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Landsat-7 Fusion Image of Hong Kong

The above image is created in natural colour by merging precision corrected 15-m resolution Panchromatic data with 30-m resolution Multispectral data. This data fusion processing technique enhances interpretability of the satellite imagery. The Landsat-7 data were acquired in November/December 1999.

Classsroom Applications of High Resolution Digital Imagery

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Abstract

This article deals with some instructional applications of high resolution, multispectral digital imagery in the authors' respective undergraduate, introductory remote sensing courses. Both authors participated in the U.S. National Council for Geographic Education's Remote Sensing Task Force's high resolution image evaluation program. This paper represents a continuation of the work conducted under this evaluation program.

Introduction

This paper provides some examples of how photogrammetric methods and basic mathematical image enhancement functions were used by students to detect certain features on a high resolution, multispectral digital image. These examples are taken from assignments used by the authors in their respective remote sensing courses. The assignments are presented to students as problem solving questions. Both authors participated in the U.S. National Council for Geographic Education (NCGE) Task Force's high resolution image evaluation program, and worked on the same data set. However, both authors worked independently of each other and were not aware of each other's endeavors until they presented their respective papers at a meeting in Santa Barbara, California.

In 1994, the NCGE Remote Sensing Task Force identified high resolution, multispectral digital imagery as one of the growth areas within the field of remote sensing. Several private and government satellites with high resolution sensors (pixel size ≤ 5 meters) have been launched and others will be launched during the first decade of the 21st century (Ager, 1999). The Task Force elected to examine this major change in imagery resolution in order to bring to the attention of college level instructors teaching remote sensing courses any new approaches for handling and analyzing such imagery. Such instructors need to incorporate the topic of high resolution imagery in their courses so that their students will be well-prepared to pursue careers within the remote sensing field. One recent article addressing new higher resolution imaging systems can be seen on the internet web page at http://www.geoplace.com/ge/1999/1199/1199grs.asp (Celentano, 1999).

One of the findings of the Task Force was that many of the conventional statistical techniques applied in classifying imagery with 30-meter and 20-meter pixel resolution generally do not work as well with high resolution imagery. To illustrate this point, one 10-meter pixel might encompass the entire crown of a large tree and have reflectance values representing the average of the total crown. At a 1-meter resolution, it will take 100 pixels to cover the same crown. This level of detail will make it nearly impossible to detect the full tree using the standard statistical classification techniques developed and employed during the 1970s and 1980s. Figure 1, showing the area covered by several standard size pixels in relationship to an American football field, further demonstrates the problem especially when one compares the 1-meter pixel to the other pixels.

In 1995, the Task Force acquired five high resolution, multispectral data sets. These data sets were taken from an airborne platform and have pixel sizes varying from .75-meters to 3-meters. These data sets were given to several individuals within the remote sensing community throughout the United States for evaluation and the development of course assignments. Two paper sessions, one at the 1996 NCGE annual meeting in Santa Barbara, California and the other at the 1997 Association of American Geographers' annual meeting in Forth Worth, Texas, were presented by the Task Force dealing with the findings of the individuals who evaluated the data sets. One of the major findings was that traditional photogrammetric methods used in identifying and measuring items on aerial photography are very effective in analyzing high resolution imagery. Another finding related to the use of these techniques in conjunction with multispectral digital imagery and the power of modern desktop computers. The ability to conduct simple mathematical enhancement functions on images and to display images in various color schemes brings out information that would not be easy to

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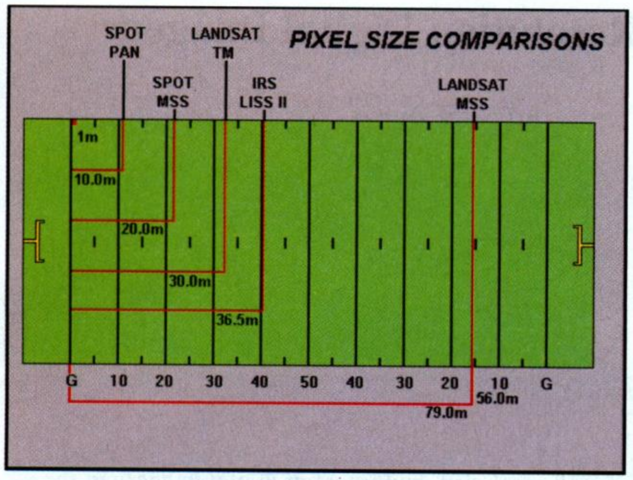

Figure 1 Pixel size comparisons on an American football field.

ascertain from non-digital images such as printed black and white aerial photographs.

