Very high resolution satellite data: New challenges in image analysis

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Abstract

Early years of coming century will see a large number of satellites with very high spatial resolution reaching beyond 1 m in the visible range of electromagnetic spectrum. Such images will come very close to giving a ground-based view of a terrain with the exception that a ground-based view covers the entire optical range from 400 to 700 nm while satellite images will be wavelength-specific. Although the images will not surpass details observed by a human eye, they will, in principle, be comparable with aerial photographs obtained from the top of a skyscraper with suitable filters. This will generate enormous interest among users working in the area of coastal and urban studies where the rate at which features on the ground vary is much higher than that over oceans or other natural landscapes.

Having very high resolution digital data over a landscape will however create new challenges in the field of atmospheric correction, ground registration, image processing and finally the image interpretation itself. Even the computer hardware presently in use for handling images with resolution from about 10 m to 1 km will become unsuitable for handling high resolution data. For example, one would need 100 images of 1 m resolution to cover an area on the ground that is covered by a single image of 10 m resolution. As a result, display of a single image of 1 m resolution would cease to give a synoptic view. Seemingly smaller images to construct a synoptic view would make the image fairly big and unwieldy. Moreover, the excessive information made available through such efforts is more likely to shield the signal rather than enhance it.

The present paper discusses some of the challenges posed by very high resolution satellite images and offers possible solutions around which the new developments in image analysis will have to evolve.

1. Introduction

Until a few year ago, SPOT panchromatic scene was the ultimate in high resolution satellite imaging with a spatial resolution of 10 m (Narayanan, 1999). Later in 1996, the Indian satellite IRS 1C improved the resolution further to 5.6 m in their PAN images. Another Indian satellite CARTOSAT (IRS-P4 Handbook, 1999) promises 2.5 m resolution while US satellite IKONOS (Harden, 1999) has offered a resolution of 1 m (see Figs. 1 and 2). Considering the rate at which, space science is advancing, one might see a satellite image with the ultimate resolution of 50 cm in the near future. The resolution limit of 50 cm obtainable from space is set due to earth’s atmosphere. But for the atmosphere, satellite images would have evolved further to resolve grains of sand on a beach.

Human eye is often compared with a remote sensing satellite operating from a height of about 1.5 m with a resolution of 1 mm on the ground. This is indeed a very poor comparison in terms of efficiency because if human eye were to view a landscape from a height of 1000 km, its resolution would barely exceed 500 m. Satellites prove to be 500 times more efficient than a human eye.

Reception of high resolution data from space, however, will create new set of challenges in image analysis and interpretation. The existing techniques for handling images of upto 10 m resolution will no longer be valid. The present article reviews some of the problem areas that would need development of new techniques.

2. Loss of synoptic view

Satellite images presently available have resolutions ranging from 10 m to 1 km. Microwave images have resolution as high as 125 km. A typical image may have about 1000 lines each with 1000 pixels. The area on the earth covered by such images also varies in accordance with their resolution. Microwave images may cover the entire earth’s surface while AVHRR images can cover the entire Arabian Sea (Shenoi and Sathe, 1997). Images in visible channels cover regions as large as 50x50 km or more. Smaller satellite pictures cover an area of at least 25x25 km. In any case, such images offer a synoptic view to the user. Unfortunately, this will not be the case with very high resolution images. Consider an image with 1x1 m resolution with 1000 lines each with 1000 pixels. The total area covered by such an image will be barely 1 square km, small enough to be covered on foot. Such an image cannot even be called bird’s eye view as birds flying at 500 m see larger landscapes. Thus, high resolution satellite images, though extremely useful for a variety of applications, will no longer give synoptic view of a region, a fact, often overlooked by enthusiasts of high resolution imaging.
3. Indexing, storage and retrieval

Images are normally indexed by the path/row numbers of the satellite, latitude/longitude of the location or, if geocoded, by the toposheet number of the region. Ordinary users know neither of these parameters for the image of their interest. They refer to an image by conventional geographic names such as image of Goa, Calcutta or Arabian Sea. These names are more user-friendly. The archival and sales agencies have their own softwares that convert these user-friendly names into their indexing scheme. Once high resolution images are available, individual images would become too tiny to be referred to by their geographic locations. A single city may be covered by as many as 200 mini images, each covering an area of one square km or less. Most such areas in a city or its suburbs do not have names. Some of these images will assume local names of bus-stops, markets, parks, play grounds etc. but most would remain nameless. In case of coastal regions, the problem would be more difficult because users would simply not know how to refer to a particular spot while mentioning an image over it.

