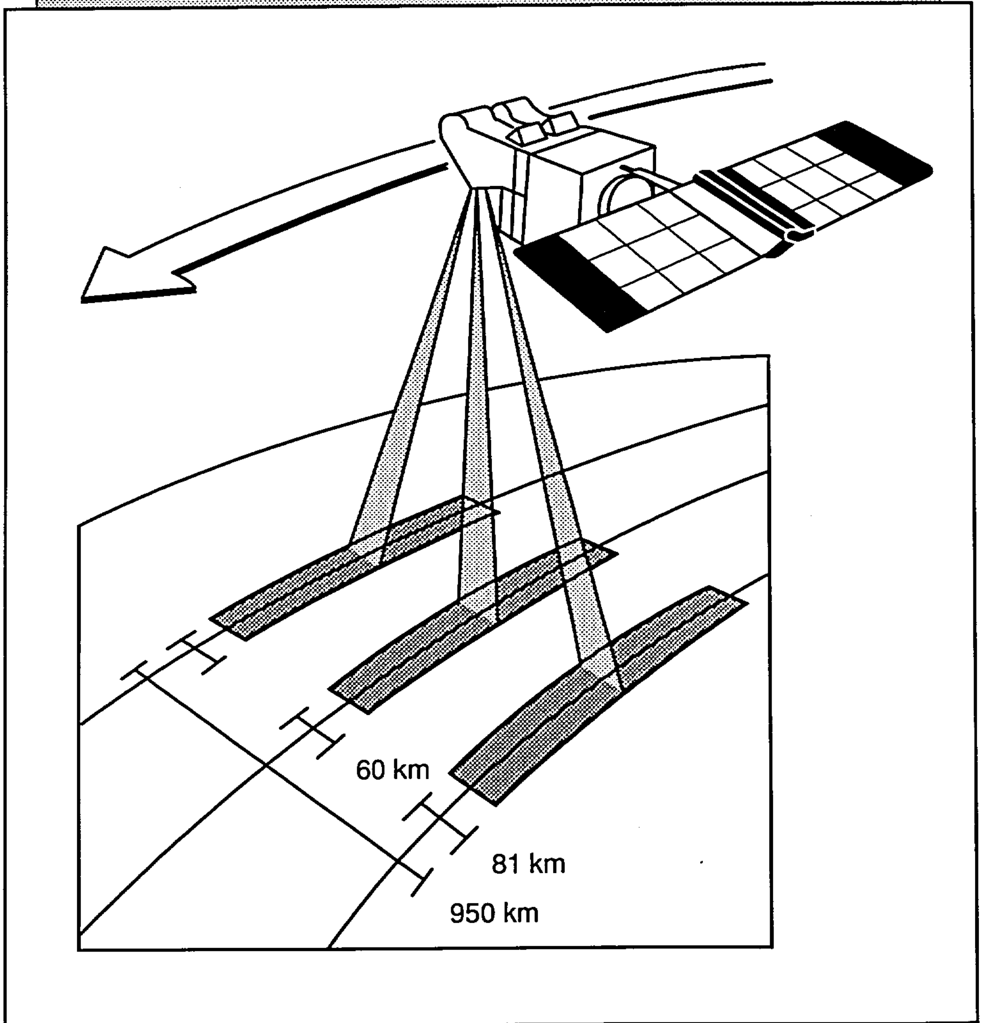
The HRV sensors have the capability to operate over a range of look angles out to 27° from vertical. A strip-selection mirror for each sensor can be instructed from the ground to observe areas of interest that are not directly beneath the satellite, providing a 950 km-wide observable corridor centred on the satellite's ground track. The width of the imaged area on the ground will vary from 60 km if the area was directly beneath the satellite to 81 km if the image was acquired obliquely (Figure 2). Lengths of the imaged scenes remain constant at about 60 km.

Table 1

Characteristics of the SPOT Sensors

	Panchromatic	Multispectral
Swath width	60 – 81 km	60 – 81 km
Spatial resolution	10 – 13.5 m	20 – 27 m
Spectral bands	0.51 – 0.73 µm	0.50 – 0.59 µm (green) 0.61 – 0.68 µm (red) 0.79 – 0.89 µm (near IR)
Radiometric resolution	64 gray levels	256 gray levels

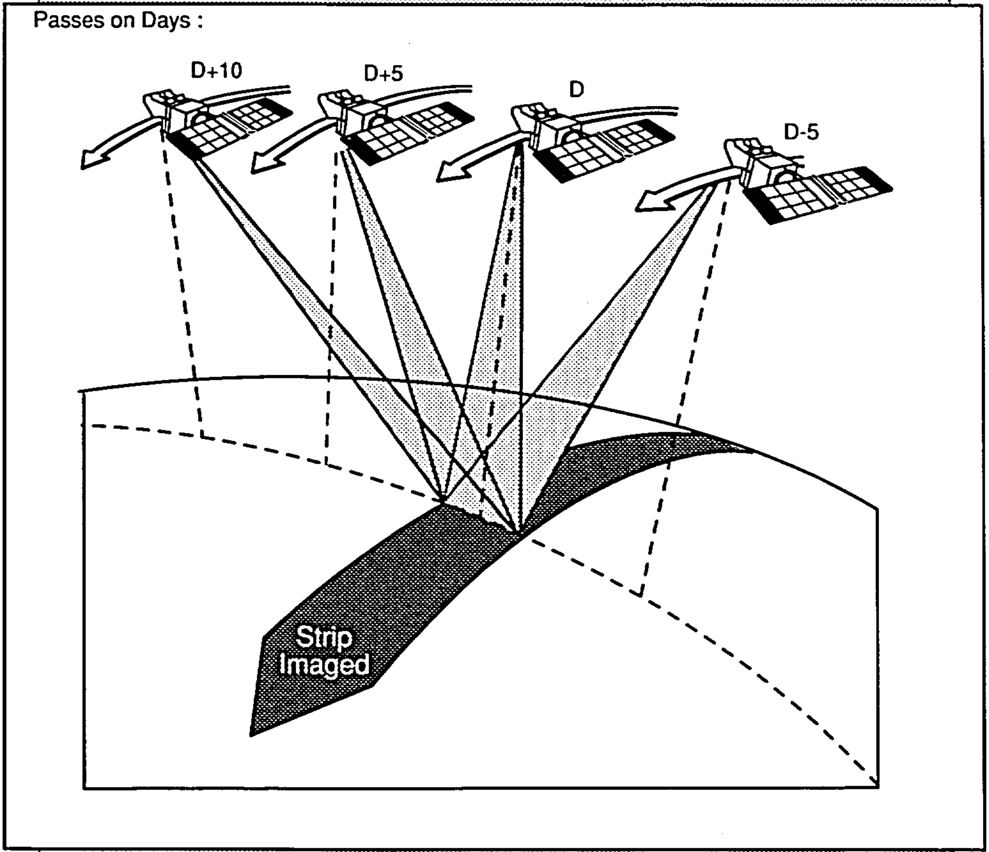
Figure 2 Observable Corridor and Ground Strips Accessible Using Vertical and Oblique Viewing



(Courtesy of SPOT Image Corporation.)

If the satellite were capable of only vertical viewing, it would be possible to image a particular location only once during the 26-day orbital cycle of the satellite. The SPOT satellite's oblique viewing capability provides the means to collect images more frequently for a particular site (Figure 3).[3] At 45° latitude, up to 12 images can be acquired during one 26-day orbital cycle with time intervals from one to four days between successive images.[4]

Figure 3 Revisit Capability of the SPOT Satellite



Using oblique viewing, it is possible to acquire imagery of a particular location on a more frequent basis than the 26-day orbital cycle of the satellite. (Courtesy of SPOT Image Corporation.)

Oblique viewing also reduces the spatial resolution of the images. The raw image line sampling interval (in the across-track direction) at the maximum viewing angle is 13.5 m for panchromatic images and 27 m for multispectral images.[5] In the along-track direction, the column sampling interval remains unaffected by changes in the viewing angle.

SPOT imagery is produced using two image-receiving station networks. The decentralized network consists of SPOT Direct Receiving Stations (SDRS) located throughout the world. These stations mainly produce imagery for their own use but can also supply imagery to SPOT Image. The SDRS stations can receive images only through direct mode imaging, acquired while the satellite is within range of the receiving station.[6] The central network has two sites: Toulouse, France and Kiruna, Sweden. These stations produce imagery for SPOT Image and Satimage, its Swedish sister-company. They can collect imagery from anywhere in the world by using the onboard recorders and recorder-playback telemetry mode.

Landsat

The U.S. Landsat 5 satellite has two primary imaging sensors: the Multispectral Scanner (MSS) and the Thematic Mapper (TM). Table 2 outlines the characteristics of the two sensors. Both sensors are capable of only vertical viewing, effectively restricting the satellite to a 16-day revisit capability assuming no cloud cover.

The Multispectral Scanner has four bands, sensitive roughly to green, to red, and to two bands of near-infrared light.[7] The spatial resolution is poor compared with what is available from the other systems. However, if the level of resolution is sufficient, broad area coverage with the MSS is more economical with its 185-km swath width and lower cost per scene.

Thematic Mapper images have additional bands with finer spectral, spatial and radiometric resolution. TM bands 2, 3 and 4 correspond roughly to the three multispectral bands provided by SPOT. TM band 1, sensitive to blue light from 0.45 to 0.52 µm, was intended to provide increased penetration into water bodies.

