Information dominance

What it is and some examples on how it can be achieved

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1. Information dominance and situational awareness

Information dominance and information superiority are closely related terms. The *US Army Field Manual 100-6* on *Information Operations* defines information dominance as:

> The degree of information superiority that allows the possessor to use information systems and capabilities to achieve an operational advantage in a conflict or to control the situation in operations short of war, while denying those capabilities to the adversary.

In his well-known book *Information Warfare, Principles and Operations*, E. Waltz (1998) quotes the US DoD:

> Information superiority is the capability to collect, process and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same.

The objective of this flow of information is to provide *dominant battlespace awareness* (the understanding of the current situation based, primarily, on sensor observations and human sources) and *dominant battlespace knowledge* (the understanding of the meaning of the current situation, gained from analysis).
The benefits of information superiority are to be found in the following operational areas: intelligence preparation of the battlespace, battlespace surveillance and analysis, battlespace visualisation and battlespace awareness dissemination. A key step towards achieving information dominance is reached when one commander's level of battlespace visualisation is significantly greater than that of his opponent's (*US Army Field Manual 100-6*, 1996).

Depending on the source, the quality of the information and the contribution to information dominance can vary. Important *quality assessment criteria* are:

- accuracy (does the information convey the true situation);
- relevance (does the information apply to the mission, task or situation at hand);
- timeliness (is the information available in time to make decisions);
- usability (is the information in common, easily understood formats and displays);
- completeness (does the decision maker require more information);
- precision (does the information have the required level of detail).

From the technical point of view, sensor systems are important sources of information. They can be mounted on different platforms, either space-based, airborne or ground-based. The accuracy, timeliness, completeness and precision of the information are highly dependent on the sensor/platform combination that is used. This is elaborated in the following sections where emphasis is placed on the large class of sensors that use electromagnetic radiation.

After a brief description in section 2 of the general properties of sensors and platforms, some selected topics will be treated in section 3. Intelligence Preparation of the Battlespace (IPB) is an ongoing activity, using existing databases and accurate (but not necessarily real-time) information. Reconnaissance and Surveillance (RS) produce actual information with a (near) real-time character. Some examples of both IPB and RS will be presented; it is clear that in practice these processes show mutual interference and overlap. The final topic in section 3 is Vehicle Positioning Systems, using GPS, as a basic information system for a Battlefield Management System (BMS). Apart from GPS, no ground-based sensors will be considered in this paper.

2. Sensors and platforms

2.1 Sensors

The timeliness of information depends greatly on the ability of the sensor to function during day and night and in adverse weather conditions (fog, rain, clouds). The accuracy of information in general decreases with time, unless it can be updated regularly within intervals consistent with the rate of change of the situation. Precision (information details) strongly depends on the resolution that is offered by the systems.

Optical sensors include (analog) photographic systems and (digital) CCD cameras for daylight operation and image intensifiers and night vision goggles (mainly for individual use) for night time. Their use is limited to clear weather conditions: no fog, no rain and (depending on the height of the platform) no clouds. These restrictions can have severe consequences for the timeliness and accuracy of the available information, especially if (near) real-time information is required. An advantage of the optical sensors is their good performance as far as the geometrical resolution is concerned: they are, in principle, capable of offering very detailed information. The resolution, measured in meters, is range dependent.

Panchromatic optical sensors use a relatively broad wavelength band, containing a lot of energy, to generate a black and white image. Due to the large signal-to-noise ratio that is available a good geometrical resolution can be obtained. *Multispectral* sensors make observations in different, relatively narrow, wavelength bands of the electromagnetic spectrum. Because these bands contain less energy, the required signal-to-noise ratio can only be achieved at the expense of the geometrical resolution. Since the elements in the terrain have different reflective characteristics in different wavelength bands, the sensor signals can be used to discriminate between these elements. *False colour images* are generated when three sensor signals, originating from three wavelength bands, are displayed in red, green and blue respectively. The same technique can also be used to generate false colour polarimetric SAR images or fused images from different sensors (image fusion). The composition of these images must be carefully chosen in order to highlight the required information, thereby using the relevant sensor properties in an optimal way.

Thermal infrared sensors (thermal imagers) can operate during day and night and are slightly less vulnerable to weather conditions (light fog can be tolerated). Completeness of information is sometimes better than for optical sensors since thermal camouflage is (still) less effective. Geometrical resolution is not as good as for optical systems.

Active microwave systems can be used during day and night and under nearly all weather conditions (except heavy rain). This favours the timeliness of information. Detection performance is good, but geometrical resolution is in general insufficient for object recognition. In (conventional) side-looking airborne radar (SLAR) the geometrical resolution in azimuth direction (flight direction) is range-dependent and the use of these sensors is restricted to airborne platforms. The azimuth geometrical resolution of synthetic aperture radars (SAR) is range-independent; this sensor can be mounted on satellites, airplanes and RPVs as well. SAR signal processing is very complex and requires more computation facilities than the platform can generally carry. Therefore, high capacity storage facilities or data links are necessary. Real-time operation is not yet possible.

2.2 Platforms

Commercial satellite services show an explosive growth, both in communications and intelligence (spaceborne remote sensing). Satellites are very well suited as a platform to monitor large areas on a regular basis. The orbit of these platforms is elliptical in shape, but satellites carrying image forming sensors are usually put in orbits which very much approximate a circle. Gravity laws cause a high orbiting satellite to take considerably longer to circle the earth than a low orbiting satellite. The orbital period of a geostationary satellite at a height of nearly 36,000 km is (of course) 24 hours, while for the SPOT satellite, having an 830 km altitude orbit, the period is approximately 100 minutes. SPOT is a typical example of the class of image forming remote sensing satellites. Quite often these are placed in a sun-synchronous orbit, which is a low altitude polar orbit that allows the sensor to take repeated images at the same time of day. Since the orbital period is much less than one day, images can

System	*Timeliness/accuracy*	*Precision/completeness*
Optical sensors	daytime; clear weather	high geometrical resolution, range dependent; high radiometric and spectral resolution
Thermal infrared sensors	day and night; weather dependent	Medium geometrical resolution; high thermal resolution; less vulnerable to deception and camouflage
Side looking airborne radar (SLAR)	day and night; all weather	good detection performance; low resolution
Synthetic aperture radar (SAR)	day and night; all weather	Medium geometrical resolution, range independent; polarimetry/interferometry/MTI
Airborne platforms	Depending on access to the area of interest	Depending on the sensors on board
Spaceborne platforms	Depending on the revisit time	depending on the sensors on board

Table 1: Selected characteristics of some sensors and platforms

be acquired of several ground tracks within 24 hours. After a number of days (for SPOT: 26 days) the ground tracks are repeated; the revisit time (the minimum time between two observations of the same area) can be much shorter, depending on the capability to steer the sensor's field of view. For SPOT, the revisit frequency can be as high as 11 times in the track repeat period of 26 days.

The revisit time is an important parameter with respect to the timeliness and accuracy of information. A second important parameter is the geometrical resolution: high precision information, showing many details, requires a good (i.e. small) geometrical resolution. For electro-optical sensors, the geometrical resolution gets worse as the range to the scene increases, which favours low flying platforms. The resolution of SAR systems is independent of the range: 'SAR on a satellite is as good as SAR on an RPV', but the resolution cannot match that of electro-optical sensors.