High Resolution Imagery and Data Set

Over the next few years several high resolution satellites will be launched. See Table 1. Imagery from these satellites will compete with aerial photography at scales up to 1:40,000. However, with lower prices, a digital format, and direct transmission to a user's microcomputer, satellite imagery will be the preferred choice. Data sets will be acquired by the square kilometer, which will allow a user to obtain only what is needed. Such small data sets will be transferred directly to a user's microcomputer via an Internet connection. Under this type of delivery arrangement, students will be able to select data sets of their choice and download them directly to their own machines. Data sets will be geo- and ortho-corrected, eliminating the need for expensive and complex image processing software packages (Foresman, 2000). Students can already download free or inexpensive software packages, which permit them to perform a number of image enhancement procedures. Thus, in the very near future, students, on a regular basis, will be downloading and analyzing high resolution data sets on machines in their homes or dorm rooms. This arrangement is already occurring in the authors' remote sensing courses, which changes the way the courses are offered and the support level required from the department to offer the courses.

The five high resolution, multispectral data sets acquired by the NCGE Task Force were collected by Positive Systems, Inc. using its Airborne Data Acquisition and Registration (ADAR) System 5500. Since satellite based high resolution data sets were not yet readily available when the Task Force started its analyses of such data, it was necessary to use

Table 1 Satellite Specifications*

Satellite Name	Source	Expected Launch	Sensors	Types	No. of Channels	Resolution (meters)
EROS-A1	West Indian Space, Ltd.	1999	PAN	PAN	1	1.5
Ikonos	Space Imaging	1999	MSS	MSS	4	4
			PAN	PAN	1	1
QuickBird	EarthWatch	2000	MSS	MSS	4	3.2
		PAN	PAN	1	0.82	
OrbView-3	Orbimage	2000	OrbView	MSS	4	4
			PAN	2	1-2	
IRS-P5	India/US	1999	PAN	PAN	1	2.5
SPIN-2	Russia	1999-2000	KVR-1000	PAN Photo	1	2
LightSAR	US	2000	SAR	Radar	4	3-100
OrbView-4	Orbimage	2000	OrbView-4	PAN	1	1
			MSS	4	4	
EROS-A2	West Indian Space, Ltd.	2000	PAN	PAN	1	1.5
NEMO	US	2000	PIC	PAN	1	5
SPOT-5	France	2001	HRV	PAN	1	5
EROS-B1	West Indian Space, Ltd.	2001	PAN	PAN	1	0.82
ALOS	Japan	2003	AVNIR-2	PAN	1	2.5

*Several of these satellites will carry more than one sensor. Only high resolution sensors are listed.

airborne imagery. The five data sets can be downloaded at no charge from the Task Force's homepage at the URL, http://www.oneonta.edu/~baumanpr/ncge/rstf.htm. The ADAR System 5500 has four synchronized, digital cameras, each of which can be calibrated to a certain portion of the spectrum from 400nm to 1000nm (0.4 to 1 micron). They can also be configured with a variety of spectral bandwidths, with a data set ranging from 40 - 80 nm in width and in different pixel sizes, extending from 50cm to 3-meters. For more information about the ADAR System 5500, check Positive Systems' homepage at, http://www.possys.com/.

The particular imaged data set discussed in this paper has a resolution of .75-meters. Table 2 identifies the center wavelength and bandwidth for each of the four bands within the data set. This data set is 1465 elements by 945 rows in size and covers a ground area of .78 km^2 (.30 square miles). It was recorded on Wednesday, April 6, 1994 at 00:17:08 GMT or 04:17 p.m. local time and covers a portion of the central business district of Pasadena, California. This data set was selected because urban areas will represent a major market for high resolution imagery (Corbley, 1996). Consequently, students will receive experience working with imagery covering such a landscape. Previous satellite imagery was only able to detect major land cover categories within urban areas.