Table 2

Characteristics of the Landsat Sensors

	Multispectral Scanner	Thematic Mapper	
Swath width	185 km	185 km	
Spatial resolution	79 m × 79 m	30 m × 30 m	
Spectral bands		0.45 – 0.52 µm	(blue)
	0.50 – 0.60 µm	0.52 – 0.60 µm	(green)
	0.60 – 0.70 µm	0.63 – 0.69 µm	(red)
	0.70 – 0.80 µm	0.76 – 0.90 µm	(near IR)
	0.80 – 1.10 µm		(near IR)
		1.55 – 1.75 µm	(mid IR)
		10.40 – 12.50 µm	(thermal IR)*
		2.08 – 2.35 µm	(mid IR)
Radiometric resolution	64 gray levels	256 gray levels	

* The thermal infrared TM band has coarser spatial resolution (120 m) than the other bands.

TM band 5, sensitive to mid-IR light from 1.55 to 1.75 μm, was selected to provide information regarding crop water content and soil moisture conditions. TM band 7 (2.08 to 2.35 μm) is important for discrimination of rock formations. TM band 6, a thermal infrared band sensitive to radiation from 10.40 to 12.50 μm, is useful for investigation of a variety of thermally evident events.

Landsat imagery is directly received through a global network of earth receiving stations. When the Landsat satellite is within line-of-sight of a receiving station, image data are transmitted in real time to that station. Landsat TM or MSS imagery can also be relayed to EOSAT at the Earth Resources Observation System (EROS) Data Center in Sioux Falls, South Dakota, using the Tracking Data Relay Satellite System (TDRS) communications relay satellite and RCA's domestic communications satellite (DOMSAT).

Soyuzkarta

Soyuzkarta offers satellite imagery acquired using KFA-1000 and MK-4 cameras. Table 3 outlines the characteristics of the two camera systems. Both have a reported spatial resolution of close to 5 m. The imagery is recorded onto photographic film. Digital images are produced by digitizing the first-generation films. Both systems provide 60% north-south overlap between scenes, permitting stereoscopic viewing of the imagery.

Table 3

Characteristics of the Soyuzkarta Sensors

	KFA-1000	MK-4
Number of channels	1	4
Focal length	1000 mm	300 mm
Frame format	300 × 300 mm	180 × 180 mm
Original scale*	1:220 000 to 1:280 000	1:6 500 000 to 1:1 500 000
Longitudinal overlap	60%	60%
Width of survey band	120 km or more (2 cameras)	120 – 270 km
Spectral bands	0.560 – 0.670 μm 0.760 – 0.810 μm	0.635 – 0.690 μm 0.810 – 0.900 μm 0.515 – 0.565 μm 0.460 – 0.505 μm 0.580 – 0.800 μm 0.400 – 0.700 μm
Spatial resolution	5 m	6 m

* Depending upon altitude of survey.

KFA-1000 photography is available in panchromatic mode or colour mode. The colour film is spectrozonal, with two individual emulsion layers. The colour of the final photographic product depends upon the selection of filters used during film processing. Original scales are approximately 1:250 000 on 30 cm × 30 cm film, covering an area of about 50 km × 50 km. Photographic scales as large as 1:25 000 can be produced.

The MK-4 is the most advanced Soviet large format mapping camera. It is a multispectral camera recording four black and white images that may later be combined to produce a colour image. The imagery is recorded at an original scale of approximately 1:700 000 on 19 cm × 19 cm film. Scales as large as 1:25 000 can be produced.

Airborne Systems

Commercially available airborne remote sensing systems could be valuable for arms control and peacekeeping applications. A variety of sensors and platforms might be appropriate.

Aerial sensor systems

The major categories of sensors include photographic cameras, thermal infrared systems and imaging radars. Table 4 outlines some of the main features of each sensor type.

Traditional photography using a standard aerial camera is an economical and reliable option. Photographic systems can provide very fine spatial detail. Aerial cameras and film are inexpensive compared with many of the other systems. Photographic prints can be easily made for use in the field.

Photographic systems, however, have a number of disadvantages. They cannot provide real-time data. Exposed films must be processed before they can be interpreted. The need for darkroom facilities to develop film can be inconvenient in remote or isolated regions. Photographic systems are primarily suited to daytime use, ideally in the brightest part of the day from 10:00 a.m. to 2:00 p.m. local time.[8] Finally, cloud cover can pose serious problems by forcing delays in overflights or degrading the information value of photographs.[9]

Several types of commercially available aerial cameras could be used, including metric survey cameras, medium-format reconnaissance cameras and hand-held aerial cameras. Metric survey cameras can take large-scale photographs with very fine detail, negligible distortion and homogeneous image quality over the full photo frame. Many missions will not require this type of accuracy.

Table 4

Remote Sensors for Monitoring Applications

Sensor	Features
Photography	fine spatial resolution daytime, clear skies, film requires processing
Thermal infrared	fair spatial resolution night or day, clear skies, can provide real-time data
Radar	coarse spatial resolution night or day, all weather, can provide real-time data

A 70-mm format reconnaissance camera can be used in these cases. It is relatively inexpensive, rugged, reliable and easy to use, requiring a minimum of maintenance. Some cameras are specifically designed to acquire hand-held oblique aerial photographs. These cameras typically use 70-mm film to provide a film format large enough for serious interpretive tasks. They can take high quality oblique photographs from ranges of up to several kilometres.

Thermal infrared sensors are another type of aerial imaging system. Thermal infrared systems produce images by sensing the thermal energy that is emitted by all surfaces according to their temperature. They can be used at night as well as during the day. They are better than photographic systems for penetrating haze and smog. However, thermal infrared radiation cannot penetrate cloud cover, so thermal systems are most effective when used under clear sky conditions.[10] Aerial thermal infrared reconnaissance can be done using thermal infrared linescanners or forward-looking infrared (FLIR) systems. The two kinds of sensors are intended for different missions. Table 5 contrasts selection criteria for the two sensor systems.

FLIRs produce real-time thermal imagery in a framed format, similar to that of a video camera. They are usually used to view a scene or specific targets obliquely. Systems designed for reconnaissance missions have a sensor head mounted beneath the aircraft, which can be pointed toward points of interest by an operator inside the aircraft using a video display and a set of controls. Most FLIR systems have several fields of view (FOVs). A good FLIR will provide very high spatial resolution in its narrowest FOV.

Infrared linescanners (IRLSs) use a rotating mirror and optics to direct thermal energy from a small ground surface area to a detector or array of detectors. The mirror rotates perpendicularly to the line of flight. With each cycle of the mirror, a strip of ground normal to the flight direction is sensed. The forward motion of the aircraft causes successive scan lines to cover adjacent strips on the ground, making a two-dimensional image (Figure 4). The data may be displayed in near-real time on a display screen or dry silver paper during the overflight.

Table 5

Criteria for Selection of Infrared Sensors for Reconnaissance Missions*

IRLS Selection Criteria	FLIR Selection Criteria
• hard copy imagery required	• real-time imagery required
• image mensuration and analysis required	• image mensuration and analysis not required
• wide field of view across track, continuously-mapped imagery desired	• narrow field of view providing details of selected areas desired
• operator has little or no control over pointing of sensor	• operator has full control over pointing of sensor
• sensor operation may impose velocity/height restrictions on aircraft	• sensor operation will not impose velocity/height restrictions on aircraft

* William T. Noel, "Utilization of IR Imagery in Tactical Reconnaissance," in ***Aerial Reconnaissance Systems — Pods/Aircraft.*** Vol. 79. Edited by Ed Shea. (Reston, Virginia: The Society of Photo-optical Instrumentation Engineers: 24-25 March, 1976), pp. 99-100.

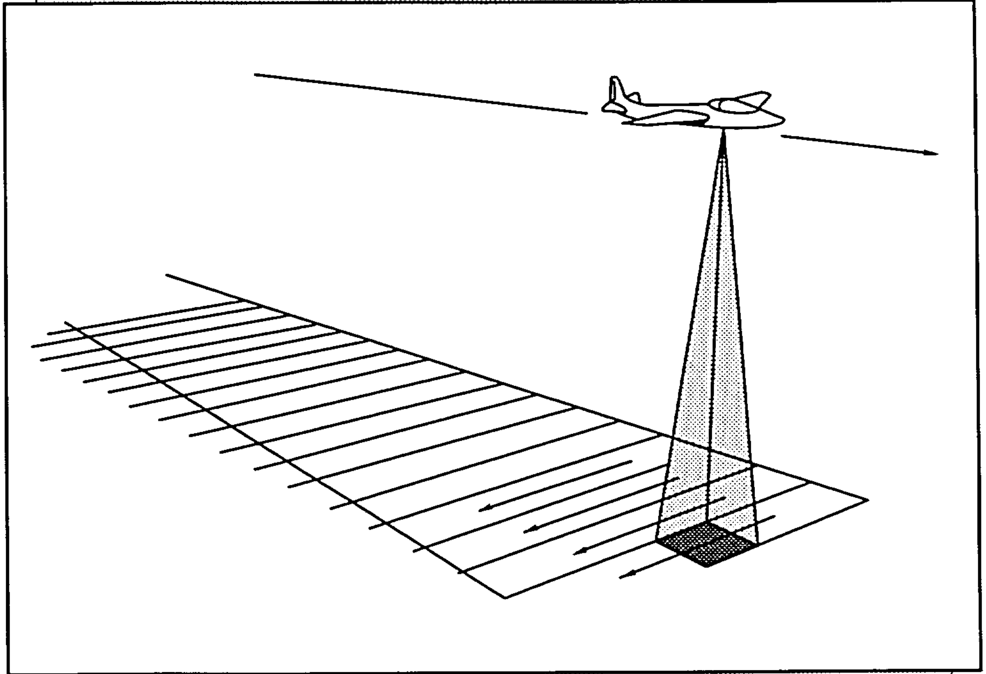
However, the data will likely be recorded on magnetic tape, or a similar storage medium, and processed after the aircraft has returned to base to provide the final interpretable product.