Compared to airborne platforms, a great advantage of satellites is their extraterritorial status: an essential asset in nearly all stages of a (potential) crisis situation. Data can only be transmitted to a ground station when a line-of-sight is present. This requires either a storage capacity on board of the platform or an adequate number of ground stations. For real-time operations in a certain area, a (semi)mobile ground station can be a good solution. Airborne platforms may have the possibility to adapt their position (height) in order to establish a line-of-sight.

3. Selected topics

3.1 Intelligence Preparation of the Battlespace (IPB)

The major elements of IPB are shown in Figure 1 (Waltz & Llinas, 1990).

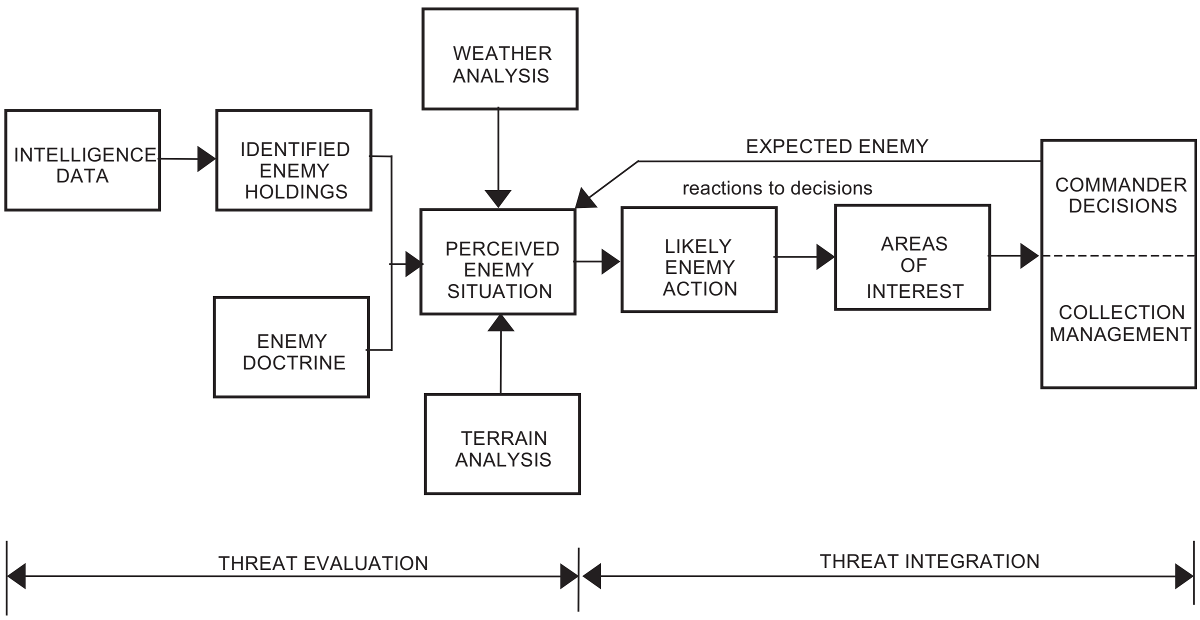


Figure 1: Intelligence Preparation of the Battlespace

Intelligence preparation of the battlespace comprises two major parts: threat evaluation (using multisource intelligence data, providing an initial assessment of the situation) and threat integration (leading to the identification of areas of interest and priority information requirements. The IPB process is continuous. It concentrates on building the IPB data base prior to hostilities and outlines its applicability in support of tactical operations.

This section will focus on the element labelled ‘terrain analysis’ in figure 1. Geographic Remote Sensing (GRS) from spaceborne or airborne platforms provides input for Geographic Information Systems (GIS) which form a basis for systems such as ISIS (Integrated Staff Information System) and BMS (Battlefield Management System). A GIS can also be used in the mission planning process to predict terrain trafficability estimated from soil type, slope gradients, tree size and distance, road width, ditch size, etc. (provided this information is contained within the GIS). Important features in a GIS can be selected from a DIGEST database (Digital Geographical Exchange Standard); they can be grouped in several categories:

- culture: buildings, roads, bridges,…
- hydrography: rivers, lakes,…
- relief: contour lines,…
- land forms: soil type, soil condition,…
- vegetation: cropland, trees (including height, stem diameter, spacing,…),…

Airborne and spaceborne remote sensing examples will be given in the categories landforms/vegetation, culture/hydrography and relief. The actualisation of an existing topographic map will be demonstrated as an application.

Figure 2 shows three images of the area around the city of Olst (size 3 km by 2 km). The sensors were mounted on *airborne* platforms. From top to bottom:

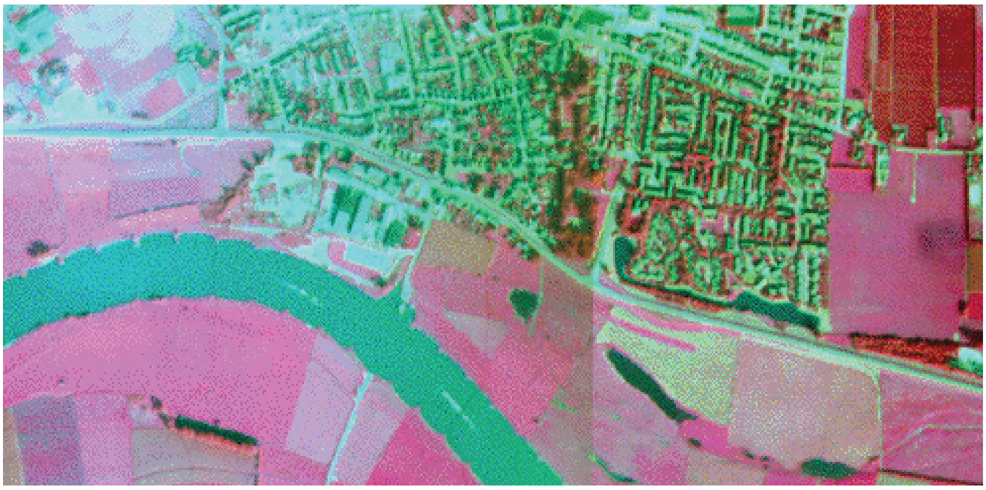
- a false colour image, generated by a multispectral optical sensor; geometrical resolution 3 m;
- a thermal infrared image; geometrical resolution 5 m, thermal resolution 0.15 K;
- a SAR image; geometrical resolution 6 m.

Classification of ground elements in a false colour image is based upon knowledge of the reflective properties in the different wavelength bands, supplemented by collected ground truth (field checking), for example: maize fields are displayed in brown, pasture in red, barren ground in green.

The thermal infrared image reveals the (radiation) temperatures in different grey-levels. Culture elements (e.g. buildings) are shown in white, just like barren land (heated by the sun), while pasture, having a lower temperature, is nearly black.

Buildings exhibit strong backscatter of the microwave radiation and appear as white spots in the SAR image. In some systems the SAR transmitter and receiver are both operating in the same (vertical or horizontal) polarisation mode (single channel mode). A polarimetric SAR has three channels for three combinations of vertical and horizontal polarisations. Examples of images are given in Figure 3 (Smith et al, 1999), showing a larger area around the same city as in figure 2. From top to bottom: three channel mode (avaraged polarimetric channels, featuring less noise than the one channel mode), false colour (using the outputs from the three channels independent of the classification of the ground elements) and the ‘classification image’ (using the signals of the three channels for the classification: water is blue, grass is light green, forest is dark green, barren ground is black, etc.). The geometrical resolution in all three images is 6 m.

