FUSION OF INSAR HIGH RESOLUTION IMAGERY AND LOW RESOLUTION OPTICAL IMAGERY

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ABSTRACT:

High resolution (1.25 meter) ortho-rectified radar imagery (ORI) from an airborne InSAR platform was recently created for the whole of Great Britain as part of the NEXTMapUK program which simultaneuosly generated a DSM (Digital Surface Model) and DTM (Digital Terrain Model) with 5 meter samples, for the same national area. A similar initiative is underway in the USA. In order to provide a broader range of useful products for the user community, the NEXTMap data-base, which normally includes a single X-Band channel ORI (OrthoRectified Image) along with associated DSM and DTM, will be supplemented by an optical layer. The optical layer may be able to take advantage of relatively recent air-photo archival data in some urban areas, but in order to economically capture large rural areas it is has been proposed that widely available, lower-cost, coarse-resolution multi-spectral (MS) satellite imagery from candidate sources such as SPOT (10 m), ASTER (15 m) or Landsat(30 m) be merged with the 1.25 meter STAR-3*i* ORIs being created currently. Thus a new high-resolution hybrid color layer would be generated. This paper addresses some of the challenges associated with this task.

There are basically three technical issues that need to be resolved in this process: (1) the candidate satellite imagery must be ortho-rectified, (2) the MS optical and radar imagery must be merged despite pixel size differences of a factor of 8, 12 or 24, depending on the MS source, and (3) color transformations need to be considered either pre- or post-merge.

The least onerous problem is the ortho-rectification of the optical imagery, since the radar ORI is a source of ground control points and there is a simultaneous DSM available. The merging activity is more challenging since it is desired to create a stable and predictable process in which the spectral content of the MS is largely preserved in the merged product. A modified version of a wavelet transformation process has been developed at UNB and applied to this problem. Lastly, there are color issues because while it is desireable to create a facsimile of the standard RGB color imagery associated with aerial photography, at least two of the MS source candidates (ASTER and SPOT) have spectral bands that are essentially Green, Red and Near-IR. Several approaches have been examined. In this paper we will describe these issues, the processes evolved and the results of tests on the candidate MS images.

1. INTRODUCTION

High resolution ortho-rectified colour images from aerial photography or satellite are widely desired but often prohibitively expensive particularly over large areas. On the other hand, monochromatic ortho-rectfied radar images at 1.25 meter resolution with corresponding horizontal accuracy are now available at relatively low cost over relatively large areas – for instance, the whole of Great Britain as part of the NEXTMap UK program (Mercer, (2004)). It would be desirable for many applications to create a fused product from the radar ORI and a suitable MS low resolution source. In this paper we wish to demonstrate the quality that can be achieved through fusion of the STAR-3*i* ORI (ibid) with ASTER 15 meter MS imagery. While optical fusion of panchromatic and coarser MS images has been widely studied using a number of techniques,- for example, IHS, PCA, Brovey and more recently wavelet fusion - there appear to be few recent publications citing high resolution radar and low resolution optical fusion. While the authors, among others, have utilized IHS transforms for this purpose, the problem is to maintain to the extent possible, the spectral content of the original MS image while retaining the detail of the high-resolution radar despite a large difference (x12) in resolution of this MS source. In this paper, a new approach developed at UNB by Zhang et. al. (2005) uses a hybrid of IHS and Wavelet transformations to better resolve this problem.

The virtue of ASTER is its wide area coverage and inexpensive availability. Among the challenges that creating a suitable fused product include are: (1) ASTER ortho-rectification, (2) the fusion itself, (3) the color-transform problem. The latter issue relates to the use of a pseudo-color MS source: the three MS bands used in this instance, corresponding to ASTER channels 1, 2 and 3 are essentially in the Near IR, Red and Green parts of the spectrum. From a remote sensing perspective, this is well understood and has distinct advantages. However from the perspective of a prospective user anticipating natural color products, this a disadvantage. We address this issue with a new color-matching and transformation approach described in section 4.

In this paper we will describe the three major activities in the process including examples of their implementation.

2. THE PROCESSES

2.1 Orthorectification of the MS Image

The purpose of the orthorectification stage is to ensure that the pixels of the radar and MS image are co-registered. Ideally, radar pixel would be centered on the larger MS pixel. The extent to which there is a departure from this ideal will impact the process but this has not been instigated thorougly in this work. However it is clear that large systematic errors (i.e. larger than the MS pixel) degrade the quality of the fused product increasingly. In particular it results in color artifacts that appear to be unacceptable.

