SATELLITE IMAGERY FOR AIR OPERATIONS

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Satellite technology in the regional context has usually been associated with the more strategic functions of military intelligence, as opposed to the tactical perspectives of warfighting. In recent times, advances in hyper-spectral analysis provide extensive information beyond that of simply locating and optically analysing an object.

There are many applications where hyperspectral imagery (HSI) could enhance the execution of various tactical air functions like analysing the plume of a rocket to determine and further extrapolate its type and possible trajectory and payload; obtaining real-time battle damage assessment (BDA) after a strike mission; detecting and pinpointing an explosion involving an aircraft, like a crash situation; identifying enemy radars, surface-to-air guided weapons (SAGW) units or other formations in dense camouflage; or detecting and processing, in real-time, data of reheat-assisted take-offs from many airfields.

This article suggests that the value of purely optical imagery will be significantly minimised by HSI platforms; this new technology would permit conventional optical analysis as well, but the bulk of upgradations in analytical capability would be through HSI. The most significant effects, however, would be by a combination of HSI and synthetic aperture radar (SAR) working in conjunction with each other either on a combination (*combo)* platform or on separate vehicles. The first military technology demonstrator of an HSI payload carried aloft the US satellite Warfighter-1 is planned to be launched soon. Three limiting factors which affect optical surveillance

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are cloud cover, darkness and camouflage; the use of HSI and SAR would circumvent these limitations.

Perhaps as a result of riding piggy-back on the driving force of civilian applications of space technology, the tools available to the Indian military have largely, hitherto, restricted themselves to the visible wavelengths and the more traditional forms of image analysis. While today's possibilities in the area of visible imagery are considerable (the latest in the Keyhole series of satellites with resolutions in the order of 2.5 cm, or even less, spring to mind), imagery using visible wavelengths is only one of a number of options, and suffers from a number of serious limitations like clouds and darkness. The Defence Intelligence Agency (DIA) has, recently, articulated the requirements and expectations of the Services through a Space Vision document, the first of its kind, which is under consideration by various agencies including the Indian Space Research Organisation (ISRO). Beyond this document, however, is a need to evolve specific requirements; the need for a payload exploiting HSI and SAR (either individually or in a '*combo*' vehicle) is one such requirement. This article seeks to drive home the point that analysis of optical imagery is restrictive in many areas as compared to new technologies like HSI and SAR sensors; operational aims, therefore, dictate that the necessary changes be brought about at the earliest, so as to induct this new technology at the earliest.

HYPERSPECTRAL IMAGING

Spectra and Spectral Analysis

What is spectral analysis? In 1666, Newton showed that the white light from the sun could be dispersed into a continuous series of colours and introduced the word "spectrum" to describe this phenomenon. His instrument employed a small aperture to define a beam of light, a lens to collimate it, a glass prism to disperse it, and a screen to display the resulting spectrum. Newton's analysis of light was the beginning of the science of spectroscopy. In the early 1800s, many workers, J.F.W. Herschel, W.H.F. Talbot, C. Wheatstone, and A.J. Angstrom among them, studied spectra from terrestrial sources such as flames, arcs and sparks. These sources were found to emit bright spectral lines, which were characteristic of the chemical elements in the flame. By recognising that each atom and molecule had its own characteristic spectrum, Kirchhoff and Bunsen established spectroscopy as a scientific tool for probing atomic and molecular structure, and founded the field of spectral analysis for analysing the composition of materials. These techniques are used today to analyse both terrestrial and stellar objects, and continue to be our only means of studying the chemical elements present in stars.[1] Spectral analysis carries more information than mere imagery. Spectroscopic analysis, first used more than a hundred years ago in astronomical observation, is astonishingly accurate and dependable.[2] For more than a century, astronomers have been analysing the photospheres of distant stars and galaxies, using data sensitive enough to generate accurate classifications, and to determine even the state of ionisation of the element being examined. Such analytical capability would enable hitherto unsurpassed levels of intelligence gathering.