A



B

C

Figure 2: Three images of the area around the city of Olst
A. False colour optical image
B. Thermal infrared image
C. SAR image

A

Olst

B

C

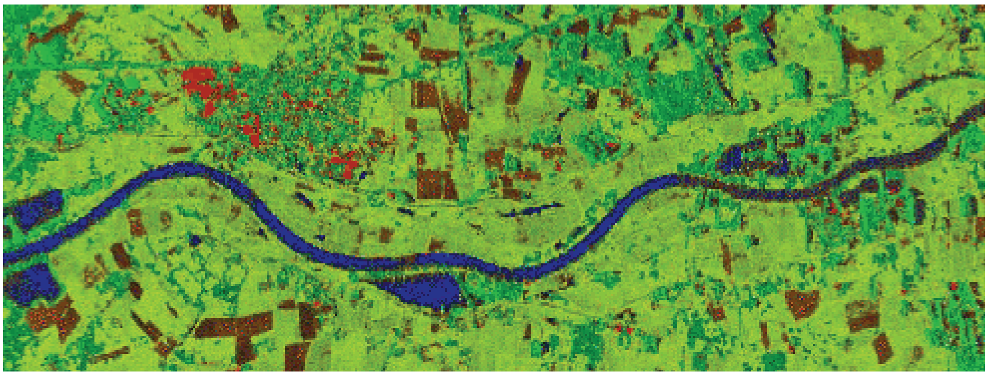
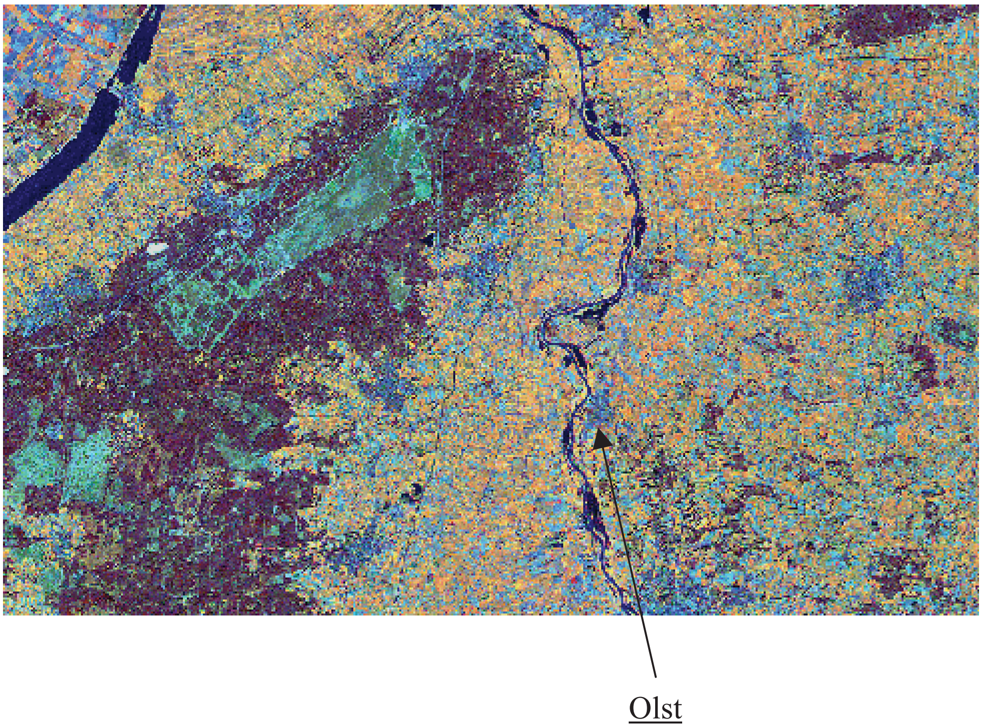


Figure 3: SAR images of a larger area around the city of Olst

A. Three channel mode
B. False colour
C. Classification result

Examples of *spaceborne* remote sensing are given in Figure 4 (Wijnhoud, 1995); the city of Olst is indicated.
In each of the images the false colour is generated by combining in red, green and blue the signals from three out of the seven wavelength channels of the LANDSAT/TM satellite (land observation satellite/thematic mapper). The ground resolution is 30 m. Specialists use these false colour images to classify and monitor landforms and vegetations. LANDSAT images are available from one of the many commercial satellite services that are in operation.

A



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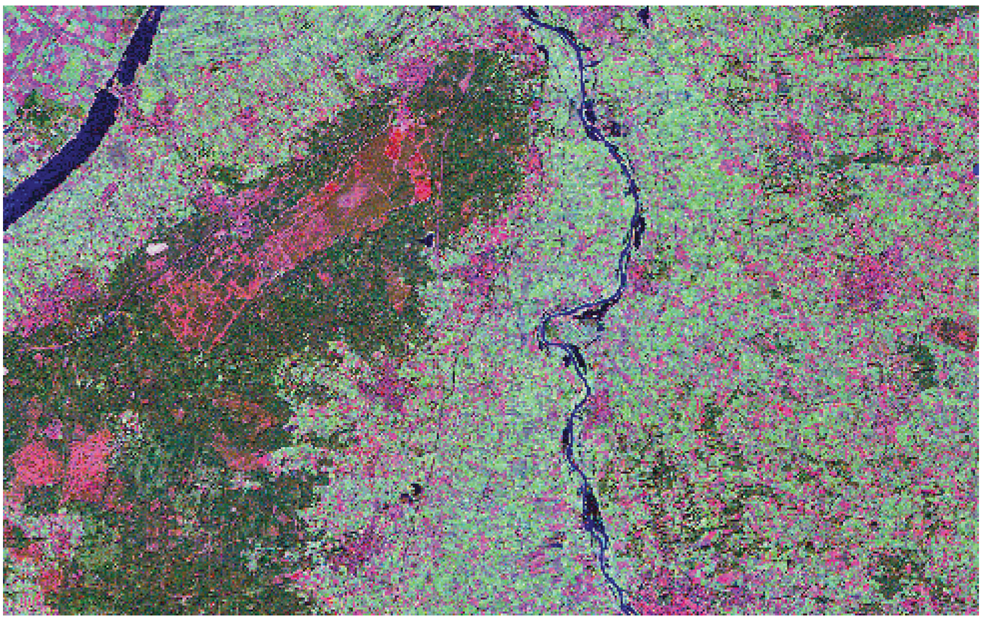

Figure 4: Examples of spaceborne remote sensing of the area around the city of Olst

Figure 5 (van de Broek et al., 1998)) shows satellite images of a power plant and the corresponding topographic map. The sensor/platform combinations are LANDSAT/TM (optical/false colour, resolution 30 m), SPOT XS (optical/false colour, resolution 20 m), SPOT PAN (optical/ /panchromatic, resolution 10 m), KVR (optical/photographic, resolution 2 m), ERS (SAR, resolution 25 m) and JERS (SAR, resolution 25 m).