In this work, using ASTER as MS source, orthorectification was facilitated by the availability of the InSAR-derived DSM which is co-generated with the ORI. About 15 control points over the test area (typically based upon a 7.5' x 7.5' tile) were acquired by manually selecting match points between the ASTER image and radar ORI. The PCI Geomatica 'rational functions' implementation with low order polynomials was used for the orthorectification, with the forementioned DSM and GCPs as inputs. The rational functions approach to orthorectification of Ikonos and Quickbird data has been well described (Di, et. al. (2003), Fraser, et. al. (2001), Mercer (2003), Tao, et. al.(), Toutin (2003)).

2.2 The Fusion Approach

2.2.1 Conventional Wavelet Fusion Techniques: Wavelet transformation is a mathematical tool that can detect local features in a signal process. It can also be employed to decompose two-dimensional signals – a digital image – into different levels of resolution for a multi-resolution analysis. This multi-resolution characteristic is utilized for fusing images with different resolutions. The process has been well-described (Yocky, (1996), Aiazzi, et. al. (2002), Shi, et. al. (2003), Garguet-Duport (1996)). In the following brief summary of the conventional approach, we denote R, G, B as the multi-spectral input channels in a generic sense, although as noted the spectral content for ASTER channels lies mainly in the Near IR, Red and Green bands.

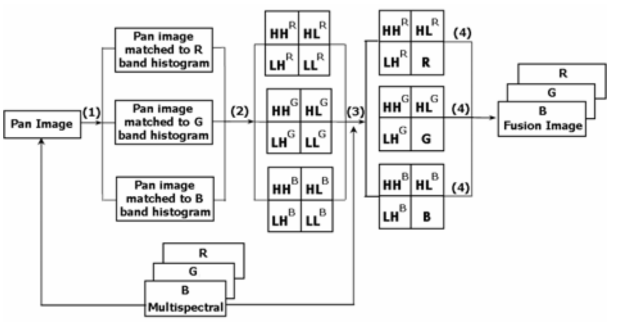

Figure 1: Schematic of conventional wavelet fusion approach

The conventional process is illustrated in the schematic of Figure 1 (adapted from Garguet-Duport, et. al. (1996)). First, three new panchromatic images are produced by matching the panchromatic image histogram to that of each of the R, G, B bands of the multispectral image respectively. Then, each of the histogram-matched panchromatic images is decomposed into a set of four images: a low-resolution approximation image (labelled LL) and three 'images' of the wavelet coefficients (labelled HH, HL and LH), also called detail images, which contain information of local spatial details. The three decomposed low-resolution panchromatic images are then replaced by the real low-resolution multispectral image bands (B, G, R), respectively. Finally, a reverse wavelet transform is applied to each of the image sets containing the three local spatial detail images and one of the multispectral bands (B, G, R). The result of these three reverse wavelet transforms, is to modulate the MS bands with the high-resolution spatial details from the panchromatic image resulting in fused high-resolution multispectral bands.

2.2.2 An Integrated Wavelet/IHS Technique for SAR-MS Fusion: To better utilize the advantages of the IHS transformation for colour-feature integration and the wavelet technique for feature extraction and colour preserving, and to overcome the shortcomings of the two techniques, we proposed an integrated wavelet/IHS fusion approach (Zhang, et.al.(2005)). The concept and the process steps of this approach are illustrated in Figure 2. The label LL refers to low resolution approximations of the MS and panchromatic input images repectively. The 'P' and 'I' super-scripts reference their origin: either Panchromatic (i.e. radar in this case) or the Intensity generated from the IHS-transformed MS image set. In general, the approach uses the IHS transform to integrate the low-resolution multispectral colour information with the high-resolution panchromatic spatial detail information to achieve a smooth integration of colour and spatial features (part I of Figure 2). The wavelet transform is utilized to generate a new panchromatic image (new intensity in Figure 2) that has a high correlation to the intensity image and contains the spatial detail of the original panchromatic image (part II in Figure 2). Results of this approach are shown in section 2.2.3.