Hyperspectral Imaging

Hyperspectral imaging, also known as imaging spectroscopy, is an enhancement of multispectral imaging that records hundreds of bands of imagery at very narrow bandwidths. Measuring the energy that is reflected (or emitted) by targets over a variety of different wavelengths results in a spectral response for that object. By comparing the response patterns of different features, we may be able to distinguish between them, which would not be possible if we compared them at only one wavelength. For example, water and vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared.[3]

All significant military structures, machines or devices have well known quantities of specific elements in their composition; thus, combat aircraft, for

1. "Spectral Nature of Light," http://web.mit.edu/spectroscopy/history/history-classical.html
2. To the extent that, by spectroscopic analysis of the sun's rays, helium was first discovered in the photosphere of the sun, before it was discovered on earth!
3. "What is Hyperspectral Imaging," http://www.nova-sol.com/default.asp?area=sensing

example, have a significant element of aluminum and titanium alloys, certain plastics and composite materials in their construction. Hyperspectral imaging involves acquiring and analysing images simultaneously at multiple electromagnetic wavelengths, the information being interpreted as spectral 'signatures' of materials present; thus, analysts can identify them remotely[4]. Consider: if the chemical nature and, hence, identity of each component of the spectral image were to be instantly analysed, it would be possible to classify the source of such light. Based on the deductions of such an analysis, automated sequences could be triggered. Static targets like camouflaged or buried structures can also be detected by hyperspectral sensors on spaceborne platforms, which promise to significantly improve surveillance, target identification, terrain mapping and visualisation capabilities for both land and sea operations.[5] Another significant advantage of hyperspectral systems is that they can potentially identify an object even if the image has only a few (or even one) picture elements (or pixels) covering the object. For hyperspectral systems, if the blob has a unique spectral signature, the analyst can identify it by this signature.[6] An HSI sensor can differentiate, not just different materials, but variants of the same basic material, ie, various crops through their individual spectral characteristics in different wavelengths.[7] *The military implications of such a capability are clear, and sound a veritable death-knell for well established military arts like camouflage, decoys and concealment*.

Hyperspectral imaging involves acquiring and analysing images simultaneously at multiple electromagnetic wavelengths, the information being interpreted as spectral 'signatures' of materials present.

Like multispectral or optical imagery, HSI also requires the target to be illuminated by a light source; however, the angle of the light is not as critical

4. "Hyperspectral Imaging From Space," Ibid.
5. "Other Remote Sensing Systems: HSI," http://rst.gsfc.nasa.gov/Intro/Part2_24.html
6. n. 4.
7. n. 5.

as in the case of optical analysis, as analysis of the imagery would not be affected by shadows and other factors affecting the visual appearance as seen by human analysts and which mandate a sun synchronous orbit to achieve identical lighting conditions during every pass. In effect, this implies that the temporal window available for HSI operations would be very much more enlarged, with obviously greater flexibility of usage. Certain satellites such as the Defence Meteorological Satellite Programme are able to tune the amplifiers of their scanning devices so as to operate at night under very low illumination conditions.[8] However, the technology in this area being relatively new, the integration of this facility with military applications has yet to materialise.

The Hyperion and Warfighter-1 Programmes

In November 2000, the National Aeronautics and Space Agency (NASA) launched its first earth remote-sensing hyperspectral imager operating in space. Launched onboard the Earth Observing-1 spacecraft, the Hyperion hyperspectral imager began transmitting images of the earth's surface in January 2001, observing the earth in 220 spectral bands from the visible to shortwave infrared with 30 m spatial resolution.[9] The first military-oriented HSI programme ever, the Warfighter-1 programme, is an advanced technology demonstration programme that will provide hyperspectral imagery and related technology and services as a part of the high-resolution imaging satellite. Basically, Warfighter-1 will be a mission focussed demonstration of a tactical HSI remote sensing system. [10]

MILITARY IMPLICATIONS

The Concept

To a hyperspectral camera, decoys, camouflage netting or paint are meaningless because the camera is more oriented towards sensing the nature