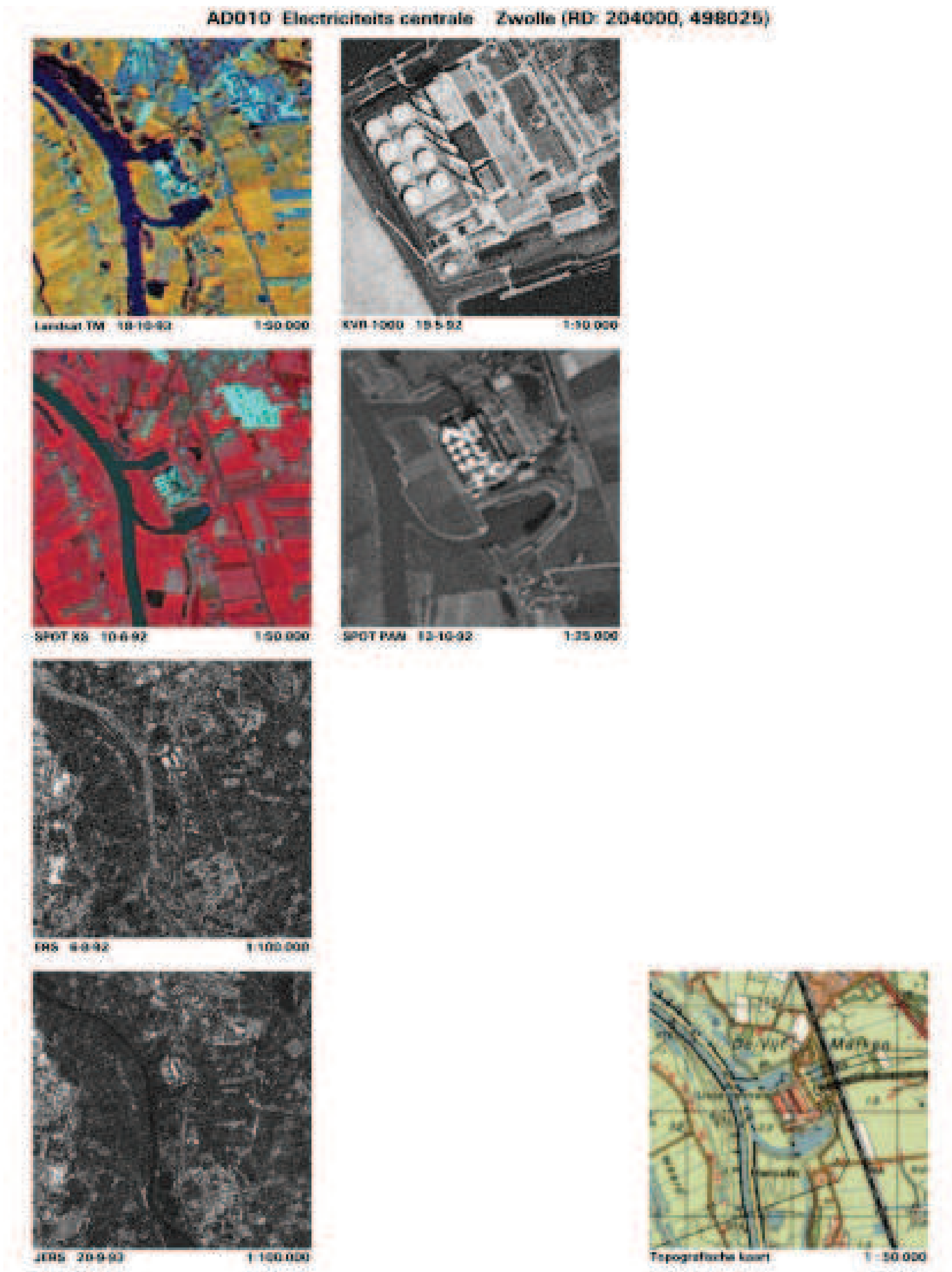

Figure 5: Satellite images of a power plant and the corresponding topographic map

Feature extraction from airborne and spaceborne imagery can be an essential element in the process of updating topographical maps. From the given examples it may be clear that in order to achieve completeness of the information, landform and vegetation features require good sensor performance with respect to spectral and radiometric resolution, while culture and hydrographic features require good geometrical resolution. In addition to this, the relief is of great importance for different reasons.

Distortions of airborne and spaceborne imagery occur when height differences (relief) are present in the terrain. These distortions can be corrected if a DEM (Digital Elevation Model) is available. Furthermore, a DEM can be used to generate relative and absolute height maps (slopes, height contour lines) and synthetic environments for the purpose of mission rehearsal (flight simulation for aircraft, helicopter or RPV as part of the mission preparation).

Both optical and microwave sensors can be used to generate a DEM. The most important techniques are optical and microwave shadowing (mainly for small scale height determination such as tree height), optical stereo and microwave interferometry. The latter two methods require images from the same area, taken under different viewing angles. SPOT satellites produce ‘repeat pass’ stereo images: the same area is observed during different orbits. Appropriate optical stereo image pairs are not always available in existing databases, but can be obtained from present spaceborne systems within a number of weeks, depending on the weather conditions. Future planned optical satellite systems will often have forward-backward viewing capabilities so that stereo-pairs can be acquired during one overpass. Present sensors offer a height resolution of about 10 m with a grid size of 100 m.

ERS 1 and 2 ‘repeat pass’ microwave interferometry can, in principle, produce a DEM with an accuracy of about 10 m. Small environmental differences in the repeated passes (vegetation!) introduce noisy figures, degrading the accuracy. Single pass interferometry (which requires two antennas on the platform, separated by some distance), does not suffer from this effect. In an experiment in 1999/2000 the Space Shuttle carried two antennas, 60 m apart, providing a height resolution of 15 m and a ground resolution of 30 m. A ‘world wide’ DEM will be created, covering the area between 60^0 North and South latitude.

An important application of geographic remote sensing products is the actualisation of existing topographical maps. In a demonstration experiment, conducted by the Topografische Dienst Nederland (Dutch Topographic Service) and GeoPerfect TWI b.v. (currently ESRI Nederland b.v.), an older map of the former Yugoslavia was taken as a starting point. SPOT satellite images of the same area were selected from an existing catalogue, on the basis of a quick-look via Internet. With two overlapping images a DEM was constructed and used for the distortion correction of the SPOT images. These images were then compared with the (digitised) topographical map. The two products are shown in Figure 6 (a, b):