None of the sensors described previously is able to penetrate cloud cover. In contrast, airborne radar systems can collect imagery regardless of cloud cover. They can also be used day or night because they provide their own illumination.

Radar, an acronym for *ra*dio *d*etection *a*nd *r*anging, is an active sensor that transmits short pulses of microwave energy and then records the echoes received back in their order of arrival. Airborne radars are called side-looking airborne radars (SLAR). SLARs produce continuous strips of imagery of the terrain adjacent to the flight path of the aircraft.

There are two main types of SLAR. Real aperture, or brute force, radars (RAR) require a physically large antenna to achieve any reasonable amount of spatial detail in the resulting images. Synthetic aperture radar (SAR) achieves more spatial detail without having to use a large antenna. It uses the forward motion of the aircraft to create synthetically the effect of an antenna hundreds of metres long (Figure 5).

Figure 4 Operation of an Airborne Linescanner

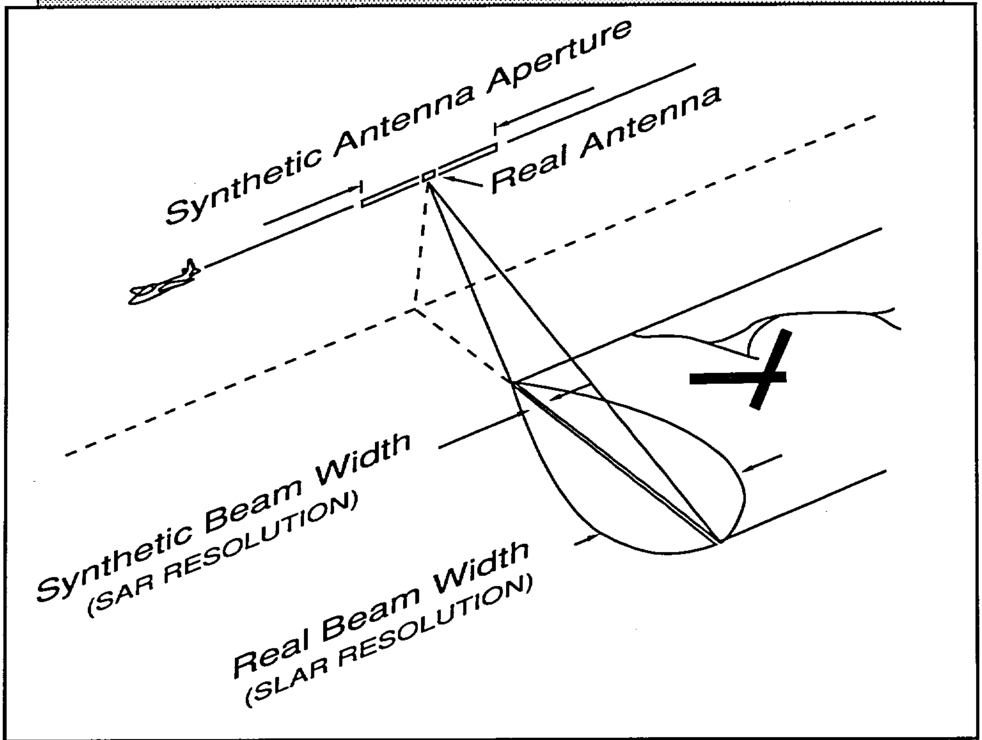


A mirror rotating perpendicular to the line of flight provides the across-track dimension of the imagery. The along-track dimension of the imagery is provided by the motion of the aircraft. (© 1979 by Board of Regents of the University of Wisconsin System. Used with permission.)

Radars use radiation with wavelengths roughly two orders of magnitude longer than those used by photographic and thermal infrared systems. This long wavelength radiation provides imaging radars with their all-weather capability. It also means that the spatial detail that can be recorded is much less than that available using optical sensors. Good spatial resolution for a commercially available SAR is measured in metres, not centimetres.

SAR systems provide real-time, on-board digital processing so that imagery can be viewed immediately on a video monitor or output to a hard copy (dry silver paper) with only a few minutes delay. It is also possible to down-link the data to a ground-based receiving station in real time. The imagery will usually be recorded onto digital tape to allow for further processing and analysis at a later time.

Figure 5 Resolution Determination for Synthetic and Real Aperture Radar Systems



Real aperture radars provide limited spatial resolution because of limitations on the size of antenna that can be mounted onto the aircraft. Synthetic aperture radar systems use the forward motion of the aircraft to create the effect of an antenna hundreds of metres long using a physical antenna size of only one metre. (Courtesy of MacDonald Dettwiler and Associates Ltd.)

Aerial platforms

Civilian aircraft may be suitable for many tasks related to verification and peacekeeping. These aircraft come with a wide range of capabilities and cost. Aircraft that cost more to purchase and operate are typically able to operate in larger envelopes. They will have better all-weather capability, a higher altitude ceiling and better navigation systems. At the same time, the cost of operating the aircraft should not be prohibitively expensive.

An aircraft suited to verification or peacekeeping missions should meet the following criteria:[11]

- sufficient payload to provide for the required sensors, processing equipment and storage;
- good range capability with the payload, ensuring large coverage per sortie;
- broad range of operating altitudes without adverse operational or economic effects;
- ability to transport passengers (for example, observers for the underlying state) without loss of surveillance capability;
- ability to operate from a majority of airfields; and
- low operating costs coupled with high dispatch reliability.

Table 6 outlines the performance characteristics for three potential aircraft: a Cessna 441 Conquest, de Havilland Dash 8 Series 300, and a Canadair Challenger 600.[12] Table 7 compares operating costs for the aircraft in 1985 U.S. dollars.

Table 6

Performance Characteristics for Selected Aircraft[1]

	Cessna Conquest[2]	de Havilland Dash 8 Series 300	Canadair Challenger
Maximum Gross Weight (lbs.)	10 800	39 000	41 100
Maximum Payload (lbs.)	2 450	11 800	7 830
Payload with Maximum Fuel (lbs.)[3]	1 500	9 122	5 375
Maximum Ceiling (ft.)[4]	35 000	25 000	41 000
Maximum Cruise (knots)[5]	287	266	443
Maximum Range (INM)[6]	2 100	2 500	3 040
Maximum Endurance (hrs.)[6]	7.3	9.4	6.8
Maximum Range @ 5 000 ft. (1 INM)	866	1 273	1 490
Take-off Distance @ Sea Level (ft.)	2 465	3 700	5 750

1 Intera Technologies Ltd. "A Comparison of the Capabilities and Costs of Aircraft for an Iceberg Radar Surveillance Role." In *Iceberg Detection by Airborne Radar: Technology Review and Proposed Field Program.* (Toronto: CANPOLAR Consultants Ltd., September 1986), p. 231. Environmental Studies Revolving Funds Report No. 045.
2 Single pilot, one operator. All others assume two pilots, one operator.
3 Payload refers to the equipment payload available plus three- or two-person crew as required.
4 Maximum ceiling is close to the optimum performance ceiling except for jets that have approximately 39 000 ft. ceiling for optimum performance.
5 Refers to optimum altitude. Will be slower at lower altitude.
6 Assumes maximum fuel load at takeoff, VFR conditions. Reserve not included.

Table 7

Operating Cost Comparisons in 1985 $US[1] for Selected Aircraft[2]

	Cessna Conquest[3]	de Havilland Dash 8 Series 300	Canadair Challenger
Specific Range (nm/lb. fuel)	0.67	0.44	0.18
Operating cost @ optimum altitude[4]			
$/hr	285	404	978
$/NM	1.00	1.52	2.21
Operating cost @ 5 000 ft. altitude[4,5]			
$/hr	430	625	1515
$/NM	1.62	2.37	3.42

1 Original figures were provided in 1985 Canadian dollars. These were converted to U.S. dollars using the conversion C$1 = US $0.85.
2 Intera Technologies Ltd., see note 1, Table 6, p. 232.
3 Single pilot, one operator. All others assume two pilots, one operator.
4 Operating costs include fuel and engine maintenance but do not include crew costs.
5 Derived by assuming 100% fuel flow increase at 5000 ft. from optimum cruise. Manufacturers do not provide full performance curves versus altitude.

A Cessna Conquest provides a cost-effective remote sensing platform. It would be capable of operating with a crew of three with aerial cameras and a thermal linescanner, or with a synthetic aperture radar by itself. These would be reasonable sensor configurations since nighttime thermal imagery would often be complemented with daytime photography to assist in the interpretation. SAR imagery is usually acquired as a stand-alone product, particularly if the survey area is perpetually cloud-covered.

A de Havilland Dash 8 Series 300 would serve as a good general purpose platform. It has enough room for a full suite of sensors and associated equipment while retaining an ability to transport inspection teams as well. It provides a range in excess of 2 000 international nautical miles (INM). Its short field capability ensures that the aircraft would be able to operate from the vast majority of airfields.

The Canadair Challenger is jet powered and can transit long distances quickly. Like the Dash 8, it is capable of carrying a full suite of sensors and passengers. However, executive jets such as the Challenger have several potential disadvantages. Their relatively high stall speeds limit their ability to acquire large-scale imagery since this requires the aircraft to fly slowly at a low altitude. The purchase and operating costs of executive jets such as the Challenger are also higher than those of turbo-prop aircraft such as the Conquest or Dash 8.

Part 2: Change Detection Using Commercial Satellite Imagery to Monitor Large-scale Withdrawals of Conventional Forces

Background

The objective of this project was to examine change detection techniques for monitoring large-scale withdrawals of conventional forces using commercial satellite imagery. The Soviet withdrawal from Afghanistan in 1988 and 1989 was used as a case study.