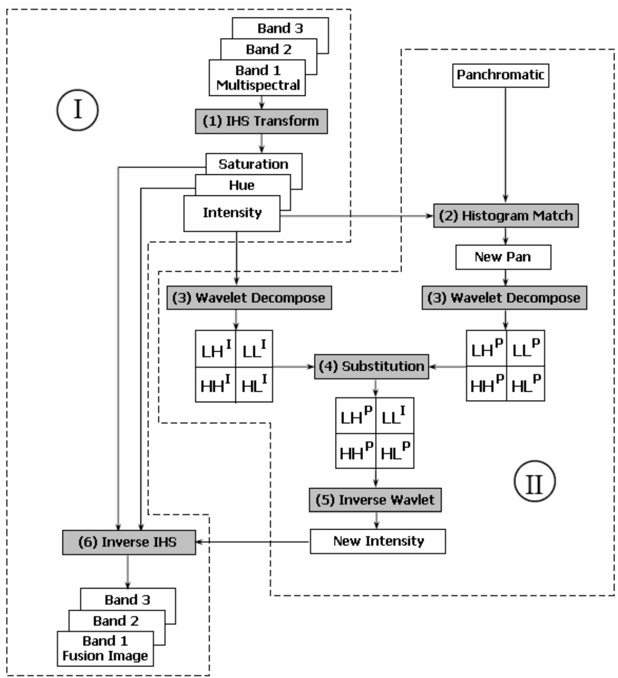

Figure 2: Schematic of integrated Wavelet/IHS technique. Two-level wavelet decomposition is applied but only one shown.

2.2.3 Examples of the Integrated Wavelet/IHS Approach: In the following sets of examples, we show a particular scene near Livermore, California, USA. The fusion program was implemented on a STAR-3*i* scene approximately 7K x 7K (1.25 meter pixels) which corresponds to dimensions of 8.75 km x 8.75 km. In the following, because of space limitations, we show subsets of the scene, of dimension 1.525 km x 1.525 km. In Figures 3, 4 and 5 we show, respectively, the 1.25 meter STAR-3*i* ORI, the ASTER 15 meter image and the 1.25 meter fused result. The ASTER image was downloaded from the USGS data centre as a L1B scene, and spectral bands B1, B2 and B3N used in this work. The ASTER scene was ortho-rectified as described in section 2.1 with residuals of a few meters.

Figure 3: Radar Image 1.25 m STAR-3*i* ORI

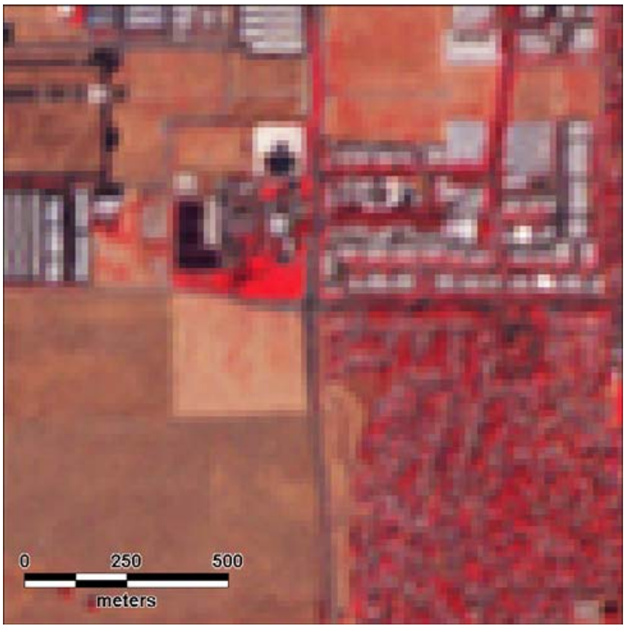

Figure 4: ASTER pseudo-color image, ortho-rectified, 15 m

Figure 5: Fused 1.25 m ASTER/STAR3*i* psuedo-color image

2.3 Color Transformation

2.3.1 Background: As a final product of the SAR-MS fusion, high resolution, realistically colored imagery is desirable. In order to satisfy the latter part of this goal, pseudocolored MS images (MSI) must undergo a color transformation. A very basic method for doing this is to set red, green and blue as combinations of the gray values of the bands in the MSI. Below is the general form of such a transformation (assuming only 3 bands of the MSI are being considered):

$$R_T = a_R M_1 + b_R M_2 + c_R M_3 + d_R$$
$$G_T = a_G M_1 + b_G M_2 + c_G M_3 + d_G \qquad (1)$$
$$B_T = a_B M_1 + b_B M_2 + c_B M_3 + d_B$$

where R_T, G_T, B_T = gray values of the red, green and blue channels of the transformed image
M_1, M_2, M_3 = gray values of the channels of the multispectral image
a_R, b_R, c_R, d_R, *etc.* = parameters with subscripts referring to the associated color channel

Qualitatively, the ‘best’ color transform is the one that produces the most realistic looking color; however it is not obvious what parameter values will yield the best results and to what extent they will vary from scene to scene. Furthermore, what looks ‘best’ is subjective and may vary among observers. In the following we present a method which appears more objective and repeatable. The current software implementation of this approach is referred to as Cal2.