This would create a situation, wherein, users will refer to images as “the second image between a railway station and race course below petrol pump” or “the fifth image in the northeast of swimming pool showing part of the boundary wall of stock market and traffic island” or worse still, “third image from the seashore, east of rocky protrusion before the second sand-dune, partly showing the newly planted cabirina trees, south of second gate of a hotel”, etc. This is inevitable because this is the only way users refer to satellite images.
The archival and sales agencies would simply not be able to convert this vernacular nomenclature into their indexing scheme. This would call for a new user-friendly system to index high resolution satellite images over urban and coastal areas, in which, potential users would be provided with an atlas of urban and coastal areas with a 1 km grid overlay showing image locations on at least 1:10000 scale. Maps of urban and coastal areas all over the world on this scale showing ground details are simply not available due to dynamic nature of the landscape. Thus, local bodies such as municipalities, regional development authorities etc. would have to help the sales and archival agencies in making available as much detail as possible that fits in 1x1 km grid before users can pinpoint their data requirements. It will be indeed a daunting task to prepare useful reference schemes for high resolution images.

4. Atmospheric correction and ground registration

Light reflected from a miniscule footprint of 1 square metre undergoes multiple scattering in earth’s atmosphere before reaching a satellite sensor 1000 kilometers above the earth. Many of its wavelengths, particularly in the blue region will be totally lost due to absorption. The quantity of radiation ultimately received by the satellite will be so feeble that its spectral character will no longer represent that of its footprint. When the footprint is large, say 10x10 m, the quantity of radiation received by a satellite is 100 times more than what is received from 1x1 m footprint. In that case, energy contained in shorter waves, which are more prone to absorption and scattering, is still above the measurable threshold. This is not true for smaller footprints. Thus, re-construction of spectral character of the ground-based features over smaller footprints becomes a difficult task.

Part of the problem can be corrected by extensive ground-truth collection over urban and coastal areas where features vary rapidly over short distances, followed by preparation of a catalog of spectral characters of objects of interest. This can be then compared with those observed in corresponding pixels to establish relationships. It will indeed be a gigantic task to identify hundreds of pixels exactly and match their spectral properties with those observed during ground-truth collection. Nevertheless, the exercise will significantly increase the confidence level in the analysis of high resolution images.

Another challenge for remote sensing community will be to geolocate the images over known landscapes. At present, maps commonly available are on 1:50000 scale, where 1 mm on the map equals 50 m on the ground. Their precision will be awfully inadequate for registering high resolution images. One would need maps and topsheets of scale better than 1:10000 for the purpose. Such maps are not available over the ever-changing urban and coastal landscapes. Alternately, high-precision maps will have to be specially generated over regions of interests.

Ground registration of ordinary images by itself is a tedious exercise since a few pixels invariably get wrong placement because of erroneous maps and inadequate surveys. In case of high resolution images, this would turn out to be a daunting task because of the very scale at which changes occur. Tides constantly change the coastline while mangroves and other vegetation on the coast change their appearance dramatically over time. In developing countries, urban landscapes keep changing due to constant expansion of cities due to influx of more and more people. Even after registering a few pixels with known landmarks, the rest would appear to be very different from what was expected by the user. In case of ordinary low resolution images, such deviations get averaged out and one still sees a picture resembling a known landscape. This will certainly not be the case with images of 1x1 m resolution.

5. Mosaicking and display

High resolution images are very useful to study features such as erosion, tidal influence, sand-dunes, coastal pollution, urban sprawl, waste disposal, traffic patterns and other cultural and environmental aspects of modern cities. Each of the above applications needs an area over 10x10 km because it is the spread of the
feature across the familiar landscape that user expects to derive from it. Since each image may cover only 1 x 1 km, one would have to mosaic more than 100 such images to construct a view, familiar to the user. Mosaic introduces errors of alignment and geometric distortion. Preparing a mosaic from over hundred images is a tedious task with compounded errors at every stage. One may simply not get contiguous pixels in the same swath either due to viewing geometry or presence of clouds. Methods like duplicating missing pixels or substituting them by the mean of the surrounding matrix (Lillesand and Kiefer, 1987) are not suitable here because each pixel gives a unique information that cannot be "averaged" or "duplicated". This would call for development of two types of additional image processing packages to deal with this situation as follows:

1. "Quick look" packages that will generate an approximate mosaic from hundreds of mini images on certain simplifying assumptions and display only the required feature through a synoptic view. This will allow the user to pre-judge the benefits (if any) of further investing his/her time and efforts in complex operations to generate an exact mosaic.

2. "Screening" packages that will eliminate redundant mini images from a region that do not give any significant information and thus reduce the noise while mosaicking. The package may still have to fill the gaps created by this operation through insertion of null images to ensure geographic contiguity of the region.