The number of Soviet forces rose to more than 100 000 at some times during the eight-year occupation.[13] Before the withdrawal began on May 15, 1988, about 22 000 Soviet troops were reportedly in the vicinity of Kabul.[14] The withdrawal of such a large force provided an opportunity to examine the extent to which commercially available satellite imagery would be useful to monitor withdrawals of conventional armed forces in other regions such as Europe.

SPOT satellite images of Kabul were acquired on two dates to be used as before and after images for a multitemporal analysis. The before image was acquired on November 11, 1987, with a viewing angle of 7.9°W. The after image was acquired almost one year later, on November 4, 1988. This image was acquired using a 26.2°E oblique viewing angle.

Panchromatic imagery (with 10 m resolution) was used for the analysis. The 1987 and 1988 images were registered using a digital image analysis system. Registering of two images involves transforming one image so that it geometrically matches the other. Once registered, the two single-channel panchromatic images can be combined in a single colour image using the 1987 data for the blue and green channels of the colour image and the 1988 data for the red channel.

Change Detection Imagery

Two images of the same location acquired at different times can be displayed to show changes between the two images. An area north of Kabul airport provides a good example of how to interpret the change imagery (Figure 6). Figure 6(c) is the multitemporal overlay image. Figures 6(a) and 6(b) are the panchromatic images acquired in 1987 and 1988. The before image is displayed using the blue and green channels of a colour image display and the after image is displayed using the red channel. Changes between the two images appear as either red or cyan. If the intensity for a pixel[15] is greater in the 1988 data than in

Figure 6 Changes in Area North of Kabul Airport as Shown by Change Detection Analysis

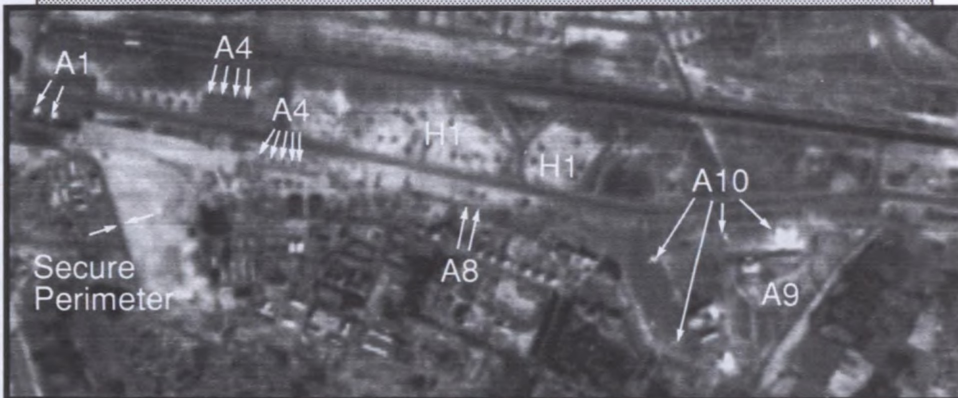
1987 panchromatic image

1988 panchromatic image

1987/88 change detection overlay image

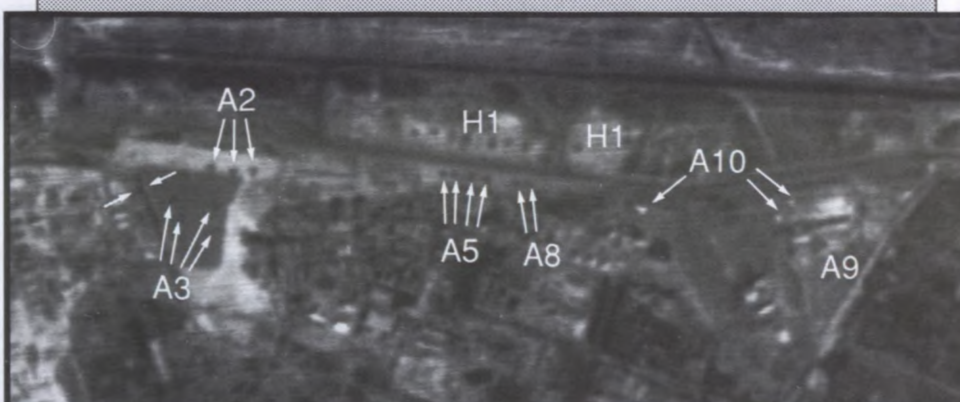
Figure 7 Changes at Kabul Airport as Shown by Change Detection Analysis

_A_



1987 panchromatic image acquired on November 11, 1987

_B_

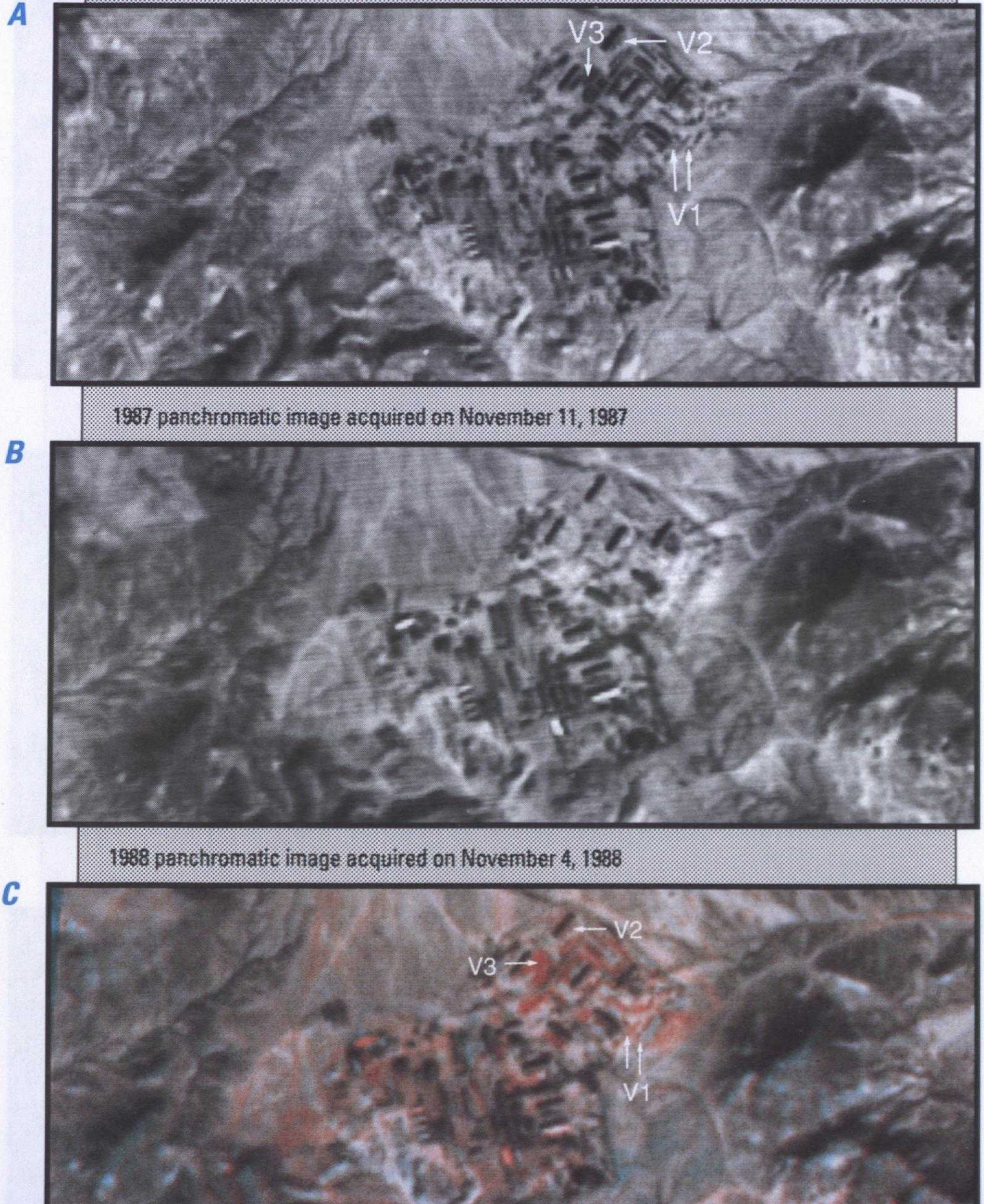


1988 panchromatic image acquired on November 4, 1988

_C_

1987/88 change detection overlay image

Figure 8 Changes at the NE Camp in Kabul as Shown by Change Detection Analysis



1987 panchromatic image acquired on November 11, 1987

1988 panchromatic image acquired on November 4, 1988

1987/88 change detection overlay image

the corresponding 1987 data, the pixel will appear red in the change image. Pixels for which the brightness values have decreased from 1987 to 1988 appear cyan.

Two buildings (C1 and C2) are present in the 1988 image that are not evident in the 1987 image. The decline in brightness for those pixels from 1987 to 1988 makes the new buildings appear cyan in the change image. There is a bright area between the new buildings in the 1988 image (C3), possibly from the construction of a foundation for another building. Since there was an increase in brightness from 1987 to 1988, the area appears red in the change image.

Other areas, such as at C4 and C5, also appear red or cyan. In these cases, however, the changes are apparently related to differences in vegetative cover from one year to another. In areas used for agriculture, many changes shown by the imagery will be due to routine variations in the types and status of crops. Some sources of change may be artifacts of the imaging or analysis process rather than any actual changes. For example, errors in registering the panchromatic images or differences in sun angle when the two images were acquired may lead to changes in mountainous areas.

The change detection enhancement shows only differences in image intensity between two images. Many factors affect the image intensities, most of which have no significance for the interpretive task at hand. A human image interpreter must still identify the changes that have meaning and disregard the remainder.