8. "Meteorological Satellites," www.spatial.maine.edu/~peggy/Teaching/Ch6_E.ppt
9. n. 4.
10. "Global Security Org," http://www.globalsecurity.org/space/systems/warfighter.htm

of the materials used, and not their physical form. In fact, hyperspectral imaging can detect the subtle differences between two types of similarly coloured paint—one applied to a friendly military vehicle and the other used by the enemy, provided the two vehicles can be differentiated by different materials used, or significant differences in their proportions. That could very well spell the end of camouflage as we know it, as camouflage paint or nets will no longer keep an enemy hidden. In the short wave infrared portion of the spectrum, many paints are transparent, so these bands can be analysed to look at materials beneath the paint. A typical hyperspectral image, after processing, looks like an ordinary picture except that special colours can be programmed to identify objects of interest. For example, all the non-armoured material in a suspected tank harbour can be made to look red, clearly exposing decoys and camouflage. With a resolution of eight metres, Warfighter-1 will be able to spot large targets of military interest.[11]

Some specific attributes of hyperspectral imagery described below could be exploited for military operations.

Detection of Missile Launches

Relevance. While not falling strictly into the area of HSI, spectral analysis of missile plumes, nevertheless, would involve analysis of the relevant wavelengths and would permit an accurate assessment of their trajectory, the nature of rocket engine and, hence, even the nature of the payload, providing a realistic early warning of hostile missile launches, thereby enhancing the range and quality of response. In the case of ballistic missiles, such early warning would enable a better and more credible response. The application of such a facility would apply to nuclear as well as conventional missiles; the Ghauri and Shaheen, it must be remembered, also follow a ballistic path, like the Prithvi series, and so early warning of these weapons would be relevant in a conventional conflict as well. Admittedly,

11. "Advanced Technologies, Civil Air Patrol," http://atg.cap.gov/modules.php?name=News&file=article&sid=15

hyperspectral analysis of the plume would not indicate whether the warhead was nuclear or conventional, but it would probably give a reliable indication of the class or category of the missile.

Existing Exploitation Programmes. Spectral analysis of missile plumes is being actively studied by a number of projects. Consider the Defence Support Programme the (DSP) of the USA, which provides a spaced-based surveillance system[12] to detect and report missile and space launches and nuclear detonations in near real-time. The system consists of a constellation of satellites in geostationary orbits, fixed and mobile ground processing stations, one multi-purpose facility, and a ground communications network The DSP's primary mission is to provide tactical warning and limited attack assessment of a ballistic missile attack, as well as detecting and reporting nuclear detonation events. Indian military requirements may not dictate such an elaborate system with constellations of satellites, but the DSP is described above only to accentuate the degree of reliance that can be placed on spectral analysis sensors and their potential for development.

Monitoring Aircraft Movements

The detection of high-flying aircraft is also an area which is being studied; the TEAL EMERALD project[13] consists of detection of aircraft from space, including the determination and discrimination of the spectral signatures of ICBMs/SLBMs (intercontinental ballistic missiles/sea-launched ballistic missiles) from strategic aircraft as observed from a spaceborne sensor. The current state-of-the-art looks at the detection of aircraft flying in the higher reaches of the atmosphere; however, though the application is still in its infancy, it has obvious potential.

We can take our imagination further; after-burning combat aircraft routinely feature a long flame from the exhaust (average temperature of 850°C) at the time of take-off. This flame, when compared to the ambient

12. "The Defense Support Program (DSP)," http://www.fas.org/spp/military/program/warning/dsp.htmb
13. "Detection of Aircraft: TEAL EMERALD," http://www.fas.org/spp/military/program/warning/overview.htm

atmosphere, would stand out in stark contrast.[14] Detection of a number of such flames within a given time period could well give early warning of an impending air strike. Accurate activity patterns from potentially hostile airfields could also be monitored in real-time by satellite.

Detection of Air Crashes

Aircraft use a number of materials typical to aviation in their construction. The detection of these elements by spectral analysis from an HSI sensor would provide instant warning (assuming a geostationary platform) in the event of explosions/crashes, especially when dealing with remote and inhospitable terrain. This, even in peace-time, would be a valuable feature and would address an existing problem.[15]

Battle Damage Assessment (BDA)

Effective BDA could be carried out by employing the attributes of hyperspectral analysis.[16] It would be possible to analyse images of the target which reveal recent moving of earth or evidence of damaged structures like broken masonry, runway craters, etc, as well as similar evidence to interest the army and navy like freshly prepared minefields and underwater shore defences.