Table 2 Imagery Specifications

Band No.	Center Wavelength	Bandwidth (nm)	Color
1	450	80	Blue
2	550	80	Green
3	650	80	Red
4	850	80	Near Infrared

Figures 2 and 3 represent color composite images developed from the data set. These images provide students with general reference information before they address their particular class assignments. After working with 10- to 30-meter resolution imagery, students are generally surprised at the level of detailed information by this high resolution data set. They are frequently not sure how to approach such detail; however, those who have been exposed to aerial photo interpretation techniques are quick to make the adjustment. Figure 2 is a "normal color" composite image, where the red spectral band data are displayed in red, the green spectral band data in green, and the blue spectral band data in blue (i.e., RGB = red, green, blue). Thus, the color image tends to simulate normal human visual experience. This color image has been enhanced however to make it easier for the viewer to see and interpret. Each of the individual spectral bands was contrast stretched with a histogram equalization to enhance the visual acuity of each monochrome image. In addition, each of these individual bands was subjected to an edge enhancement filter for greater detail. The color composite image was made after the contrast stretch and edge enhancements were completed. More information concerning image enhancement can be found in Jensen, 1996 and Campbell, 1997.

Figure 3 is a "false color" composite image. Again, each spectral band was adjusted with a histogram equalization contrast stretch and edge enhancement just as the bands used to create Figure 2. However, in Figure 3 the green spectral band data are displayed in blue, the red spectral band in green, and the infrared spectral band in red (i.e., RGB = infrared, red, green). In this type of image green vegetation appears in bright tones of red.

Figure 2 Normal color composite of the full image

Figure 3 False color composite of the full image

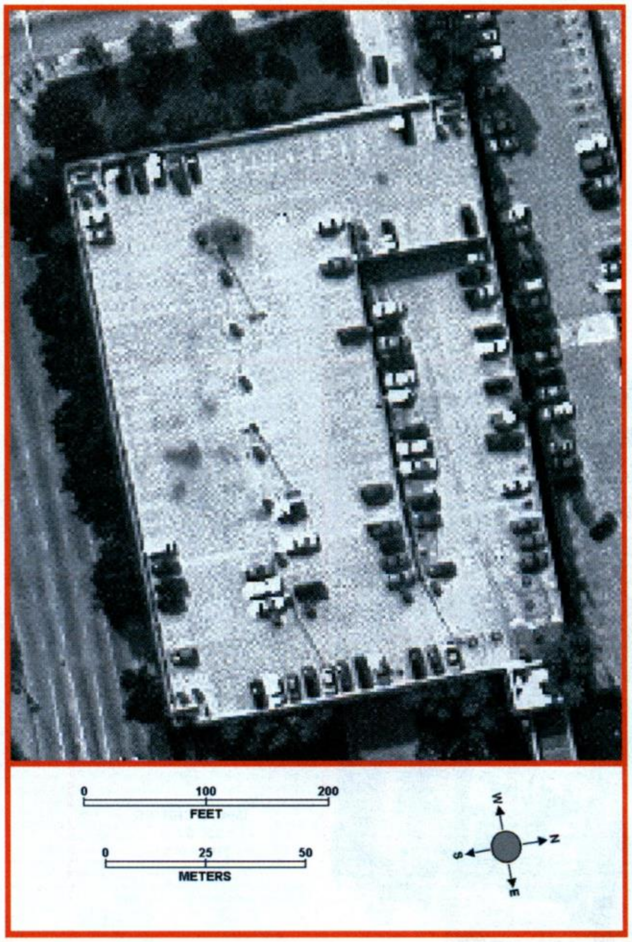

Figure 4 Light pole detection on top of parking garage.

Assignments

Fine resolution does not always ensure that one can immediately see, and map, imaged features. Various image processing techniques can be used to enhance the original raw digital image data. The following are examples of relatively simple questions that the authors have posed to students with a discussion of techniques used to obtain the answers. The authors often introduce this high resolution data set near the end of their respective remote sensing courses. Students are assigned questions about the imagery, and are left on their own to come up with tools which will best provide images that they can interpret to answer the problem at hand.

"The answers lie in photo interpretation"

Figure 4 presents an enhanced image of a parking garage. The question raised to students is, "How many tall light poles can one see on top of this parking garage?" As Figure 4 is presented here, the sun's rays are striking the scene from the upper left, casting shadows towards the lower right of the image. Three narrow dark lines can easily be seen in the left center of the image representing the shadows of three light poles. In addition, a fourth line of the same width and length can be seen in the lower right portion of the image just where the ramp reaches the upper roof level. It is possible to imagine two more light pole shadows on the right of the image mirroring the position of the upper and middle poles on the left of the image. One of these shadows can be seen with a good computer and a great deal of care in processing;

the other shadow is lost in the varying tones of automobiles. This figure was created by stretching the red spectral band with a histogram equalization, and subsequently subjecting the image to an edge enhancement filter.