Monitoring Aircraft

Figure 7 shows 1987 and 1988 panchromatic images and a multitemporal overlay image of Kabul Airport. Two aircraft can be seen at A1 in Figure 7(a). To a limited extent, the general shapes of large aircraft are discernible. Other aircraft at A2 in Figure 7(b) also have detectable shapes. However, if the aircraft are small or if the visual contrast between the aircraft and its background is poor, the shapes of aircraft will not be evident. The targets indicated by the arrows at A3 in Figure 7(b) are probably aircraft. Other examples are indicated at A4 in Figure 7(a) and A5 in Figure 7(b). The interpretation that these are possibly aircraft must be based upon their location. Because the shapes of the aircraft are not discernible, an interpreter must use less reliable, indirect clues to identify them.

Change detection imagery can help distinguish between aircraft, which one would expect to move periodically, and permanent features of a similar size. For example, the aircraft at A6 in Figure 7(c) appear red. They appeared in 1987 (labelled A4) but not in 1988. The aircraft at A7 in Figure 7(c) appear cyan. They appeared in 1988 (labelled A2) but not in 1987.

Change detection imagery is useful to highlight areas of change but must be interpreted with caution. Areas in which no changes are apparent can also be of interest. The features indicated at A3 in Figure 7(b) are not evident in Figure 7(c). They might be aircraft, because they appear dark against a dark background in the 1988 image but they are not very apparent. The features identified as A8 in all three images might also be aircraft. Since there was something at that location when both of the images were acquired, there are no indications of any changes. Aircraft will often be routinely parked in the same location at different times, although they will not necessarily be the same aircraft.

The airport in Kabul is a civilian as well as a military facility. Specific kinds of aircraft cannot be identified directly, making it difficult to distinguish between military and civilian aircraft. One might assume that civilian aircraft will be located in the civilian section of the airport. The civilian airport terminal is located at A9, in the south-east end of the airport, with a terminal building and an access road leading to it. Aircraft located nearby (A10) could be civilian. However, it is not possible to be certain of this based solely upon this imagery.

Monitoring Helicopters

Two areas that are apparently being used as landing pads for helicopters are labelled H1 in Figures 7(a), 7(b) and 7(c). Once again, the shapes of the helicopters are undefined. It is possible to interpret them only if they are located at sites that are clearly prepared for use by helicopters.

Change imagery can help distinguish helicopters from non-moveable features about the same size. This kind of interpretation, relying heavily upon association, is subject to great uncertainty. Not all moveable objects at those locations have to be helicopters. As well, it is possible for a helicopter to be at the same location when *both* images are acquired, making it appear that nothing has moved.

Monitoring Vehicles and Equipment

Using SPOT imagery, with its spatial resolution of 10 m or more, all but the largest military vehicles will be smaller than even a single image pixel. Nevertheless, imagery of this quality might provide some limited evidence of large-scale migration of vehicles from an area.

Figures 8(a), 8(b) and 8(c) show part of the North East (NE) Camp in Kabul. The Soviet 108 Motorized Rifle Division was based in the NE Camp.[16] The red areas in the change image are indicative of dark-toned features that existed in 1987 but not in 1988. The thin lines at V1 and the smaller features at V2 might be vehicles parked in rows and next to a building. The thicker red areas, such as those indicated at V3, might be vehicles parked several rows deep.

Although the spatial resolution of SPOT imagery is clearly insufficient to detect individual vehicles, it might be able to detect changes in orderly rows of vehicles. At the same time, other possible explanations for the changes are apparent in the imagery. For example, it could be tents or packing crates that have been moved. Although it is fairly certain that something has been moved, the spatial resolution of the imagery is clearly much too limited to make a reliable assessment of what this is.

Discussion

The change detection enhancement was quite effective in finding areas of change between the two images. The potential for detecting construction starts was clearly shown in the area north of the airport. The shifting positions of aircraft and helicopters at the airport were plainly visible, suggesting that activity levels could be estimated to some degree using multitemporal coverage with civilian satellite imagery. Changes in rows of parked vehicles were also evident. Based upon the large changes seen in the storage area north of the NE Camp, it seems that any large-scale departure of equipment from such storage areas would be detectable using change detection techniques.

It is clear, however, that the imagery is not really suitable for monitoring military ground forces if anything more than very superficial information is required. Although it was possible to locate many of the military facilities in Kabul, more detailed interpretation concerning the actual military forces stationed there was unreliable. The interpretation depended heavily upon indirect cues such as the locations of features rather than more reliable ones such as their shape. Ground forces at undeclared locations would be difficult to detect, particularly if any efforts were made to conceal their presence.

Another limitation of commercial imagery for monitoring of military forces is its timeliness. Space Media Network, a company that specializes in providing commercial satellite imagery to the media, has made special arrangements to get SPOT imagery within a few days for fast-breaking stories.[17] However, this kind of delivery cannot be routinely provided and is very expensive. The delivery time for commercial imagery is usually several weeks or more, even for imagery that has already been acquired and archived. The length of time necessary to acquire, receive and then analyze the imagery means that considerable time will pass from the time an order is placed to the time the analysis results are available.

Objects must be fairly large to be evident in commercial satellite imagery. Either they must be permanent features or any changes of significance must occur over periods of weeks or more. These considerations severely restrict the potential usefulness of such imagery for verification of withdrawals of armed forces. However, there are other potential applications for commercial satellite imagery, such as the one to be outlined in the following section.

Part 3: Commercial Satellite Imagery for Peacekeeping Mission Preparation and Planning

Background

The objective of this project was to examine if commercial satellite imagery could provide information to support peacekeeping operations. History shows that peacekeeping missions most frequently occur in areas of the world for which maps are of dubious accuracy and reliability. Planning for peacekeeping operations must often be done with little or no on-site access. Under these circumstances, commercial satellite imagery is one of the few potential sources of information.

The United Nations Transition Assistance Group (UNTAG) operations begun in April 1989 in Namibia and Angola were chosen as a case study of how such imagery might have been useful. SPOT imagery was acquired of four sites in Namibia and Angola during May and June 1989. Panchromatic imagery was ordered of two sites: Windhoek and Ondangwa in Namibia. Merged P + XS imagery[18] was ordered for the other two sites: Operet in Namibia and N'Giva in Angola. Digital and film products were ordered for each scene. A 1:400 000 scale negative was ordered for each panchromatic image. A 1:200 000 scale positive transparency was ordered for each of the P + XS images (on 482 mm × 482 mm format film).[19]

Information for Planning of Peacekeeping Operations in Namibia

Figure 9 shows part of a panchromatic image of Windhoek. The road network and areas of urban development are clearly visible. Areas labelled as "new housing" in Figure 9 have been identified by comparisons with a city map published in 1984. In addition to new features, there are some older ones that have changed. A former rifle range has been split in half by a new highway extension. There are also small roads evident in the images that are not shown on the map. These may be new or they may not have been included when the map was made. Nevertheless, peacekeeping forces need to know where all the roads are, and their maps should be updated to show them.

For many areas, no maps may be available that show enough information for detailed site assessments. Commercial satellite imagery can provide valuable information for those areas. For example, based upon information in the *Atlas*

Figure 9 Potential of Commercial Satellite Imagery to Update Maps

Maps can be updated to show new areas of urban development, new highways and other features. The areas outlined on this image were shown as undeveloped on a map of Windhoek published in 1984. (© CNES, 1989, SPOT Image Distribution.)

Geográfico, published by the Ministério da Educaçao in Angola, N'Giva seems to be a major centre. It is the capital of the Cunene province in Angola, it is located on the transcontinental highway and it has an airport. However, the SPOT imagery provides a different perspective. N'Giva is less than two km wide and appears to have no large buildings at all. The airport is very small and has few facilities; there is only one runway with small turnarounds at either end, and there appear to be no shelters for aircraft.

Some facilities, particularly those of a military nature, may not be shown in much detail on maps. For example, the 1:50 000 topographic map for Ondangwa shows outlines for the main runways at the South African airbase but not much

Figure 10 SPOT Panchromatic Image of the South African Airbase at Ondangwa, Namibia

The satellite imagery provides much more information regarding the airport facilities than do normal topographic maps. (© CNES, 1989, SPOT Image Distribution.)

else. Peacekeeping forces may require further information regarding these facilities. The facilities of the airport can be interpreted in much more detail using imagery (Figure 10). Features that can be interpreted include:

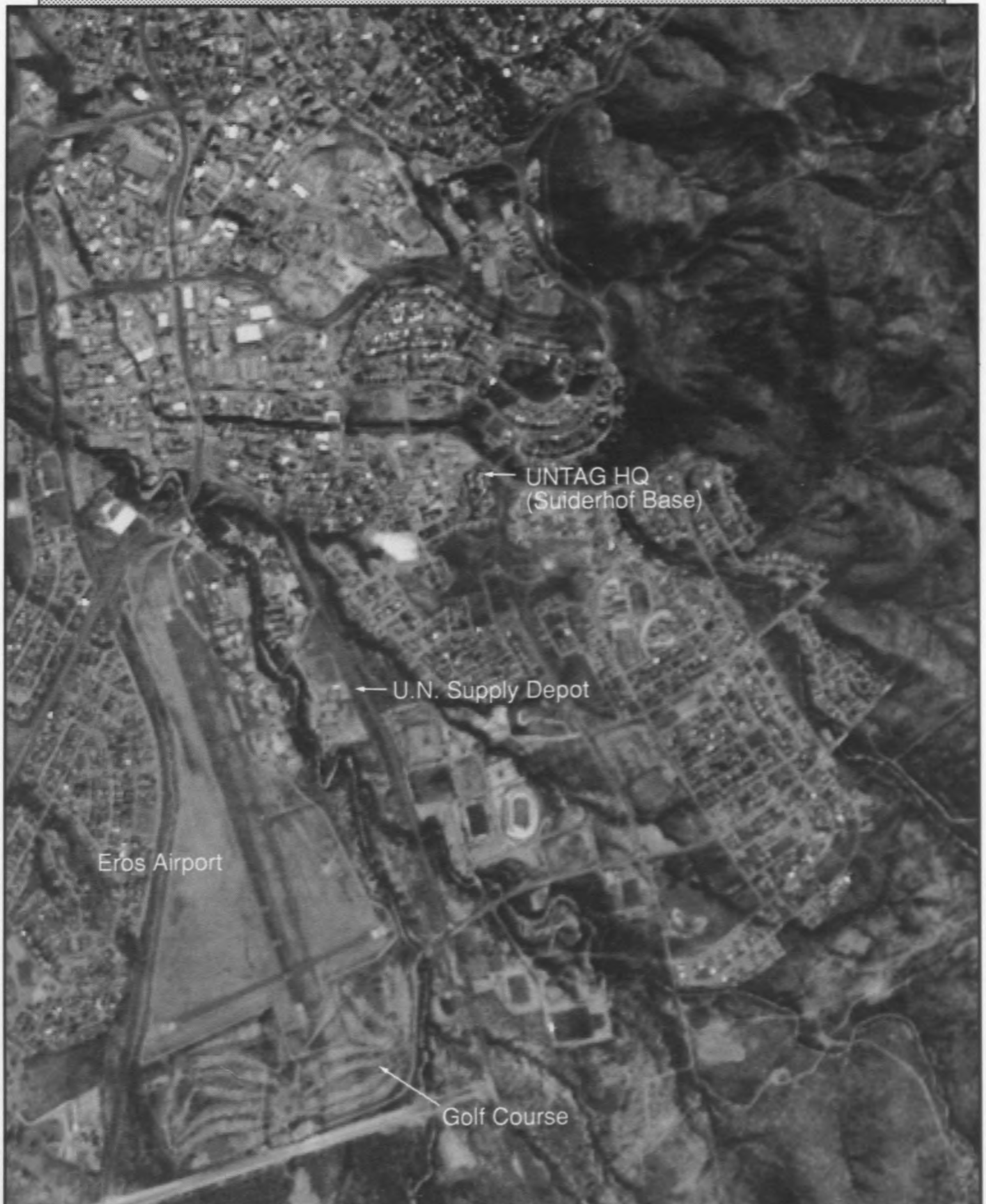
- secure perimeter
- runway lengths and conditions
- terminal building and hangars
- revetted storage facilities for ammunition or POL
- support and storage areas

Figure 11 SPOT Panchromatic Image of Leopard Valley, Namibia

Leopard Valley was a major South African military base near Windhoek, Namibia. Maps for this area showed almost no useful information regarding the facility. The imagery shows its general layout including the road network, locations of some major buildings, and areas protected by secure perimeters. (© CNES, 1989, SPOT Image Distribution.)

Figure 11 is an image of a major South African military facility located south of Windhoek, known as Leopard Valley. Topographic maps for the area simply show roads and a power line leading into the area and an outline of the rifle range. The SPOT imagery supplies much more information. It gives a good indication of the general layout of the facility, including the road network, locations of major buildings and the presence of secure perimeters.

Figure 12 SPOT Panchromatic Image of Windhoek Showing the Area of UNTAG Headquarters



The base is in the centre of a city, at the former Suiderhof military base, rather than in an isolated location. In this case, the base could not be located using the imagery alone. (© CNES, 1989, SPOT Image Distribution.)

Some military facilities, however, may not be very evident in commercial satellite imagery. UNTAG headquarters, located at the former South African Suiderhof base, is not very evident in the imagery (Figure 12). This is because it is surrounded by urban developments and lacks distinctive features to identify it as a military facility. Without first-hand knowledge of the area, facilities such as this could not be identified using commercial imagery. If a facility's location were precisely known already, commercial imagery might be useful to provide a better indication of its general layout.

Discussion

Commercial satellite imagery could be useful for preparation and planning of peacekeeping operations in several ways. Even given its limitations, commercial satellite imagery could greatly improve the quality of information available for planning during the initial preparatory phase of a peacekeeping operation. Planning for operations must often be done with little or no on-site access. Maps may well be out-of-date or have unsuitable scales.

Commercial satellite imagery is useful to detect new areas of development by comparing the imagery with a topographic map of the same area. Developments located at the periphery of a city are easier to recognize than those in areas that are already identified on the map as being developed. Areas of development within a city may be detectable if there is a clear change in land use that can be interpreted from the image. The imagery can also provide basic information on military facilities that are not shown on maps, or for which very little information is shown. In some cases, when maps may be inadequate because of scale or quality, commercial satellite imagery might be the *only* reliable source of information.

The advanced notice that would be required to order the imagery would not necessarily be a serious problem for such an application. First indications of a potential peacekeeping requirement can occur months or years before an actual commitment to undertake the mission. Meanwhile, much of the information derived from the satellite imagery could still be useful even after one year or more.

Commercial satellite imagery is usually available as a film product or as a digital product. Although a film product will almost certainly be required eventually, there are benefits to ordering the digital imagery. With a digital image, it is possible to write a section of the image onto film at *any* scale with no loss of information. The imagery of Namibia used in this report was written onto film at a scale of 1:25 000 and then contact printed to provide prints at the same scale. If these images had been photographically enlarged from film with a 1:400 000 or 1:200 000 scale, some of the fine spatial information would have been lost, impairing the usefulness of the imagery.

There are single-channel images, such as SPOT's 10-m panchromatic images, and multispectral images with several channels. For most peacekeeping requirements, multispectral imagery will provide more drawbacks than benefits. The primary use of multispectral images in a peacekeeping context would probably be to thwart attempts to camouflage military equipment. However, the spatial resolution and timeliness provided by commercial imagery limit its utility for this application. At the same time, colour film is required for hard copy products of multispectral imagery, whereas black and white film can be used for single-channel panchromatic images. Black and white film products are less expensive, available in large formats and generally easier to use.

Part 4: Commercial Airborne Systems for Monitoring in a Verification or Peacekeeping Context

Background

The objective of this project was to examine how commercial airborne systems could be used for overhead monitoring in a verification or peacekeeping context.

There has been limited use of aerial reconnaissance systems for verification and international peacekeeping to date. Airborne systems form part of the National Technical Means used by the United States and Soviet Union to verify their bilateral accords. The two superpowers employ a variety of sophisticated systems for gathering the verification-related information they require. Multilateral agreements to date have not incorporated the use of aerial reconnaissance systems.

Aerial inspections are permitted under the 1986 Stockholm Agreement on Confidence- and Security-Building Measures in Europe. However, aircraft are primarily intended in the Agreement to be platforms for human observers, not for sensors. Under the Agreement, inspectors can use their own photo cameras and binoculars, but no provision is made for use of actual aerial cameras or other specialized remote sensing equipment.

Aerial reconnaissance systems, however, have been used to some extent for peacekeeping. During the Sinai Disengagement Process (from 1972 to 1979), U.S. aerial reconnaissance aircraft were used extensively.[20] United Nations peacekeeping forces in Yemen (the United Nations Yemen Observer Mission — UNYOM) made use of eight reconnaissance aircraft to cope with the mountainous terrain of the area. However, most peacekeeping operations to date have relied more upon ground-based observers for gathering of information.

Airborne reconnaissance systems will likely become more important in the future for verification of arms control agreements and for confidence building. Aerial inspections may play a significant role in the verification of a Conventional Forces in Europe (CFE) Treaty. Negotiations are also under way for an Open Skies Treaty to permit aerial reconnaissance overflights in the Atlantic-to-the-Urals region as a confidence-building measure.

Figure 13 Conventional Aerial Photographs Provide an Economical and Reliable Source of Information

A variety of aircraft can be interpreted from this panchromatic photograph of an airfield based upon interpretive cues such as size and wing shape. (Courtesy of David M. Dorschner, Aviation Resource Management.)

It is also possible that aerial reconnaissance will have a greater role in future peacekeeping operations. To this end, the Government of Canada recently submitted a report to the United Nations, entitled *Overhead Remote Sensing for United Nations Peacekeeping*,[21] outlining the potential of such systems. That report, which was presented to the Secretary-General on May 21, 1990, derives in large part from the research summarized here.

The following section reviews potential applications of airborne systems for monitoring in a verification or peacekeeping-related context.