Identification of Mobile Radars and SAGW Sites

When deployed, mobile radars and SAGW sites are dispersed and camouflaged, making them difficult to spot and target. Using HSI, such protection would be denied to these targets, the *concept of optical or thermal camouflage being possibly rendered obsolete!* During darkness or bad weather, an SAR sensor would significantly enable the existence of all metallic objects.

14. Discussions with Dr Kiran Kumar, accomplished payload scientist of Space Applications Centre, Ahmedabad, confirm that, in theory, these could be sensed by a geostationary platform. Current obstacles are the necessary technology to pack all the requisite equipment, including the antenna, into a compact payload.
15. Ibid.
16. n. 4.

Spectroscopic Analysis of the Battlefield: The Concept of 'Mission Space'

The knowledge of 'mission space', which would include specific details of relevant terrain, is a central premise for decision-making in a tactical scenario. There are many applications of HSI which would enhance military operations, some of which are:

(a) ***Mapping, Charting and Geodesy***	(i) Image mapping
	(ii) Terrain analysis
	(iii) Feature analysis
	(iv) Elevation data extraction
	(v) Map creation
	(vi) Change detection
(b) ***Broad Area Search***	Automated change detection
(c) ***Contingency Planning Support***	(i) Intelligence of the battlefield
	(ii) Landing zone / drop analysis
	(iii) Amphibious operations
	(iv) Airfield analysis
(d) ***Mission Planning and Rehearsal***	(i) Operations planning
	(ii) Mission rehearsal fly-through
(e) ***Current Operations Support***	(i) Theatre surveillance
	(ii) Order of battle analysis (naval, ground, air-defence missile, CW/ BW)
(f) ***Targeting Support***	(i) Target detection
	(ii) Target identification and tracking
	(iii) Target vulnerability
	(iv) Target penetration analysis
	(v) Bomb damage assessment
	(vi) Cruise missile targeting

The knowledge of 'mission space', which would include specific details of geographic terrain, would be a central premise for decision-making in a tactical scenario. There are many applications of HSI which would enhance military operations, some listed above. The concept of 'mission space' would become all the more relevant while planning joint operations. A common view of the mission space is that it is based on a geospatial framework that includes imagery data, elevation data, and feature data. Geospatial information must, therefore, be an integral part of the overall defence information infrastructure. Spectral analysis would be an indispensable tool in such operations. The scope of surveillance would be immense; for example, even soil disturbance can be an indicator of changes such as those produced by foot, vehicles and buried mines, such changes being detected by physical characteristics of the soil like mineralogical composition, particle size, particle coating, lignin and cellulose content, etc.[17] Hyperspectral products (the term '*product*' is one commonly used by photo interpreters (PIs) to denote a '*scene*' of imagery which has been analysed and annotated by trained PIs) would consist of a change detection map that would locate areas which have been disturbed by military activities. This information would be merged with other data sources within a geographical information system (GIS) for intelligence/strategic planning, and would be especially relevant for, say, the planning of battlefield air interdiction (BAI) missions. For land-sea operations, knowledge of nearshore bathymetry would be critical for a variety of applications like landing beach assessment, input variables for various modelling algorithms (acoustic prediction, tide and surf forecasting, weapon systems), planning charts (command and control, mission planning, tactical decision aids), etc.[18] These map layers could be integrated with other sources of information (i.e. topography, hydrology, roads, weather, radar) within a GIS, a common system which combines aspects of mapping, graphical

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17. Ibid.
18. Ibid.

displays and database management. The system will provide predictive information on the effects of terrain on military operations and will support decision-making and planning of operations.[19]

SYNTHETIC APERTURE RADAR (SAR)

Unlike electro-optical systems, radar satellites can see through clouds, rain, and fog in order to detect land or sea targets. In addition, SAR satellites are extremely useful in tracking moving targets, and can be useful in satisfying military mapping requirements. Chinese engineers have been examining SAR satellites as a means to track enemy submarines in shallow waters.[20]

One of the most significant aspects of SAR is the extremely strong echo which results from metallic targets, thus, immediately minimising the effect of camouflage or concealment measures. For example, the barbed-wire fence along the Line of Control (LoC), when viewed from an airborne SAR camera at 40,000 feet, appeared as a very prominent white line, [21] even eclipsing adjacent objects of much larger physical dimensions or greater colour contrast in the visible spectrum. While the intensity of the return may even obscure the outline of the target, it could still form the basis of accurate positioning; for example, the 'fixing' of coordinates for location of a mobile radar whose approximate position had been triangulated by means of ELINT (electronic intelligence).