Figure 5 shows a traffic intersection which is at the corner of E. Colorado Boulevard and S. Arroyo Parkway. The students are first asked to determine north on the image using the shadows. They are reminded that the image was acquired at 04:17 p.m. This question might be presented as to which street is E. Colorado Boulevard and which is S. Arroyo Parkway. If they figured out the answer correctly, they will know that the right edge of the image is north and that S. Arroyo Parkway runs across the image. Next they are asked to notice the traffic at the intersection and given the question, "Is the traffic light red for north-south traffic or east-west traffic?" In order to answer this question students must be able to perform some very basic image interpretation and be able to see that the traffic flow across the intersection is east-west. They also might notice that one car going west had just turned north on the north-south street and another car going east had turned south. These patterns can be detected on several of the different images. Figure 5 was created by subtracting the original data for band 4 from the original data for band 3.

Figures 6a, 6b, and 6c all show a parking lot and the problem deals with the shadow of a tree in the middle of the parking lot. Figures 6a and 6b are enlarged subsets from Figures 2 and 3; whereas, Figure 6c is an edge enhanced monochrome red image. Students are asked, "What type of tree is located on the south, central side of the parking lot?" In this case the normal color image is of little help, but the false color image allows one to easily see the crown of the tree as a single mass of red. This does not provide much information for one to determine the type of tree. However, the shadow of the tree can be easily scene in the monochrome red image (Figure 6c), displaying a rather typical palm tree pattern. Sometimes students have to be reminded that the image is from southern California. There are several places on the image where palm trees can be detected. Students are also asked, "How many red cars are there in the parking lot"? Although this may seem to be a very simple question, the authors are always amused at the number of students who attempt to count the red cars using the "false color" (Figure 6b) image. It is quite easy to see the red cars in the

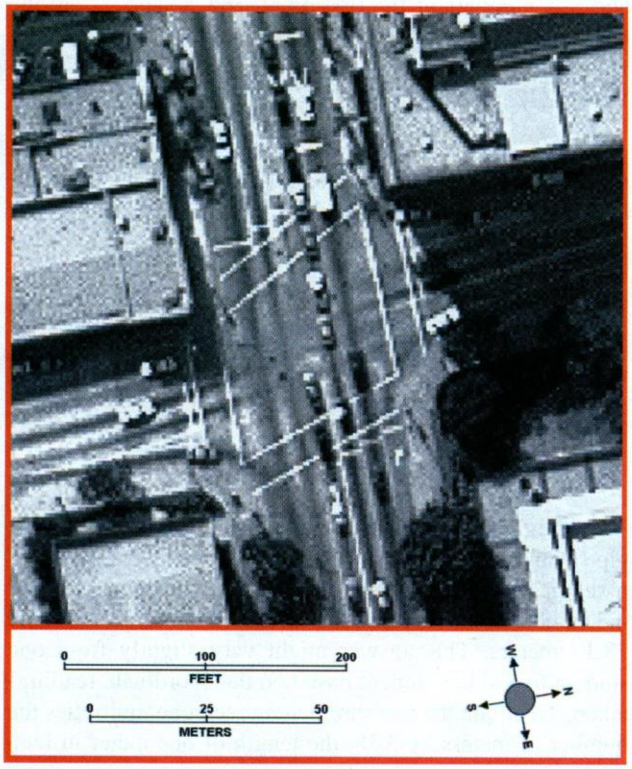

Figure 5 Traffic flow pattern at street intersection.