2.3.2 The Cal2 Approach: The Cal2 Color Transform solves these problems in the following manner:

- Cal2 accepts a reference image, such as a color aerial photograph, as a color reference image (CRI). This image defines what “realistic” means.
- Cal2 uses a Least Squares Estimation (Observation Model) to determine the optimum parameter values that will match the MSI to the CRI.

A sampling of the CRI and MSI occurs where pairs of corresponding pixels are collected. The set of sampled pixels ideally has representation of significant land and terrain cover types (all colors) of the images. Each pair of sampled pixels will yield 3 equations.

$$
\begin{aligned}
R_{CR} &= a_R M_1 + b_R M_2 + c_R M_3 + d_R \\
G_{CR} &= a_G M_1 + b_G M_2 + c_G M_3 + d_G \\
B_{CR} &= a_B M_1 + b_B M_2 + c_B M_3 + d_B
\end{aligned} \quad (2)
$$

where R_{CR}, G_{CR}, B_{CR} = gray values of the red, green and blue channels of the color reference image

This can be decomposed into a design matrix.

M_1	M_2	M_3	1	0	0	0	0	0	0	0	0
0	0	0	0	M_1	M_2	M_3	1	0	0	0	0
0	0	0	0	0	0	0	0	M_1	M_2	M_3	1

These matrices are combined to form the design matrix, **A**. For n pairs of sample pixels, **A** will have dimensions 3n x 12.

The optimum parameter values can be calculated through the equation:

$$\mathbf{x} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{y} \quad (3)$$

where **A** = design matrix
$\mathbf{x} = [\, a_R \quad b_R \quad c_R \quad d_R \quad a_G \ \ldots \ d_B \,]^T$
$\mathbf{y} = [\, R_{CR(1)} \ G_{CR(1)} \ B_{CR(1)} \ \ldots \ R_{CR(n)} \ G_{CR(n)} \ B_{CR(n)} \,]^T$

The parameters are substituted into Equation 1. Applying this model transforms the MSI into a Cal2 Transformed Image which will have realistic looking color. Normally this step is performed prior to the fusion process. The color input to the fusion process is therefore a 'natural color' image derived from its pseudo-color source.

2.3.3 Color Transform Example: The examples described in this paper refer to ASTER - specifically to spectral bands B1, B2 and B3N. These ASTER bands correspond approximately to green, red and near-IR, but the transformation requirement refers equally to SPOT5, whose spectral response is similar to that of ASTER as well as Landsat (bands B2, B3, and B4). Landsat RGB may also be subject to the transformation in instances where haze or time of year present a less-desirable image to be used for fusion.

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In Figures 5 and 6 we show, respectively, a before and after color transform example. The scene is another subset of the Livermore tile mentioned in section 2.2.3. There were two possibilities that were available for use as the color reference image (CRI). In neither case were they temporally close to either the ASTER image date or that of the STAR-3*i* ORI with which it was subsequently fused. The first attempt was from a set of 1 meter color air photos. The second attempt used a commercial product referred to as Landsat7 'NaturalVue'. For purposes of color matching, the spatial resolution of the CRI was of less importance than the degree to which the colors are representative of the range of terrain cover types in the MSI. 'Natural Vue' is itself a derivative of multiple Landsat bands in a proprietorial process of Earth Satellite Corp. The virtue of this product for the purpose of the CRI is that it is available off-the-shelf for most of the world's land mass, and is relatively inexpensive whereas color air photo is not always available, particularly in rural areas. In the examples shown here we have used Natural Vue as the CRI.

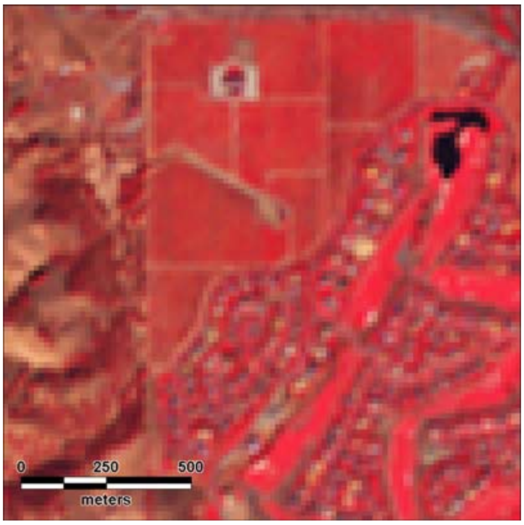

Figure 5: ASTER pseudo-color image as input to the Cal2 color transformation process.