Having mosaicked an image of appropriate size, the next problem would be to display it. Ordinary monitors can display an image of 1000 x 1000 pixels. A mosaic of say, 100 mini images covering 10 x 10 km landscape would have 10000 lines each with 10000 pixels. One needs a video memory of 100 Mb just to view such an image in black and white. Ordinary monitors cannot display such a jumbo image. Large images are normally decimated to fit into smaller display devices. Decimating an image simply means elimination of rows and columns to reduce its size. Decimation by half amounts to dropping alternate rows and columns while decimation by 0.33 means dropping two out of every three pixels! This would be improper because it would defy the very purpose of high resolution, viz., to view smaller features in urban and coastal regions. Important details will be lost through arbitrary decimation. They could be roads, bridges, streams, sand-dunes or even an airstrip. Moreover, high resolution images are expected to play an important role in legal matters as they would serve as proof of presence or absence of a feature. In such situation, to display and document a decimated high resolution image will amount to fraud. The only options available are to view high resolution images in parts (thus depriving the viewer of synoptic view), prepare thematic maps showing only the required minimum information from the large image or fabricate jumbo size wall mounted digital screens specially to view high resolution mosaics.

6. Need for special interpretation techniques

In view of above discussion, it is clear that a high resolution image that shows micro features of a landscape is a special entity in itself. There are three ways in which this mini image, specially designed to study urban and coastal regions would defer from a normal low resolution image requiring special interpretation techniques. They are as follows:

1. The rate at which micro features vary pixel by pixel is much higher than that for ordinary images. In most natural landscapes, say a patch of ocean, forests, desert, rocky mountain tops or agricultural fields, nothing really changes every meter. Changes are mostly gentle, slow, and spread over large areas. Such an image lends itself well to classification. In case of high resolution images over urban areas, where the pixel itself is less than one meter, smaller objects begin reflecting their own individual characteristic radiation (unlike in ordinary images, where several smaller objects "together" reflect an average radiation). The objects could be vehicles in myriad colours, open umbrellas held by pedestrians, heaps of garbage, isolated bushes, seaweeds scattered on the coast or even shadows of bumps on the terrain. As a result, with several abrupt discontinuities spread all over the scene, the image will look very noisy. The excessive information made available by such an image is likely to shield the signal rather than enhance it.

One would need a special filter that would reduce the inter-pixel contrast and eliminate upto 3 features with highest/lowest gray values in the first instance to make the image smooth and presentable. Later, one may eliminate more features when one understands what they stand for. While eliminating features, care would be required to assign such gray values to the null pixels that they merge well in the background.

2. The number of themes as manifested through the gray levels in the image would be too numerous. One expects upto 4 themes through image classification. A high resolution image may have as many as 25 themes based on the variety of spectral signatures contained in it. They may not be spatially separated. Some of them may even overlap. For example, concrete rooftops are often indistinguishable from sand (beach) and thatched roofs merge with moist vegetated soil.

In this situation, unsupervised classification (Estes et al., 1983) would yield chaotic results. Dozens of strips,
patches and granules spread randomly all over the image in some 20 different colours is no one's idea of a processed image. Even supervised classification would over-classify the image by including numerous artifacts in the classes that may be spectrally close. Classification in itself will be an unsuitable technique for processing high resolution images except simple density slicing (Gillespie, 1980) techniques in selected regions. An unclassified high resolution image is likely to look more meaningful than a classified one.

3. A large number of pixels lying over the boundary of two contrasting ground features will make the image noisy. Not all objects are exactly 1x1 meter large, nor the 1x1 meter gridlines separate any ground features. In fact, the gridlines in a high resolution image at 1x1 meter distance would be so numerous that a very large number of pixels will consist of multiple adjoining features. Their spectral signature will not confirm to any of the measured ones during ground-truth collection exercise. For example, a small feature like a hutment, a boat or a vehicle may lie at the intersection of 3 or 4 pixels in such a way that not even one pixel will reflect the correct spectral signature for the feature in question. In low resolution images, say a 10 meter resolution, the pixel itself is so large (100 times larger than that of a 1 meter resolution image) that most objects of our interest are wholly enclosed in one pixel. Chances of inter-pixel break up of objects are very less.

This problem is inherent in high resolution digital scanning. In principle, it has no solution. One needs a new approach of altering the gray values of such bordering pixels to match those of their neighbours for the sake of contiguity. This will ensure that a pixel represents only one feature on the ground within an error of 1 metre. Since a pixel has 8 neighbours to choose from, it may chose the gray value that is held by maximum number of its neighbours in the first instance and show the results to the user. Later, it may be assigned the correct value as desired by the user in accordance with his/her requirements.

7. Conclusions
Availability of very high resolution satellite images will require remote sensing community to develop new approaches for their analysis and interpretation. The existing image processing systems will be unsuitable for the purpose both in terms of their hardware and software. It will also call for fresh ground-truth collection exercises considering the scale at which data will become available from satellites. The excessive information being made available through such images might shield the signal unless one learns to deal with a vast amount of noise that is going to be a part of high resolution image.

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