Monitoring with Commercial Airborne Sensors

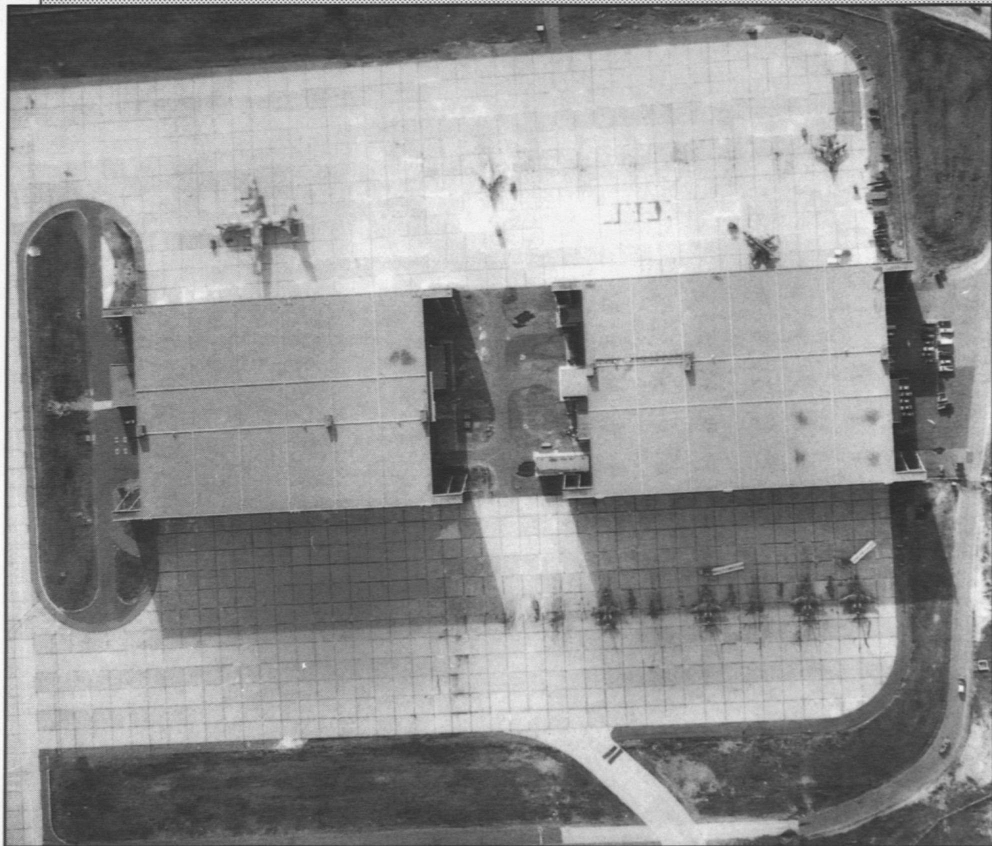
Aerial photographs can provide very fine spatial resolution, particularly if it is possible to fly directly over the features of interest at low altitude. Because

Figure 14 Hand-held Camera Systems Can Provide Oblique Photography with Very Fine Detail

This system has an interface with the aircraft navigation system to annotate basic flight information directly onto the film for each exposure. (Courtesy of Negretti Aviation, Croydon Division.)

photographic film must be developed before it is viewed, aerial photographs cannot provide real-time information. They are more suitable for those applications that require a detailed and permanent visual record to be obtained.

Figure 15 Daytime Panchromatic Aerial Photography and Nighttime Thermal Infrared

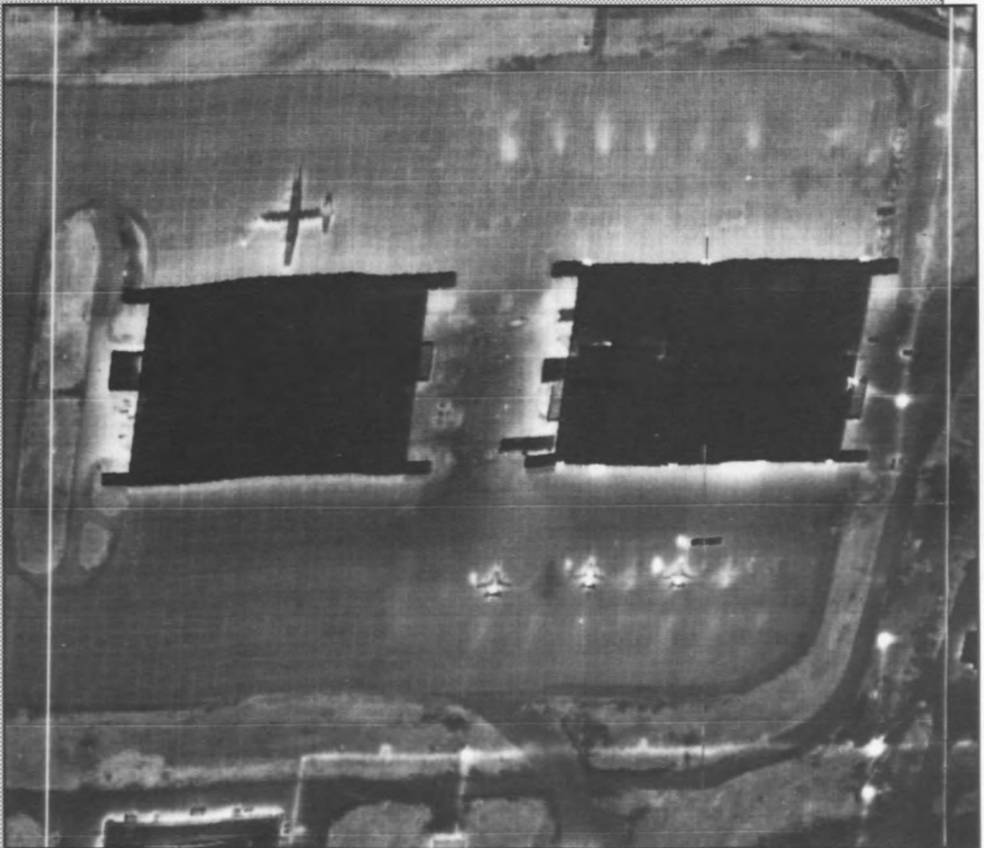


The two systems provide complementary overhead imagery. The aerial photograph (above) was acquired about six hours after the thermal image (next page). The thermal image shows warm vehicles and aircraft, warm buildings and buried steamlines, and warm spots left on the tarmac

Vertical aerial photography is most suited to acquiring coverage for **areas**, rather than individual **objects** (Figure 13). Vertical aerial photographs are usually acquired in strips to provide continuous coverage of the terrain along the aircraft's flight path. Adjacent flight lines are used to provide complete coverage for large areas. They will typically be acquired with overlap between adjacent photographs for stereoscopic viewing.

Equipment that has been destroyed according to a treaty could be displayed out in the open, and then vertical aerial photography could be acquired to provide a permanent record. The area coverage provided by the photographs is ideal for

Linescan Imagery

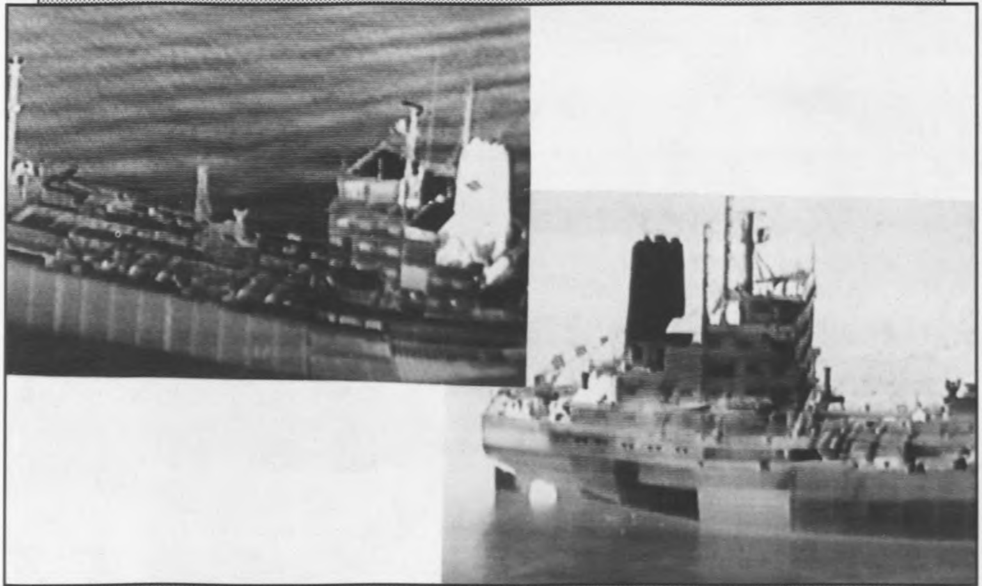


from jet exhaust. The spatial resolution provided by the aerial photograph is better than that provided by the thermal imagery.
(Courtesy of Canadian Department of National Defence.)

counting equipment spread out over a large area, while the fine spatial resolution of aerial photographs could ensure positive identification of the equipment put out for display.

Oblique photographs taken using hand-held cameras, such as the one shown in Figure 14, could provide compelling evidence to confirm or question compliance with the commitments of an agreement. The photograph has date, time and position information included in the margin through an interface with the aircraft's navigation system. The fine detail in the photograph can ensure positive identification of the objects of interest.

Figure 16 FLIR Images of Freighters



Notice the hot exhaust stack in the left image and the ability to "see through" the hulls of the ships because of the differences in surface temperature resulting from the contents of the holds. (Courtesy of David M. Dorschner, Aviation Resource Management.)

Thermal infrared systems provide a nighttime capability to complement that of photography and charge coupled device (CCD) systems. Infrared linescanners provide a good nighttime counterpart to vertical aerial photography since linescanners are usually configured to record long strips of overhead imagery (Figure 15).

FLIRs are better for acquiring oblique imagery and real-time operations. A FLIR can be pointed toward a specific object, such as the ship shown in Figure 16, and then keep it under observation continuously as it moves or as the aircraft circles around it. FLIR systems can also be equipped to show ancillary information such as the time, date and position in the margins of the image frame.

The resolution of thermal infrared systems is not as fine as that of aerial photographic cameras, but the systems provide enough detail to distinguish between most categories of equipment. Several different kinds of aircraft can be identified from the thermal image in Figure 17. As with aerial photographic systems, the detail provided by a thermal image is partly determined by the distance from the sensor to the object. If more detail is required, it may be possible simply to fly lower.

Figure 17 Thermal Infrared Linescanner Imagery of Aircraft at a Military Base

Several types of aircraft can be identified. Thermal shadows remaining in locations where aircraft were parked during the day are also visible (indicated by arrows). (Courtesy of Canadian Department of National Defence.)