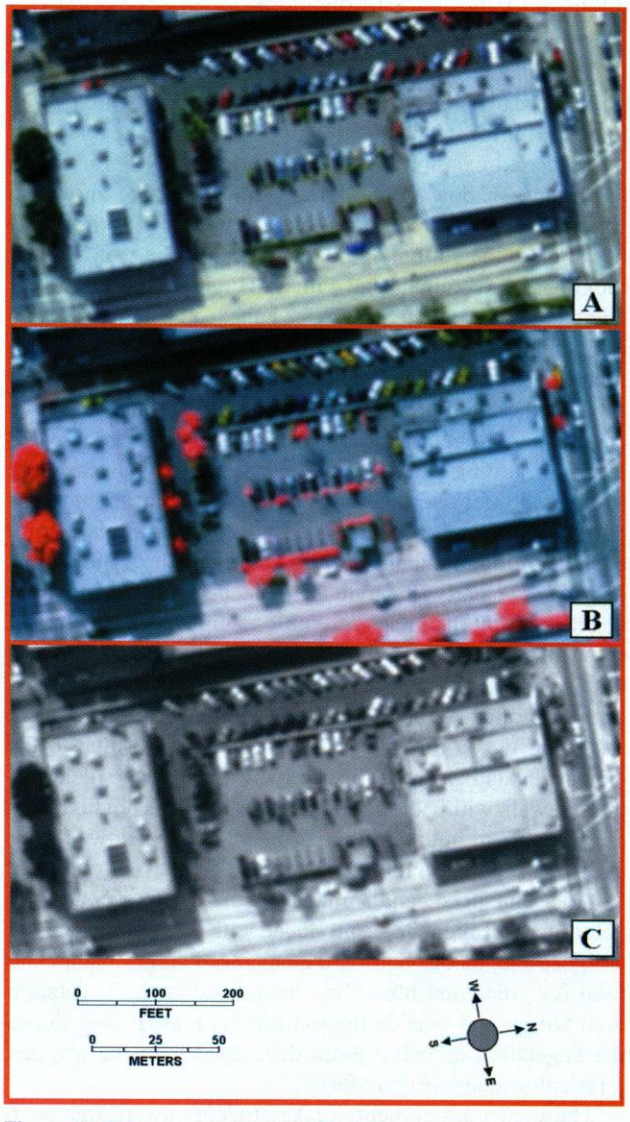

Figure 6 Palm tree detection in parking lot.

"normal color" (Figure 6a) image. Also, if one has created a sharp image, it is possible to distinguish cars from vans and pickup trucks. The cars have obvious windshield and rear windows, while the nearly vertical rear windows of the vans and trucks do not show in the image.

"The answers lurk within the shadows"

The process of image interpretation can be greatly enhanced by the presence of shadows, but it can also be hampered when shadows obscure features. In the following example, students are asked to observe the shadowed area located in the lower right portion of Figure 7a. They are then asked to sketch the pattern of shrubbery hidden in the shadows of this image. It is, of course, not possible to see this shrubbery in the shadows, but it is possible to reprocess the image with spectral band ratioing in an attempt to minimize the effects of shadows. In this case, the original digital data of the red band are divided by the original infrared band, producing Figure 7b. In Figure 7b, vegetation appears in dark tones of gray. The shrubbery in the lower right corner of the image can be easily distinguished. The use of a normalized difference vegetation index image has also proven to be useful for this task.

A second example of having students find information hidden by shadow relates to a second building shown in Figures 8 and 9. Some trees and a fountain in front of the building (at the bottom of the image) cannot be seen. In fact, looking at the original band 4 image (Figure 8a), band 4 after being contrast stretched and edge enhanced (Figure 8b), and both the normal color image (Figure 9a) and the false color image (Figure 9b), one might conclude that nothing exists in front of the building other than a large sidewalk. As in the case of the previous example, a vegetation index is created by band ratioing bands 3 and 4. However, in this case, the students do not use the original band data but employ the data which have been stretched through histogram equalization and enhanced with an edge filter. The results (Figure 8c) clearly illustrate the existence of trees and other vegetation, but the image resembles a night scene where the sidewalk appears to be illuminated by lights but everything else is dark. This image also shows vegetation along the side of the building. A false color image (Figure 9c) is generated, assigning red to this new band and green and blue to the enhanced bands 3 and 2, respectively. This image identifies the sidewalk within the shadowed area but does not highlight the vegetation, both within and outside the shadowed area. To stress the vegetation, the created image is subtracted from the enhanced band 3 image (Figure 8d). A second false color image (Figure 9d) is produced with the new band being assigned red, and as before, the enhanced bands 3 and 2 are used for green and blue. This image shows the vegetation both within and outside the shadowed areas. It also shows the vegetation as being more developed than the original false color image (Figure 9b).

These two assignments make students aware that with some simple mathematical processing of the multispectral data, information which seemed invisible can be obtained. Once students determined that these simple techniques could be used to seek out new information, they were eager to try other spectral band combinations. They not only had the original four bands of data, but they also had four enhanced bands. Students enjoy the challenge of finding new items on the images; it is like an advanced form of "hide and seek."