- an updated map
- an adapted satellite image, including selected features

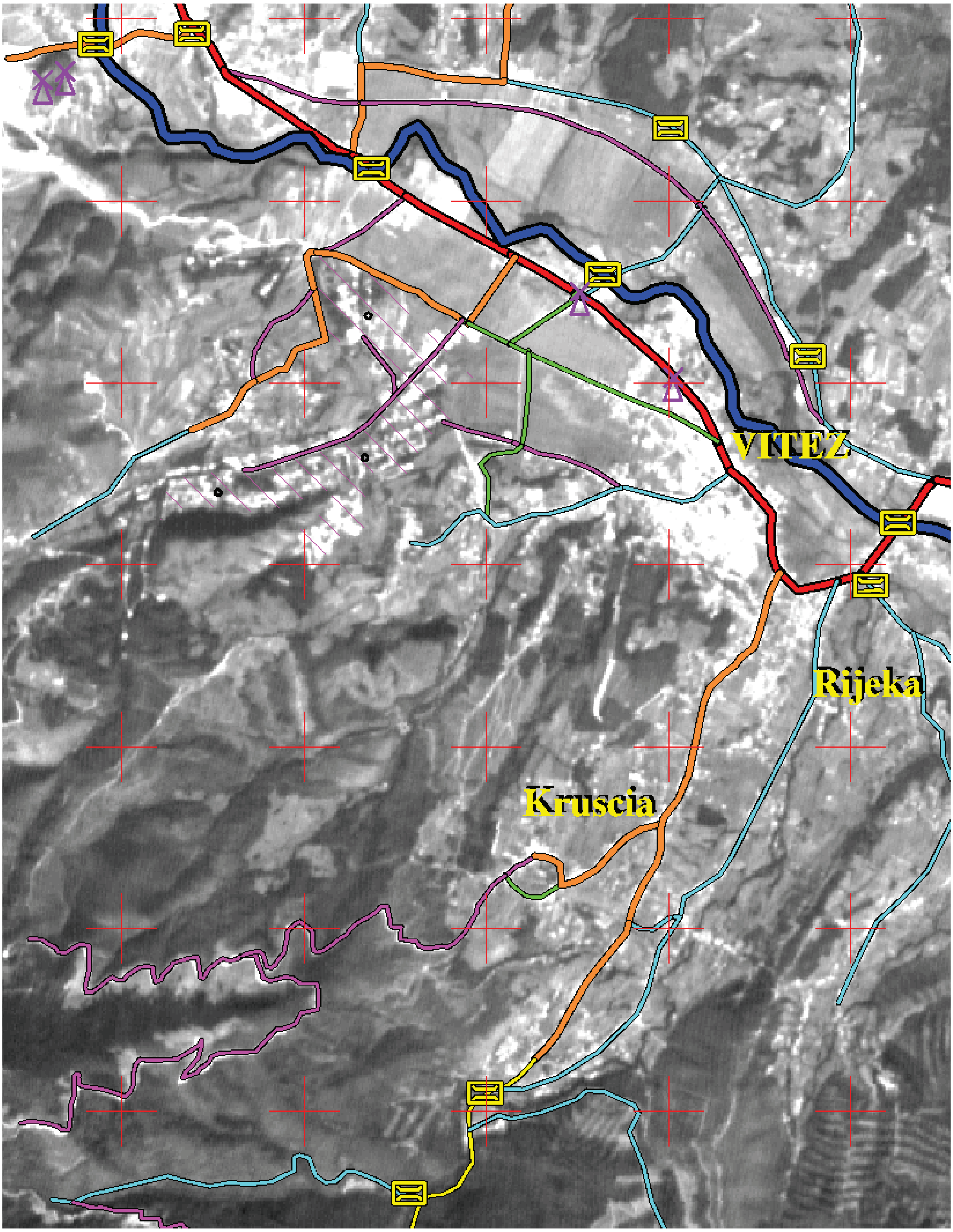

Figure 6a: Satellite image

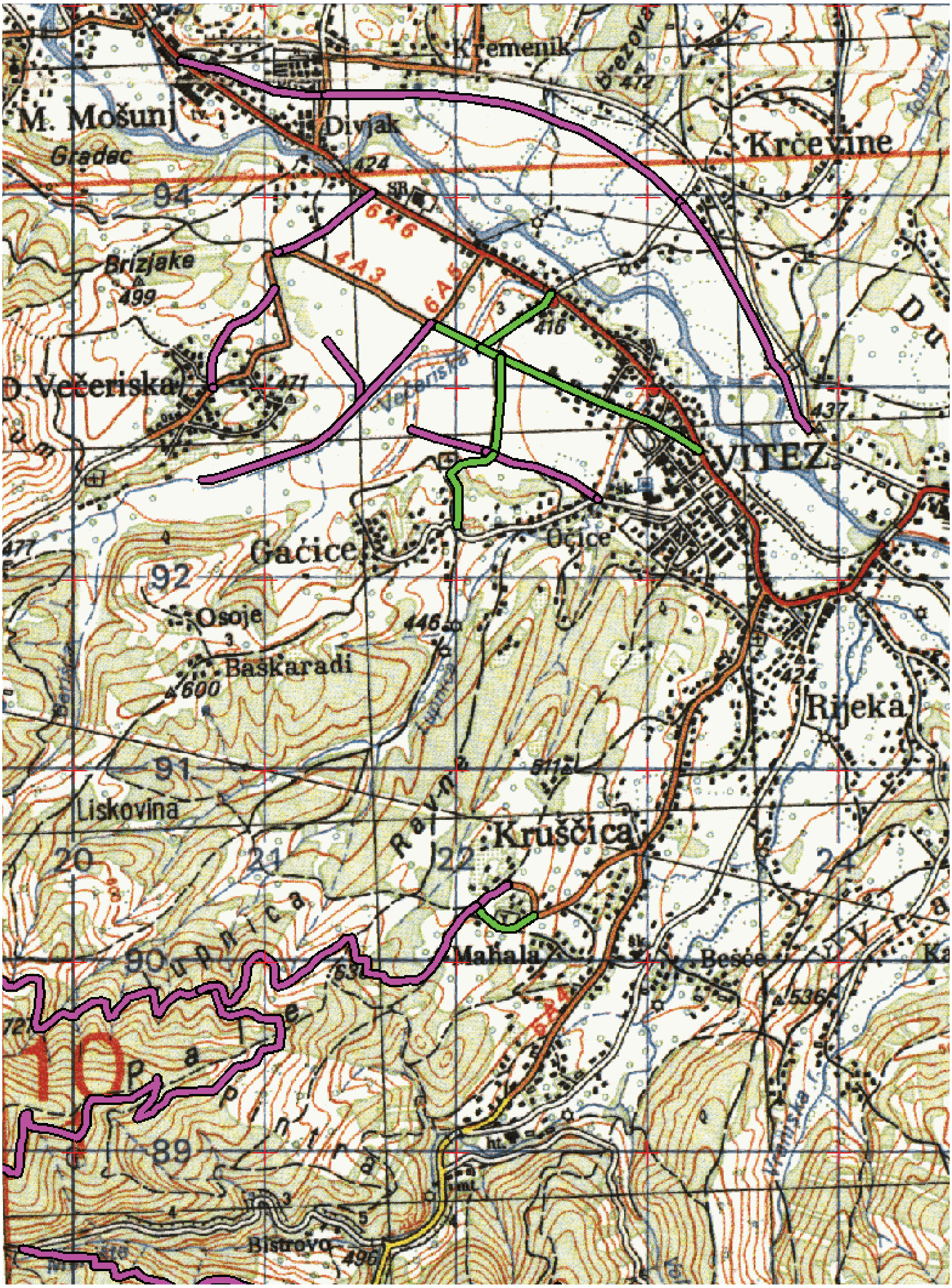

Figure 6b: Topographical map

3.2 Reconnaissance and Surveillance

Waltz (1998) distinguishes two categories of intelligence sources: *open sources* (radio, television, newspapers) and *closed sources*. IMINT (IMagery INTelligence) is supported by sensor systems on spaceborne, airborne and ground platforms. In this section emphasis is placed on a rapidly developing class of open IMINT sources: commercial satellites. They provide services for military and civil organizations, friendly and (potentially) hostile alike.