To some extent, thermal imagery might be able to provide an indication of activity levels. For example, the engines of vehicles remain detectably warm after they have been parked and turned off, thereby signalling that they have recently been moved. In Figure 17, several thermal shadows are visible on the tarmac. Aircraft were parked there during the day, providing shade to keep the underlying tarmac cool. Later in the evening, the thermal shadows remain even though the aircraft are now gone. The body heat of individual people can be resolved using some FLIR systems when operated at low flying heights. This could be useful to peacekeeping forces to detect infiltration across borders at night.

In some regions, such as Europe or Central America, an all-weather reconnaissance capability will be essential. The systems described previously cannot penetrate cloud. Commercially available airborne synthetic aperture radar would provide such a capability, albeit without the spatial detail provided by aerial photography or thermal infrared systems.

Fortunately, many of the potential objects of interest for arms control verification or peacekeeping also happen to be very good radar reflectors. Vehicles,

Figure 18 Synthetic Aperture Radar Imagery of an Airfield

The image was acquired using a SAR with 3 m × 3 m resolution. The aircraft on the tarmac appear as bright returns. The asphalt runway and river are surfaces providing low returns and appear dark. Perimeter fences appear as bright lines, particularly if they are oriented parallel to the aircraft's line of flight when the image was acquired. (Courtesy of Intera Technologies Ltd.)

aircraft and ships all appear very bright in radar imagery, making them easy to detect. A number of aircraft are clearly evident on the tarmac in Figure 18. The bright targets in Figure 19 are tethered destroyers. Although the aircraft and ships are clearly detectable, the imagery does not provide enough information to identify the actual types of aircraft or ships.

Airborne Synthetic Aperture Radar (SAR) has potential for patrolling large areas. With a typical swath width of 25 km, an airborne SAR can collect imagery for large areas in a single sortie. A twin-engine turbo-prop aircraft equipped with a SAR could acquire imagery of the entire coast of Namibia, a distance of 1350 km, in a period of four hours.

Figure 19 Synthetic Aperture Radar Imagery of Tethered Destroyers

The destroyers seen as bright returns near the bottom of this SAR image are plainly visible but not necessarily easy to identify. Many common cultural features, such as roads, an airport, and housing subdivisions, are evident in the image. (Courtesy of Intera Technologies Ltd.)

Since it operates from a considerable standoff distance, an airborne SAR could be used to acquire imagery during a military exercise without directly overflying the area. A SAR could regularly monitor a border from a distance. It could provide early warning to peacekeeping forces of military activity such as the

Figure 20 Potential of Synthetic Aperture Radar Imagery for Monitoring Border Areas

The wide swath coverage and standoff distance provided by SAR imagery could make it useful for this type of monitoring. (Courtesy of Intera Technologies Ltd.)

movement of vehicles and equipment up to the border or the construction of bridges for river crossings (Figure 20).

Discussion

A wide variety of commercially available airborne remote sensing systems exist that would be useful in a verification or peacekeeping-support context. No single sensor or platform is likely to be suitable for every requirement. However, sensor/platform packages could be put together to suit most situations.

A combination of aerial photography and thermal infrared linescanning would provide a day or night capability to collect overhead imagery. For real-time operations, CCD cameras could be used during the day and FLIR systems for operations at night. SAR would provide an all-weather capability.

Aerial reconnaissance systems are flexible. Aircraft and sensors can be modified to suit required tasks. Overflight parameters can be varied to provide imagery of a specific scale or coverage at a particular time. The imagery can be produced in real time on the aircraft, down-linked to a ground station or recorded on magnetic tape or film to be examined at some later time.

Airborne systems could be particularly appropriate for multilateral verification and peacekeeping. Aerial surveillance would be within the technical and financial resources of many countries that could not develop or operate a more sophisticated satellite-based system. The option of restricting overflight coverage and allowing host country personnel to accompany the aircraft during overflights may make aerial reconnaissance politically acceptable by ensuring that unauthorized data collection does not occur.

Co-operative verification may benefit from the use of commercially available sensors and platforms. Aircraft could be subject to inspection or could be required to have host country observers on board when overflights are done. In this way, commercial sensors may avoid concerns of spying to the extent that use of special-purpose military reconnaissance systems would. At the same time, commercial sensors would be capable of collecting data that would be very valuable for arms control verification or peacekeeping support.

Conclusion

Commercial remote sensing systems could make valuable contributions to arms control verification and peacekeeping operations. Satellite imaging systems could provide basic information for preparatory planning of peacekeeping operations. Airborne systems could provide more detailed information for arms control verification or peacekeeping. Systems are available that can provide day or night and all-weather coverage. The two types of technology — satellite and airborne — are complementary and could provide two important links in a multi-method, layered monitoring system.

Commercial satellite systems are not well suited for direct monitoring of military ground forces. Imagery from these systems would be better for interpretation of larger, more permanent features. This type of data, for example, would be useful for initial planning of peacekeeping operations, in which general information is required for updating maps to show new roads and unmarked features such as military facilities.

Airborne systems can provide more timely information with finer spatial resolution than can the commercial imaging satellite systems. Imagery from airborne systems, therefore, would be more appropriate for direct monitoring of military forces in a peacekeeping or arms control verification context. The use of commercially available airborne systems for the overflights means that the sensors and aircraft could be inspected before any overflights are made.

Although commercially available remote sensing systems are similar in some respects to military reconnaissance systems, the context in which they are most likely to be used is quite different. Commercially available systems could be more appropriate for co-operative verification or peacekeeping missions than the use of military systems would be. Technology used for verification-related monitoring may well have to be made available to all participants in the treaty regime to prevent any perception that some are at a disadvantage. The need to protect sensitive military technology generally precludes the use of such systems in these situations. Moreover, monitoring for peacekeeping purposes must usually be done in situations where trust and confidence are fragile. In some cases, the use of advanced military systems may undermine whatever trust and confidence has developed.

NOTES

1. Thomas M. Lillesand and Ralph W. Kiefer, *Remote Sensing and Image Intrepretation* (New York: John Wiley & Sons, 1979), p. 1.

2. In the Western Hemisphere, Central Trading Systems Inc. has exclusive rights to market Soyuzkarta imagery.

3. The oblique viewing capability also makes it possible to obtain stereo image pairs for a given location by acquiring images at different angles during different satellite passes on neighbouring tracks. This capability is important for cartographic applications but will not be considered here.

4. *SPOT User's Handbook. Volume 1: Reference Manual* (Toulouse: CNES and SPOT Image, 1988), pp. 1-21.

5. The line sampling interval, which determines the spatial resolution of the system in the across-track dimension, is related to the space separating individual charge coupled device (CCD) detectors in the arrays. The column sampling interval, which determines the spatial resolution in the along-track dimension, is a function of the time interval between the acquisition of successive lines.

6. G. Calhes and Y. Trempat, "Exploitation of the SPOT System," *Geocarto International* 3 (1986), p. 20.

7. Landsat-3 also had a thermal infrared band sensitive from 10.4 to 12.6 µm. However, the thermal channel proved to have excessive noise, thus making its use limited.

8. Unless equipped with a flash system to provide illumination.

9. In certain circumstances, it is possible to take photography under an overcast sky but this results in photographs with no shadows and low contrast.

10. Thermal imagery can be obtained by flying under an even cloud cover, but this generally results in imagery with a low thermal contrast.

11. Adapted from: *Airborne Remote Sensing for C.F.E. Verification: The Platform* (Toronto: Boeing Canada, de Havilland Division, June 1989), p. 7. Report SER-8-2295.

12. These aircraft are being used as representatives of categories of aircraft. Their selection for this presentation does not constitute an endorsement of these particular aircraft.

13. U.S. State Department estimates of the total number of Soviet forces were as high as 120 000. According to a statement on May 26, 1988, by Marshall Sergei Akhromeyev, Soviet Armed Forces Chief of Staff, the Limited Contingent of Soviet Forces in Afghanistan totalled 100 300.

14. Craig Karp, "Afghanistan: Eight Years of Soviet Occupation," *Department of State Bulletin* Vol. 88, No. 2132 (March 1988), p. 2.

15. Derived from "picture element" — a single location in a digital image identified by a pair of row and column co-ordinates.

16. David C. Isby, *Weapons and Tactics of the Soviet Army* (London: Jane's Publishing Company, 1988), p. 34.

17. Christer Larsson, Space Media Network. Personal communication.

18. A satellite image product offered by SPOT Image, the P + XS imagery is created by merging a panchromatic (P) image and a multispectral (XS) image that have been acquired simultaneously. The result is a multispectral image with an effective spatial resolution of 10 m.

19. Because of the problems related to printing colour transparencies of this size, SPOT Image later provided a 241 mm × 241 mm transparency at 1:200 000 scale of a specified area in each image.

20. Brian S. Mandell, *The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management* (Ottawa: Department of External Affairs, 1987), p. 13. Arms Control Verification Studies No. 3.

21. *Overhead Remote Sensing for United Nations Peacekeeping* (Ottawa: Government of Canada, April 1990).

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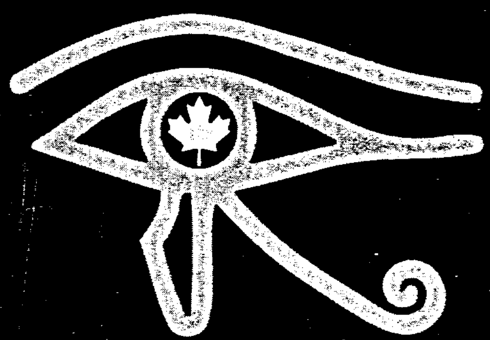

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