"The measurements rest in basic geometry"

With such high resolution imagery, it is possible to measure the length and area of particular features. Continuing to use the building shown in Figure 9a, the students are asked to measure the length of the pipe which runs diagonally across the roof of the building. More precisely they are asked to determine the length of the pipe starting at the corner of the small building known as the equipment penthouse to the point where the pipe meets the small shed. Most image processing systems will provide the column and row numbers for each pixel of interest; in this case it would be the pixel at each end of the pipe. If not, another way to obtain the data necessary to make these measurements is to export the image from the image processing software package and import it into an image editing package such as Microsoft Photo Editor. For students to handle this problem it is desirable to review some basic geometry, which they may have been introduced to when dealing with the interpretation of aerial photographs. To solve this particular problem, the following formula should be employed where X_1 and Y_1 are the column and row numbers of the first point, and X_2 and Y_2 are the column and row numbers of the second point:

$$\sqrt{((X_1 - X_2)^2 + (Y_1 - Y_2)^2)}$$

Incorporating the row and column coordinate values for the two ends of the pipe into this formula the following calculations can be accomplished:

$$\sqrt{((473 - 565)^2 + (541 - 590)^2)}$$

$$\sqrt{((-92)^2 + (-49)^2)}$$

$$\sqrt{(8464 + 2401)}$$

$$\sqrt{10864} \text{ or } 104.23 \text{ pixels}$$

At this point the students must convert the length of the pipe from the number of pixels to meters and feet. Since one pixel on the image is .75-meters, one only needs to multiply the number of pixels times .75 (104.23 x .75). The answer is 78.17 meters. This answer might vary slightly from one student to another student based on the coordinate readings taken. To obtain the measurement in feet, one multiplies the number of meters by 3.28, the length of one meter in feet. The answer in feet is 256.48.

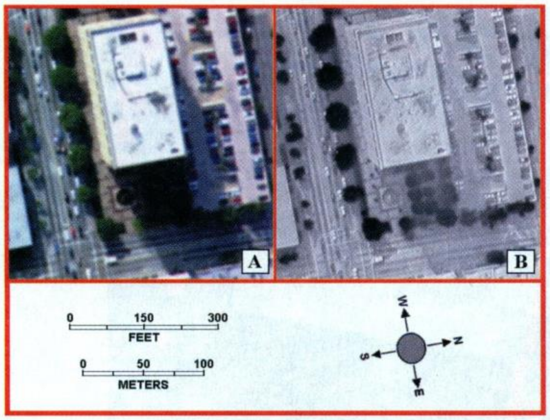

Figure 7 Vegetation pattern within shadow of building

An error students frequently make is to zoom up the image in order to obtain more precise coordinate readings. Some image processing software packages increase the coordinate values accordingly or provide users with both the zoomed up coordinates and the full image coordinates. If students use zoomed up coordinate values, they must realize that the basic size of the pixel values has changed.

After solving this problem students are asked to measure the area covered by the building, the area covered by the equipment penthouse on the roof, and to determine what proportion of the roof the equipment penthouse covers. Again, basic geometry can be applied by using the following formula to calculate the area of rectangle.