'A New Era in Satellite Imaging' was announced in *Aviation Week & Space Technology* (Anselmo, 2000) on the cover page with an Ikonos image of London as background. Space Imaging Inc's Ikonos optical satellite was launched on the 24th of September 1999. It is the first of several high resolution commercial spacecraft that will be looking at the globe from space. In the panchromatic mode the geometrical resolution of the optical sensor is less than 1 meter; the revisit time is about 3 days (or shorter when poorer resolution is acceptable). After appropriate processing the digital imagery is available to the customer within one day after the image was taken. Figure 7 shows the centre of Amsterdam, taken from the Ikonos satellite (http://neonet.nlr.nl/npoc/News/ikonos_amsterdam.html).

Figure 7: The centre of Amsterdam, taken from the Ikonos satellite

In the coming years the number of commercial satellite platforms will increase significantly. The following list has been compiled from Anselmo (2000) and Hewish (1999).

COMPANY	SYSTEM	PROPERTIES	SCHEDULE
Space Imaging	Ikonos (optical) Ikonos (optical)	Geometrical resolution 0.8 m (panchromatic) and 3.2 m (multispectral),revisit every 3 days, swath 11 km geometrical resolution 0.5 m (panchromatic) and 2 m (multispectral)	Launched September 1999 launch: 2003/2004
Orbital Imaging Corporation	OrbView 3 (optical) OrbView 4 (optical)	Geometrical resolution 1 m (panchromatic) and 4 m (multispectral), swath 6 km as OrbView 3, but in addition hyperspectral sensor for chemical analysis of ground elements	launch: end 2000 launch: 2001
Earth Watch Inc.	QuickBird 1 (optical) QuickBird 2 (optical)	Geometrical resolution 1 m (panchromatic) and 4 m (multispectral), swath 22 km as QuickBird 1	Launched November 2000 (Failed !) launch: 2001
Spot Image	Spot 5 (optical)	high resolution stereoscopic payload for relief measurements, resolution 5 m (panchromatic) and 10 m (multispectral)	launch: 2002
RadarSat International	Radarsat 2 (SAR)	Geometrical resolution 3 m	launch: end 2002

Table 2: List of commercial satellite platforms

An indication of the commercial importance of these projects comes from the US National Imagery and Mapping Agency (NIMA), which expects to spend $ 1 billion during the period 2000–2005 for commercial imagery and derived products, such as geographical data production, imagery analysis products and services (*Aviation Week's Space Business*, April 3, 2000).
A drawback of spaceborne platforms might be the duration of revisit intervals in certain areas. Another disadvantage is the time it takes to transmit imagery to the ground as the satellites occasionally take several orbital revolutions to arrive within the range of the ground stations. These problems can (partially) be overcome by putting more satellites in orbit, placing more

receiver stations at strategic intervals or by setting up mobile ground stations near (potential) crises areas or even in the theatre of operations to acquire data in near-real-time. *Timeliness* of information, which is a very demanding requirement in fast-moving military situations, can thus be improved considerably.
In a demonstration project in June 1999, under the umbrella of the German-Italian-Netherlands-Norwegian EUCLID Research and Technology Project RTP 9.8, the Dutch National Aerospace Laboratory (NLR) showed the mobile RAPIDS (Real-time Acquisition and Processing Integrated Data System) ground station at Volkel Air Base. This ground station has been developed under a United Kingdom/Netherlands program and consists of a mobile tracking and receiving antenna and smart mini-terminals for dedicated, tailored, pre-processing of the raw data, followed by automatic extraction of information.

Figure 8: Real-time Acquisition Processing Integrated Data System ground station (http://www.neonef.nl/rapids)

In the demonstration, SPOT and ERS overpasses were captured; one of these overpasses included a SPOT multispectral image of Volkel Air Base (figure 9). A fulle-scale EUCLID demonstration is scheduled for 2002.

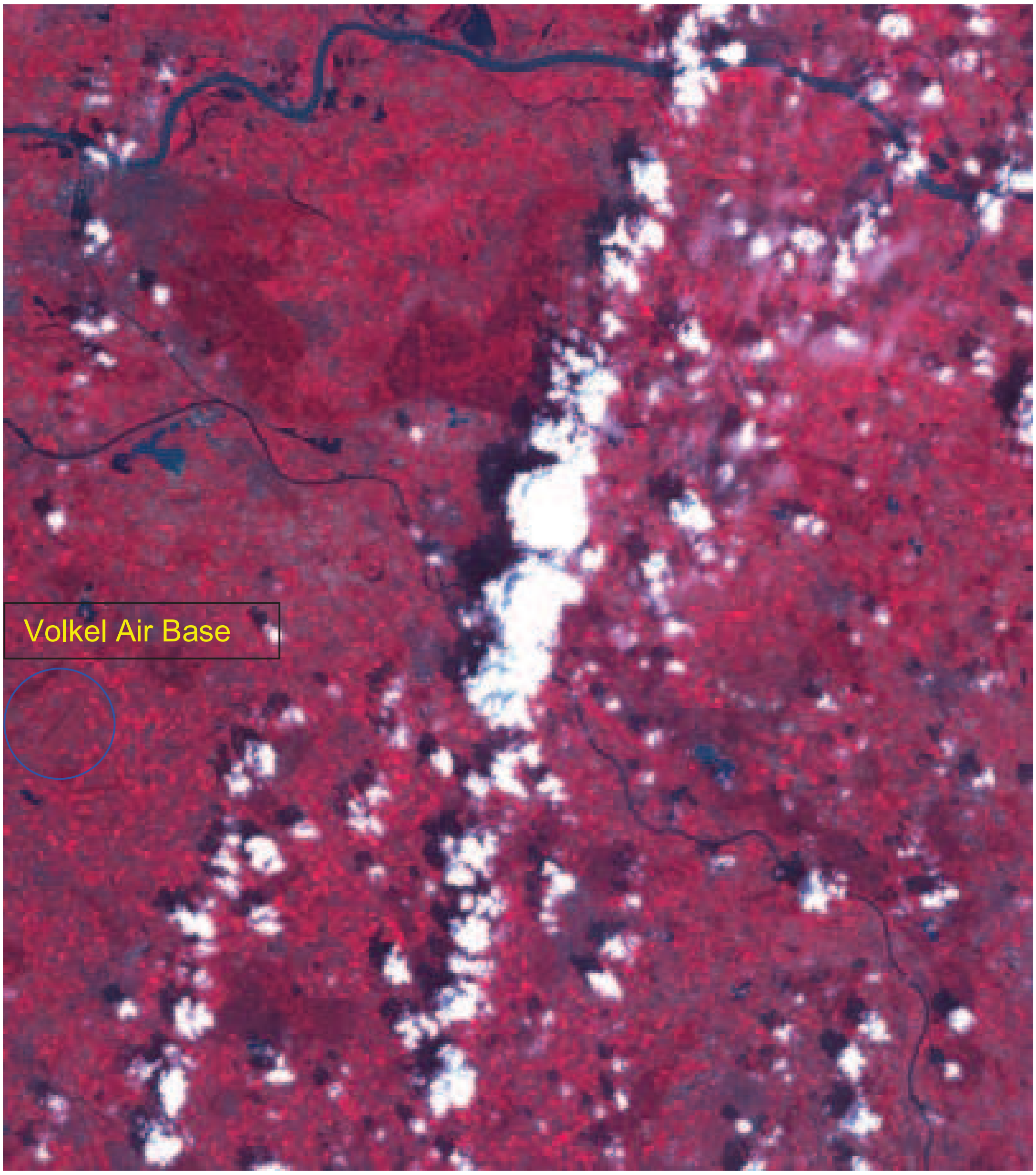

Figure 9: SPOT multispectral image of Volkel Air Base and a large area to the east

Commercial satellite intelligence is an example of COTS (commercial off the shelf) activities within the military environment. Intelligence as well as communication depends increasingly on civilian, commercially operated systems. The (technical) specifications of these systems are much more openly known than is usually the case for military systems. A few countries have military satellites at their disposal; the specifications are not advertised and the collected information is generally not made available. Knowledge of technical specifications in theory offers the possibility of (offensive and defensive) operations to decrease the capacities of the systems. Similarly this is also true for the Global Positioning System (GPS), which is the subject of the next section.