Radar has special military value because, using the right wavelengths, this active system can 'see through' clouds and can operate at night. The U.S' Lacrosse series consists of a SAR sensor mounted on a very large (reputed to be school bus sized) platform that ties to extended solar arrays. No Lacrosse / Vega images are available on the Internet, suggesting the secretive and classified nature of this system. The current Lacrosse can probably achieve one metre or better resolution. Missions have included providing

19. Ibid.
20. "Chinese Radar Satellite," http://www.fas.org/spp/guide/china/military/imint/radar.htm
21. As observed by this author; unfortunately, the image, being classified, could not be reproduced in this text.

imagery for BDA of the consequences of Tomahawk missile attacks on Iraqi air defence installations in September 1996 and monitoring Iraqi weapons storage sites and troop movements.[22] Vega photographed the Shifa Pharmaceutical Plant in Sudan that was hit in the U.S. retaliatory strikes after the embassy bombings in 1998. The TESAR (Tactical Enhanced SAR) programme also produces high resolution images.[23]

BENEFITS OF A 'COMBO' PAYLOAD: HSI AND SAR

A Judicious Mix of Capabilities

Unlike electro-optical systems, radar satellites can see through clouds, rain, and fog. Considering the benefits of both HSI and SAR, a combination ('*combo*') payload combining both facilities would yield the following payoffs:

(a) Since HSI is not as demanding of light conditions as multi-spectral or normal optical imaging, a larger window of utilisation would be available; assuming eight usable hours of daylight and a 100 minute period per orbit, it would be possible to extract many more orbits per day during daylight hours than is currently possible[24] with visual imagery satellites (where manual analysis in the visible wavelength demands a sun synchronous orbit aimed at close to noon over the target area)..

(b) In the case of a '*combo*' option, the satellite could be gainfully used during hours of darkness by employing the SAR sensor.

(c) As an aid to HSI would be the definition of form and outline; SAR would be able to provide an input in this area, which may be integrated with the HSI data by suitable software developed for the purpose.

(d) During daylight hours, both HSI and SAR could be used to augment each other; this may save the wastage which would occur in the case of the target being obscured by heavy clouding.

22. "Military Reconnaissance Satellites," http://www.cdi.org/terrorism/satellites.cfm
23. "Military Intelligence Satellites," http://rst.gsfc.nasa.gov/Intro/Part2_26e.html
24. Ignoring, in this example, the different areas being overflown during every pass due to the earth's rotation.

Would a '*combo*' payload be possible? There could be various aspects of size, weight (especially in view of the bulky onboard processing facilities which may be necessary in the case of an HSI payload) or power consumption which could render the proposal prohibitively expensive or practically unworkable. To adequately address this point, the issue would need to be studied by ISRO. In the event that a '*combo*' arrangement were not possible, separate satellites would need to be used for each payload; even so, the gains from each would be substantial and would be justifiable in their own rights.

Antenna Size

A significant problem could be that of antenna size. Terrestrial astronomical radio telescopes have no constraints regarding antenna size, which could go into hundreds of metres; however, the same problem applied to a satellite, with the attendant complexities of stowage and subsequent deployment, could prove to be a taxing issue. One alternative could be an arrangement which unfolds in numerous sections to deploy as a large antenna (certain US projects are reported to feature plans for a 100 m antenna)[25]; whatever the chosen solution may be, at this stage of expertise the Indian space industry would need to meet the demand which would be more in the area of innovation and mechanical dexterity rather than electronic technology.