$$(X_1 - X_2) * (Y_1 - Y_2)$$

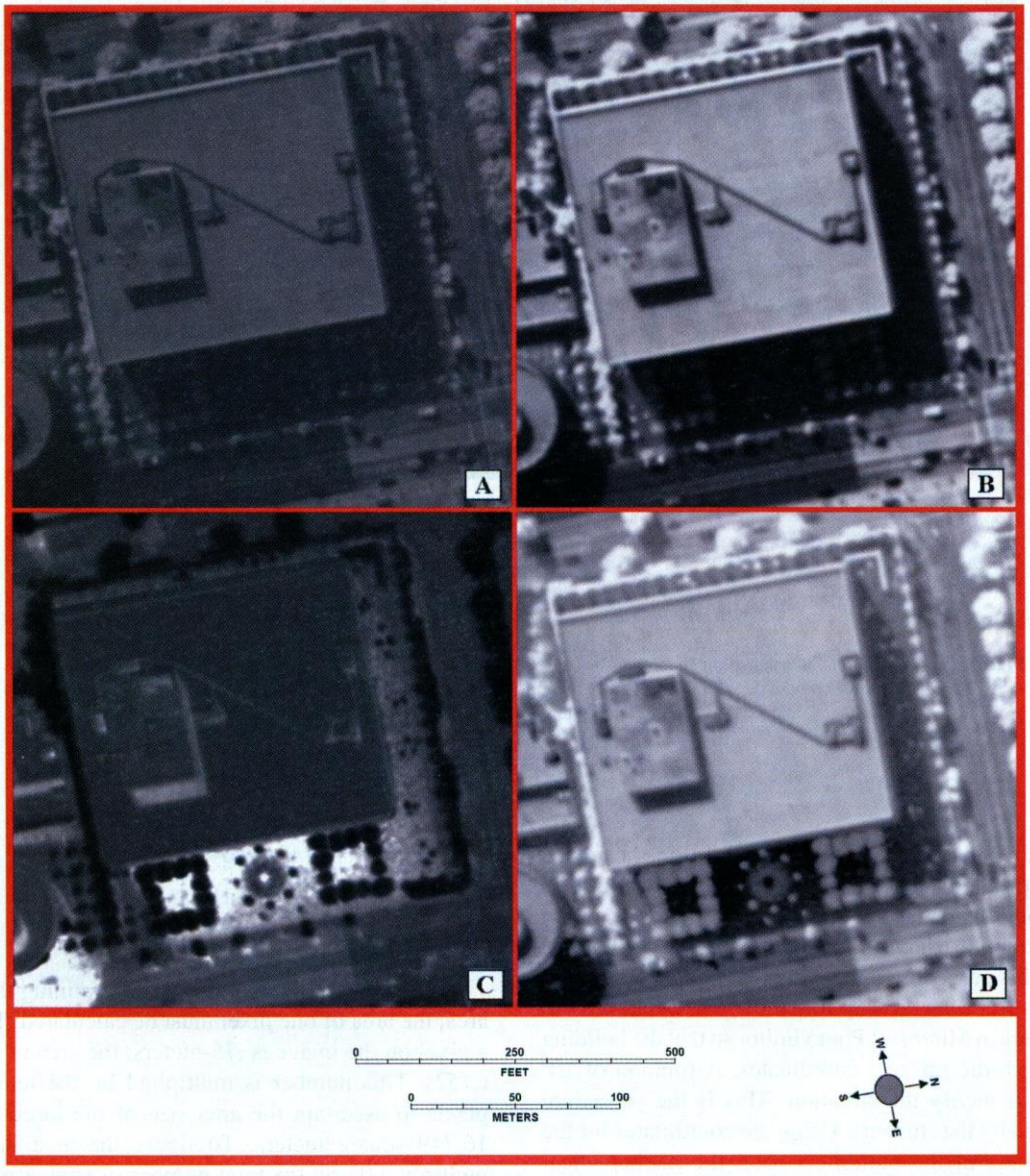

Figure 8 Vegetation pattern within shadow of building: A. original IR image, B. stretched IR image, C. vegetation index of stretched red and IR images, and D. vegetation index image subtracted from red image.