Figure 6: ASTER image after Cal2 color-transformation.

2.4 Fusion of the Color-Transfomed ASTER Image

Figure 7: Fused, color-transformed ASTER/STAR-3*i* image

3. Results and Discussion

The following examples show as input the STAR-3*i* and ASTER images along with the fused, color-transformed images that result from the previously described processes. Figures 8-13 show two sub-areas of the Livermore scene described previously. The Landsat7 NaturalVue was used as the CRI and the derived coefficients of Equation 2 were common for the whole scene. The dimensions are 3.125 km x 3.125 km in all cases. The two sets of examples are presented at a viewing scale of 1:20,000, considerably coarser than full resolution would permit.

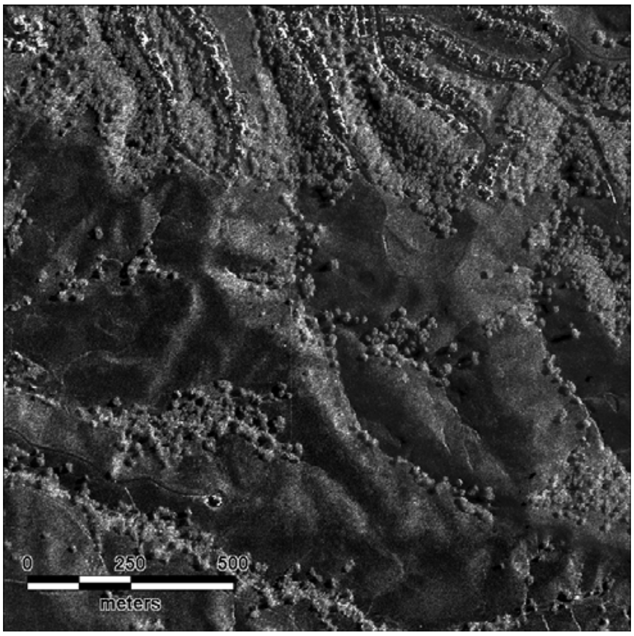

Figure 8: Sub-area 1 STAR-3*i* ORI

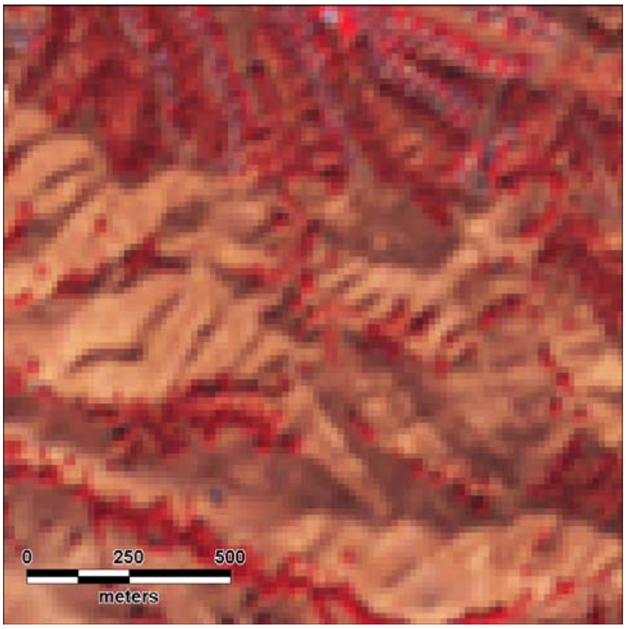

Figure 9: Sub-area 1 ASTER image

Examination of Figures 8-13 and the preceding examples of Figures 3-5 enables a qualitative assessment to be made of various aspects of the process.

1. The orthorectification accuracy of ASTER with respect to STAR-*i* was satisfactory for purposes of fusion at this scale. Otherwise systematic offsets would have manifested themselves in the fused image. Color shifts do not appear to be evident in either Figure 5 or the subsequent final product examples of figures 9 and 11.