Large Data Content

One of the characteristics of HSI is the large data content. If hyperspectral data has 256 pixels in the x direction, another 256 pixels in the y direction, and 200 spectral elements in the v direction for each of the pixels, then the overall image (or datacube, since it has three dimensions x, y, and v) will have over 13 million values, which is about the minimum size of a datacube, which could be about 500 Mbytes in size. This large data content has both

25. "American Geosynchronous Satellites," http://www.fas.org/spp/military/program/sigint/androart.htm

good and bad features. The good feature is that the information richness of so much spectral information should allow highly accurate and reliable automated object detection, either on the satellite or on the ground. On the 'bad' side, a large quantum of data would need to be transmitted from space and analysed on the ground, requiring very large bandwidths. For this reason, significant development is going into onboard processing, so that the sensor only needs to transmit the actual detection information to the user; however, this in turn is likely to result in very large sizes of satellites, with snowballing escalations in the areas of launch vehicles and other associated areas.

DEPLOYMENT AND ORBITS

Timeliness

While the technology itself may permit such applications, associated measures required to ensure its effectiveness may considerably increase the total cost of the option. Thus, the timeliness of the delivery of data from the spacecraft to the user directly affects its utility. This delay could extend from days to weeks or more, and is a consequence of relatively long revisit time, relatively limited capabilities to look off to the side of the satellite's ground track, and relatively low throughput for image-processing systems on the ground. Overcoming these limitations is expensive, in both equipment cost and personnel hours, even in the case of the US, where one would assume a much lesser degree of resource allocation problems![26] Thus, there would be a need for a mechanism to prioritise various requirements, especially relevant in our context where the number and type of platforms are, as yet, restricted. Timeliness, therefore, justifies sufficient reason to invest in a significant effort to provide the means to convey the data from the satellite to the warfighter/operational planner within a timeframe which is of relevance to the end user; this could affect, decisions, affecting the number of satellites or types of orbits.

26. Steve Berner, "Proliferation of Satellite Imaging Capabilities: Developments and Implications," http://www.fas.org/irp/threat/fp/b19ch5.htm

Timing of BDA Passes

Especially in the case of BDA, the relevance of the time factor in which the data is provided to the end-user is all-important, beyond which the data would cease to be of any value. In a typical air operation, for example, BDA would be required in order to assess the damage to the target, which would determine the need for follow-up attacks, perhaps the same day; in case this information were delayed beyond a certain point, the value of the data would cease to be relevant.

BDA missions would, in the foreseeable future, probably continue to comprise dedicated manned aircraft augmented by unmanned aerial vehicles (UAVs) for important targets. As a comparison, however, BDA during the Iraq War was rarely less than a couple of hours following the strike, frequently within the hour. It must be noted, however, that the US philosophy apparently mandates the launch of one or more satellites to cover specific operations; in our context, this would be akin to including the satellite launch in the overall mission plan or air tasking order! The schedule of the passes by US satellites was frequently within the hour, almost always within two to three hours.[27]

In the Indian context, while the warfighter would probably like BDA as soon as he could get it, within minutes of the strike if possible, financial constraints would be unlikely to support such a capability; however, the requirement for timely BDA would exist, nonetheless; a possible method to meet this demand is discussed below.

Limited Constellations

Ideally, HSI and SAR sensors, if placed on a geostationary platform, would provide the optimum coverage in all areas while, most important, ensuring 24-hour availability of the facility; however, the state of the technology at the present time would be unlikely to support this requirement due to difficulties of both HSI and SAR applications to perform at orbital ranges exceeding circular or polar orbits. Such being the case, a small number

27. Newsgroup report at http://www.fas.org/spp/military/program/imint/at_960917.htm

of manoeuvrable satellites would meet the requirements, while emergent demands could be catered for by vectoring the satellite as required. For example, if we had three more satellites of the capability of our existing indigenous manoeuvrable vehicle (ie, a total of four such vehicles), we could ensure a revisit time of less than three hours. With such an arrangement, requirements like BDA, for example, could be met.