3.3 Vehicle Positioning Systems

In 1998 *Jane's International Defense Review* Foxwell and Hewish published an article with the worrying title: 'GPS: is it lulling the military into a false sense of security?'. The message is summarized as follows:

> Activities […] are well under way to equip all (US) military forces with GPS receivers […] However, as dependance on GPS increases, so does the advantage that an enemy can gain by preventing its use.

Jammers can be used for this purpose.

АВИАКОНВЕРСИЯ

Общество с ограниченной ответственностью

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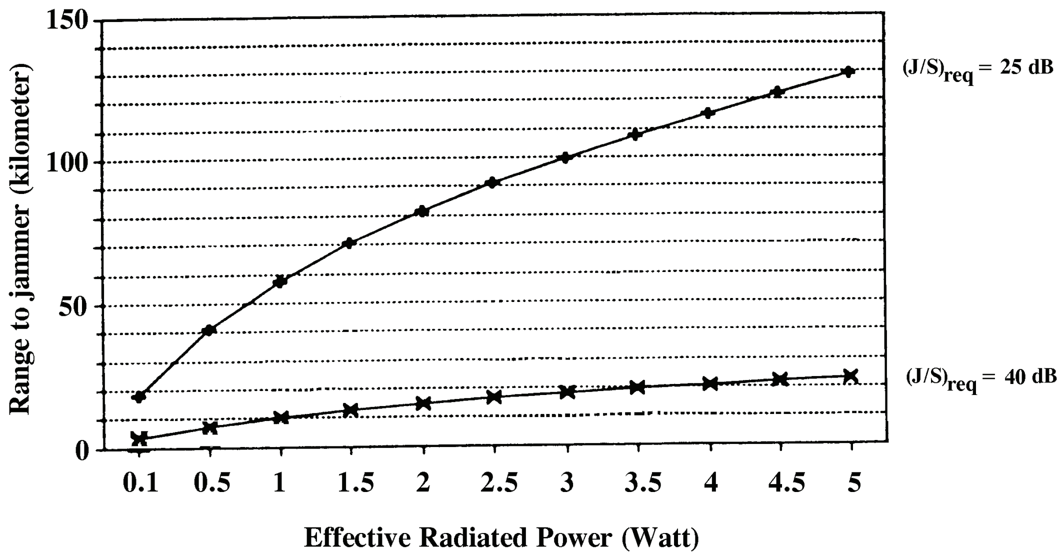
Portable Jammer for GPS/GLONASS User's Receivers

The advertised jammer is described in the *Journal of Electronic Defense* (1999); the output power is 8 W in the four frequency bands of the GPS and GLONASS systems. According to the advert 'this power is enough for suppressing the normal operation of the receivers at the range of several hundred kilometers if the direct radiation from jammer to receiver will be ensured'. In (Kaplan, 1996) the required jammer-to-signal ratio for effective jamming has been calculated for different modes of operation of some generic GPS receivers: acquisition (C/A) mode, tracking mode (both for civil and military receivers) and for different jamming signals (e.g. wide band noise, single frequency). Each of these scenarios requires a specific jammer-to-signal ratio for the jamming to be effective. Figure 10 (adapted from Kaplan (1996)) indicates the dependence of the effective jamming range on the radiated power for a few required jammer-to-signal ratios.



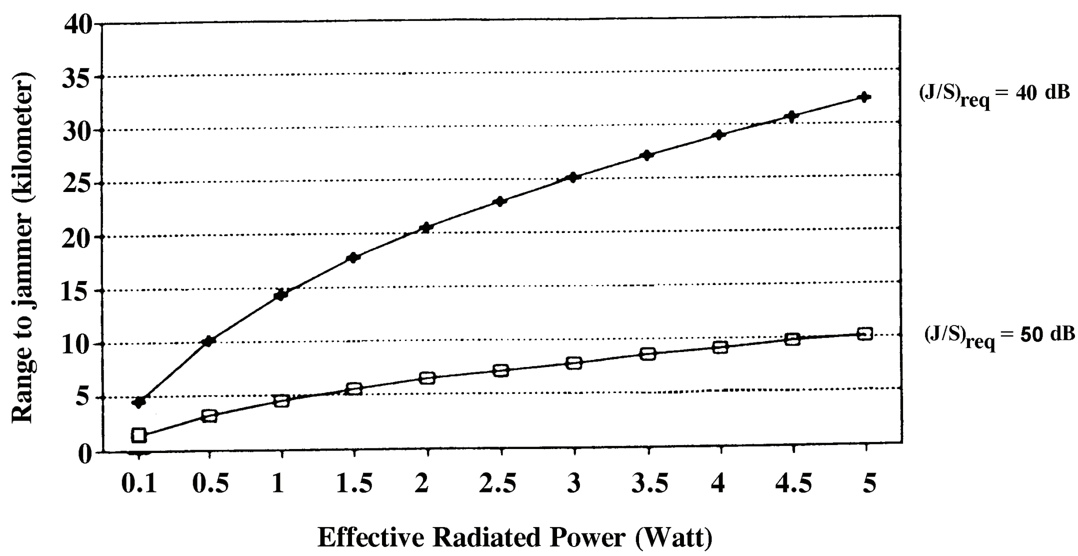


Figure 10: Dependence of the effective jamming range on the radiated power of the jammer
Top: receiver in C/A mode
Bottom: in (military) P mode

It is important to note that the effective jamming range decreases considerably if the required jammer-to-signal ratio can be increased. One way to achieve this is to decrease the electronic bandwidth of certain electronic circuits within the receiver, but this is only permissable if the receiver is aided in some way to acquire and track the satellite's signals. In sophisticated commercial vehicle positioning systems (navigation systems) this is accomplished by feedback of information from other sensors like inertial sensors, odometers, wheel sensors and a (digital) compass. In addition to this feedback, which increases the jamming resistance of the GPS receiver, the data from the different sensor systems are combined in an intelligent way, using, for example, the Kalman filtering technique, thereby increasing the robustness of the positioning system (Zhao, 1997; Drane & Rizos, 1998). Temporal interruption of the GPS system (e.g. if less than four satellites are visible due to blocking by mountains, buildings or foliage) is less of a problem then. The advantage can be appreciated from figure 11 (Miller et al., 1995).