2. The integrated wavelet/IHS fusion of high resolution (1.25 meter) radar and coarser (15 meter) MS optical works well in terms of its objective of preserving the spatial detail of

Figure 11: Sub-area 2 STAR-3*i* ORI

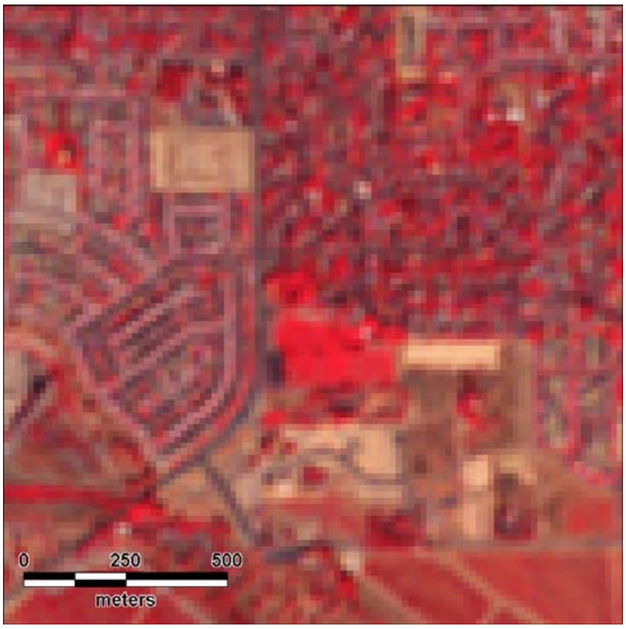

Figure 12: Sub-area 2 ASTER image

the former and the spectral content of the latter. This observation is supported by visual inspection of Figures 3-5.

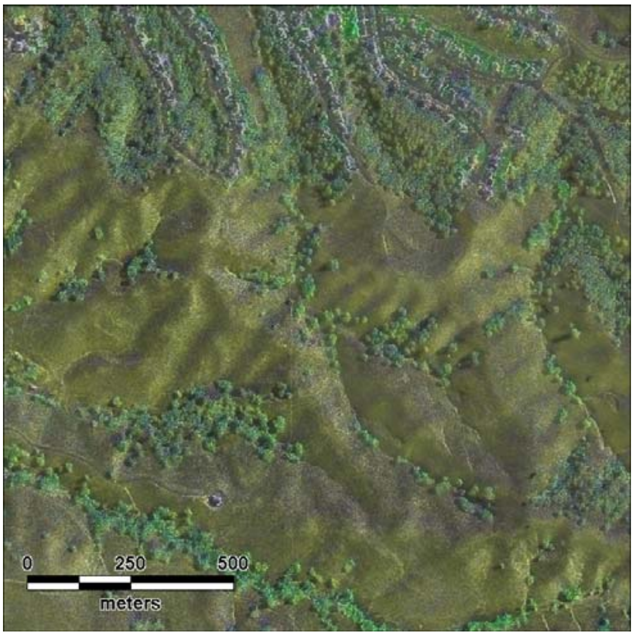

Figure 10: Sub-area 1 Fused and color-transformed image

Figure 13: Sub-area 2 Fused and color-transformed image

3. The color transformation methodology provides a reasonably realistic and repeatable quasi-natural looking source image. However it is dependent upon the quality of the CRI used and the time of year represented. Moreover there are observable differences in the color-transformed and ultimately the fused product depending on the choice of color sampling areas. For instance in Figures 10 and 13 a purplish component is observed in some of the trees. These are traceable to the ASTER response and perhaps enhanced by the fusion process. Current efforts indicate that such effects may be mitigated by choice of CRI. Additional work is needed to determine how robust the process is with respect to the variability of terrain cover types in the sampled area. From a production standpoint it would be desirable to minimize the number of sampling areas.

4. The final color-transformed, fused product appears to be cosmetically attractive and to offer the potential for use in a variety of applications where spatial detail and quasi-correct spectral content are desirable, together with the precise georeferencing underlying this product. It is in this context that a national color layer, based on this approach, is being planned as a part of Intermap's NEXTMap data base.

4. CONCLUSIONS

This work has demonstrated the creation of a new quasi-realistic color radar image product which results from the fusion of high-resolution InSAR imagery with low-resolution optical imagery. Specifically, in this work, we have shown the results from the fusion of a color-transformed, ortho-rectified multi-spectral ASTER image at 15 meters resolution with a 1.25 meter STAR-3*i* ORI. The process invokes two new techniques which have been described herein: (1) an integrated Wavelet/IHS fusion approach, and (2) a color-transformation methodology for creating a quasi-realistic spectral appearance.
The resulting product combines the spatial detail and accuracy of the radar ORI and color content originating with ASTER but modified to more closely resemble realistic land scenes.

5. REFERENCES

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