FUTURE DEVELOPMENTS

Micro-Satellites

The current emphasis in the satellite industry is on replacing large satellite platforms with one or more smaller satellites, built at lower costs, yet able to accomplish similar mission objectives. In this context, there is increasing interest in the potential capabilities and applications of so-called "micro-satellites" of 10-100 kg. However, it is recognised that such small satellites pose severe constraints on payload volume, mass and power. Thus, they would appear to be inappropriate for missions such as SAR imaging, where payloads have significant size and power demands—specifically the large SAR antenna and high-power radar transmitter. The primary reason for the high transmit power requirement is that traditional SAR systems use backscatter, which is weak from most terrain types as most energy is scattered in the forward direction. Thus, if it were possible to gather this forward scattered element, then the transmit power requirements could drop significantly, potentially making it feasible for installation on a micro-satellite. This research is based on the principle of collecting to the forward scattered element—a novel method by which two micro-satellites 'fly' in a specific formation to accomplish a SAR imaging mission bi-statically. The transmitting satellite will be the master, with the receiver satellite slaved off it for synchronisation. The satellites view a swath of 30x30 km, at a ground resolution of 30 m, from an altitude of 700 km. The constellation geometry proposed requires minimal orbit control resources, and allows for the resolution of the left-right ambiguity. The satellite design is based on the

Surrey Satellite Technology, Ltd. enhanced micro- satellite, with a mass of 100 kg, and a standard volume of 1x1m base and a 0.6 m height.[28] Such innovative options are relevant to India's peculiar position of an exclusively civilian space programme with, nevertheless, military commitments.

THE BIG PICTURE

State-of-the-Art as an Aiming Point

Operation Enduring Freedom, the US operation in Afghanistan post 9/11, may not have had much opposition as far as a battle goes, but was an effective demonstration of the state-of-the-art use of the space medium. To quote from a documented account[29]...

> Before the first soldier, sailor, airman, or Marine was placed in harm's way, we used satellites to scan hundreds of thousands of square miles of Afghanistan's rugged terrain, giving us a feel for the terrain, for the weapons that potentially could be employed against us, and for an initial set of targets to be attacked with cruise missiles and high-altitude bombers. We used satellites to collect electronic and signals intelligence on the enemy. Satellites fed constant data about cloud cover and moisture into weather forecasting programs. Satellites with spectral imagers were used to detect changes in terrain features indicating potential use by the enemy. Satellites were also available to detect the infrared signature of a missile launch if the terrorists had possessed that capability. Satellites were our first "eyes on target" operating 24 hours a day, during day and night and in all weather. Digital terrain data provided by satellites were used to develop 3-D images of terrain and streets and even to give military planners an idea of the view from a terrorist's window. This proved to be a boon for pilots flying low-altitude missions through rugged mountains and for special operations forces carrying out covert raids.

The Indian space programme is basically a civilian roadmap, with little or no military considerations. As major decisions regarding the utilisation of space are invariably shaped at forums like the Space Commission, it is hardly surprising that during the early years military considerations were, perhaps,

28. "A Novel Method for Achieving Synthetic Aperture Radar Imagery by Means of a Micro-Satellite Constellation," http://www.stormingmedia.us/30/3077/A307704.html
29. Joseph M. Cosumano, Jr., "Space Criticality to Ongoing Military Operations," http://www.armyspace.army.mil/SpaceJournal/Article.asp?AID=1

not considered the way they should have been. A beginning has been made with the articulation of the Defence Space Vision 2020.

CONCLUSION

HSI will trash many old concepts and perceptions; like the X-ray eyes of the legendary Superman of fiction, HSI will enable its users to look below layers of paint to see the nature of the structure below; to differentiate a wooden mock-up, however realistic, from the 'real thing'; to spot locations of freshly laid minefields or beaches with booby-traps just by scanning the terrain, and that too, not after hours of painstaking effort by human PIs, but by almost immediate, colour coded computerised images. The possibilities presented by HSI go far beyond those presented by optical imagery, and will be instrumental in transforming the utility of satellite inputs from a strategic and long-term assessment tool to a warfighter's tactical aid.

The time is ripe for the air force and the Services to look beyond conventional optical imagery and consider the wealth of information available through a combination of HSI and SAR.

Conventional optical imagery, a now mature science, will continue to be of significance, the weightage of which will progressively reduce once HSI becomes available. However, the time is ripe for the air force and the Services to look beyond conventional optical imagery and consider the wealth of information available through a combination of HSI and SAR. While HSI also figures on the roadmap of ISRO, civilian priorities do not ascribe the urgency of military implications of this technology. Development in the space area is as slow as in any other field, and gestation times are large. The Services have recently articulated their concept of development in space in the years to come through the Defence Space Vision 2020; there is a need now to focus on the development of selected, emerging technologies like HSI, as the chosen technology for tomorrow. ■