Percent time vs. Number of Satellites Tracked,

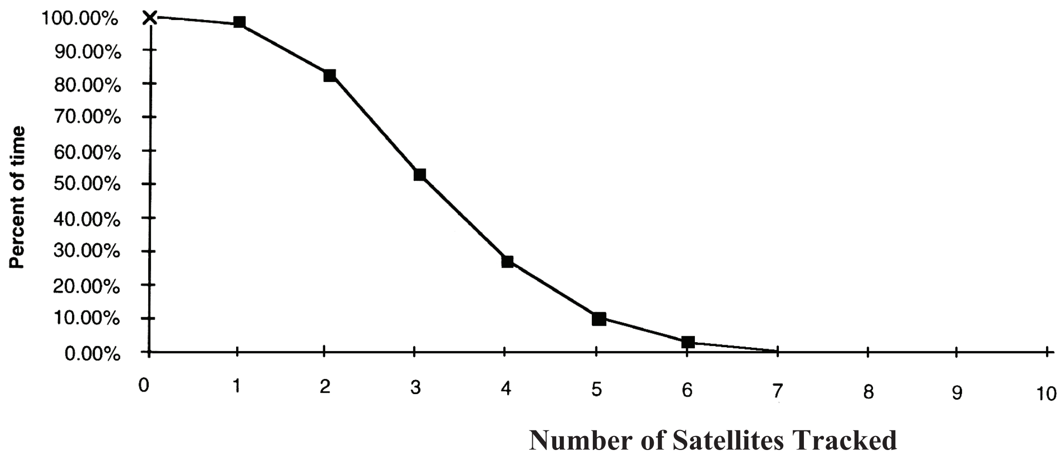


Figure 11: Foliage Scenario 12 Channel GPS Satellite Availability

In this 'foliage scenario' a car equipped with a GPS receiver drove on a tree lined lane along the Hudson River (USA). If, as is normally required, 4 satellites have to be tracked, the GPS system will function properly in 30 % of the time. If sensor data fusion reduces the number of satellites to be tracked to 3, this percentage nearly doubles to 55 %.

The jamming resistance of the GPS system can be increased by the use of adaptive receiver antennas; their purpose is to reduce the received jammer-to-signal ratio. *Beam steering* (e.g. maximum sensitivity in the direction of the satellite) and *adaptive nulling* (e.g. minimum sensitivity in the direction of the jammer or another interfering source) can be achieved by using multi-element array antennes. Protection against jamming for military aircraft –see figure 12- is described in Nordwall (1998).

Vehicle positioning systems are an essential part of (commercial) intelligent transportation systems and (military) battlefield management systems. Complete, accurate and uninterrupted (timeliness!) information about the position of own vehicles is essential for the situational awareness which is the basis for information dominance.

This GPS adaptive antenna was designed by Mitre to null out multiple wideband jammers. The design is curved to mount flush on the fuselage of the aircraft with minimum drag. Feed network underneath shows the phase-matched cables used on the 7-element antenna to null unwanted signals.

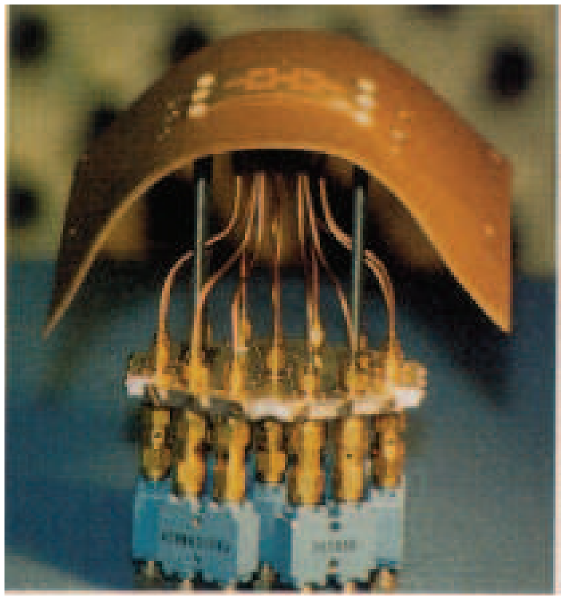


Figure 12: GPS adaptive antenna

4. Conclusions

Sensor systems contribute to a situation of information dominance if the sensors provide information of a higher quality than that which is available to an adversary. Increasingly, however, relevant information is available from commercially operated or government owned public systems almost without any restrictions.

Optical and radar sensors on board of commercial satellites provide high-resolution imagery of nearly all parts of the world, advertised on the Internet. In the forthcoming years the number of satellites will increase significantly, which will reduce the information gaps between the players, military or civil, in the battlespace.

The same holds good for navigation systems relying on the US-owned Global Positioning system (GPS). This system, however, is quite vulnerable, both to natural degradation (e.g. obscuration by buildings, hills and foliage) and to jamming. Advanced commercial automotive navigation systems combine GPS with other sensors, like wheel sensors. Dominant battlespace knowledge requires robust sensor systems, linked to high quality information systems and networks.

References:

Anselmo J.C. (2000), Commercial Space's Sharp New Image
in: *Aviation Week & Space Technology*, January 31, 2000: 52-54

Aviation Week's Space Business, April 3, 2000

Broek, A.C. van de, et al. (1998), *Geographical information extraction with remote sensing*
TNO report FEL-98-A077, Den Haag

Drane C, Rizos, C. (1998), *Positioning Systems in Intelligent Transportation Systems*
Artech House, Boston/London

Foxwell D., Hewish, M. (1998), GPS: is it lulling the military into a false sense of security ? in: *Jane's International Defense Review*, 31, 1998 / 9: 32-41

Hewish M. (1999), Military takes a giant leap with commercial space technology in: *Jane's International Defense Review,* 32, 1999 / 4: 41-47

http://neonet.nlr.nl/npoc/News/ikonos_amsterdam.html

http://www.neonet.nl/rapids

Journal of Electronic Defense, Editorial, 22, 1999 [August]/ 8: 28

Kaplan, D. Elliot (ed.) (1996), *Understanding GPS* Artech House, Boston/London

Miller L.C. et al. (1995), Measurements of GPS and LORAN Performance in an Urban Environment, in: *Environmental Factors in Electronic Warfare Related to Aerospace Systems*. AGARD Conference Proceedings CP 573, Paper 23 (Conference Sensor & Propagation Panel [SPP], Rome), Neuilly-sur-Seine, May 1995

Nordwall B.D. (1998), 'NAVWAR' Expands EW Challenge in: *Aviation Week & Space Technology*, November 23, 1998 / 11: 57-58

Smith A.J.E. et al. (1999), *Visuele interpretatie van SAR beelden* [Visual interpretation of SAR images], TNO-rapport TM-99-A078 / FEL-99-A211, Soesterberg

US Army Field Manual 100-6 on Information Operations (August 1996)

Waltz E. (1998), *Information Warfare, Principles and Operations* Artech House, Boston/London

Waltz E., Llinas, J. (1990), *Multisensor Data Fusion* Artech House, Boston/London

Wijnhoud J.D. (1995), *Het gebruik van remote sensing en GIS ten behoeve van inventarisatie en analyse van terrein en bodem voor militaire doeleinden* [The use of remote sensing and GIS for making an inventory and analysis of terrain and ground for military purposes], TNO-rapport FEL–95-S287 (in Dutch), Den Haag

Zhao, Y. (1997), *Vehicle Location and Navigation System* Artech House, Boston/London

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