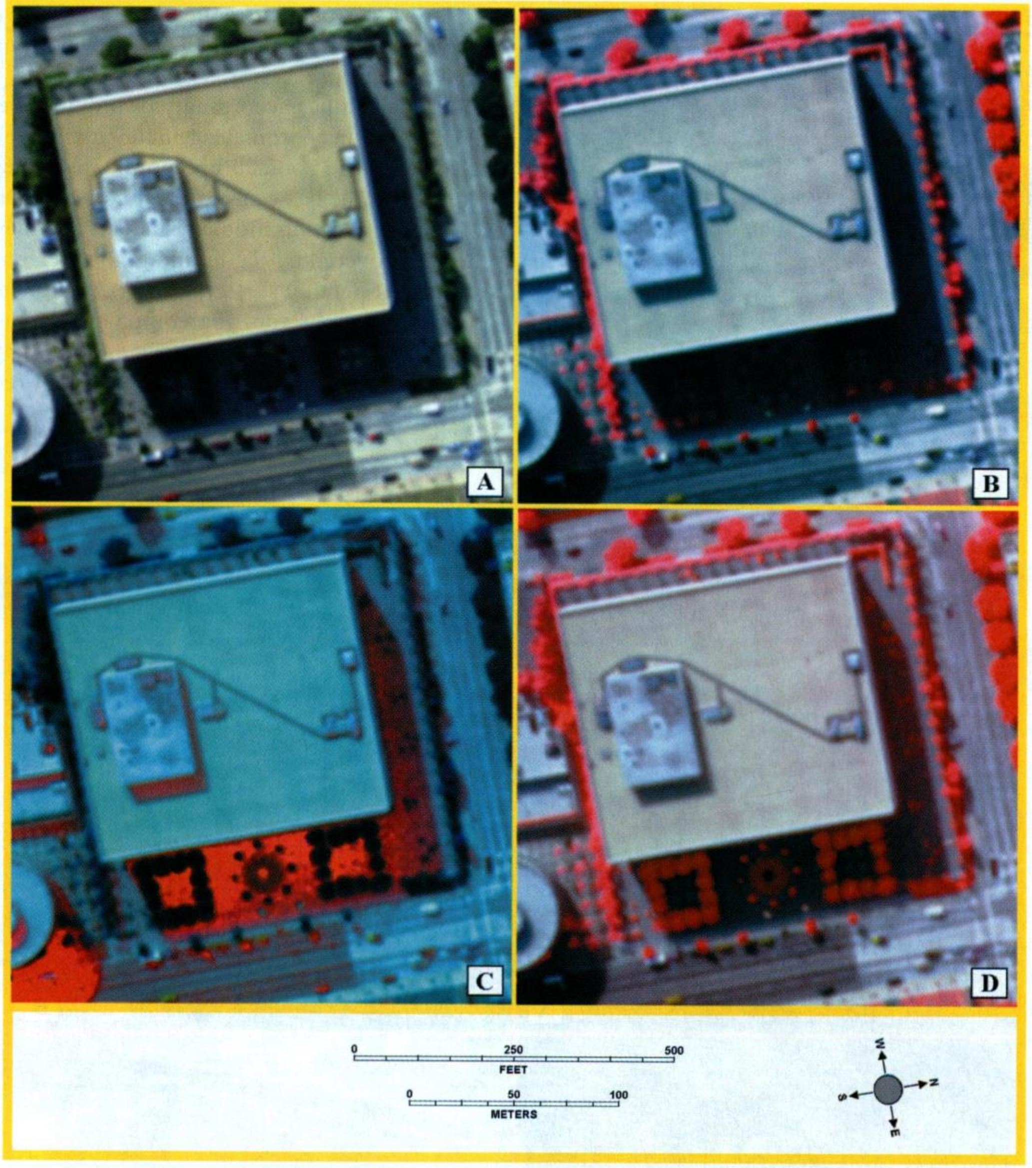

Figure 9 Vegetation patterns within shadow of building: A normal color composite with red, green, and blue images, B. false color composite with IR, red, and green images, C. false color composite with vegetation index, red, and green images, and D. false color composite with subtracted red image from vegetation image, red, and green images.

However, the building is rotated slightly on the image making the problem more complex to solve. It could be handled through calculating and summing the area within several right-angle triangles. Students are shown how to accomplish this procedure on another rectangular feature on the image. A more direct way to handle the situation is to rotate the image in Microsoft Photo Editor so that the building is squared with the image's coordinates. A rotation of 10º clockwise will rectify the situation. This is the procedure generally used by the students. Using the coordinates for the opposite corners of the building's roof, the mathematical steps are:

(464 - 649) * (570 - 729)

-186 * -160

29760 pixels

Since the problem deals with determining the amount of area, the area of one pixel must be calculated. The length of a pixel on the image is .75-meters; the area is .5625-meters (.752). This number is multiplied by the total number of pixels to ascertain the area size of the building, which is 16,749 square meters. To figure the area in square feet multiply 6.05 by the total number of square meters, which produces the value of 101,304 square feet. The number, 6.05, is the amount of square feet in a .75-meter pixel. These same steps are repeated for the equipment penthouse on the roof, which should be about 1,863 square meters or 11,271 square feet in size. To obtain the proportion, divide the area of the equipment penthouse by the area of the main building. It should be around 11.13 percent.

Students enjoyed determining these measurements. It introduced them to how geometry can be applied to solving specific problems.

Conclusion

High resolution, multispectral digital imagery will become a major source of information for addressing various environmental issues during the beginning of the 21st century. It is important that students taking remote sensing courses be introduced to this type of imagery and be given the opportunity to use it. Through traditional photogrammetric methods in conjunction with digital color and enhancement techniques, a great amount of information can be obtained from satellite-based, high resolution imagery, information not obtainable from low resolution digital imagery or regular aerial photographs. The assignments presented in this paper are examples of what instructors can have students do in their courses.

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