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The Effect of Using the Different Satellite Spatial Resolution on the Fusion Technique

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Abstract

Bilinear interpolation and use of perceptual color spaces (HSL, HSV, LAB, and LUV) fusion techniques are presented to improve spatial and spectral characteristics of the multispectral image that has a low resolution to match the high spatial resolution of a panchromatic image for different satellites image data (Orbview-3 and Landsat-7) for the same region. The Signal-to-Noise Ratio (SNR) fidelity criterion for achromatic information has been calculated, as well as the mean color-shifting parameters that computed the ratio of chromatic information loss of the RGB compound inside each pixel to evaluate the quality of the fused images. The results showed the superiority of HSL color space to fuse images over the rest of the spaces, as it recorded the highest SNR and the lowest mean color-shifting. The quality of the fused images using Lab color space was not affected by the type of intermediate algorithm used for XYZ space, unlike LUV color space. The XYZ algorithm type affected the fused image results, which recorded the worst consequences. It is noted that the computational time taken increased exponentially with the difference in spatial resolution between the fused images.

Keywords: Image fusion, bilinear interpolation technique, up-sampling process, Orbview-3 image data, RGB color space, HSL, HSV, Lab, and LUV perceptual color spaces.

تأثير استخدام الدقة المكانية المختلفة للقمر الصناعي على تقانة الاندماج

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الخلاصة

في هذا البحث، تم تقديم الاستيفاء ثنائي الخطي واستعمال فضاءات الألوان الحسية HSL) و HSV و LAB (LUV لتحسين الخصائص المكانية والطيفية للصورة متعددة الأطياف التي تتميز بدقة منخفضة لمطابقة الدقة المكانية العالية للصورة البانكروماتيك لبيانات صور الأقمار الصناعية المختلفة Orbview-3) و Landsat-7) لنفس المنطقة. تم حساب المعلمات معيار دقة الإشارة إلى الضوضاء (SNR) للمعلومات الالونية، ومتوسط تحول اللون التي تحسب نسبة فقدان المعلومات الالونية لمركب RGB داخل كل بكسل

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لتقييم الجودة من الصور المدمجة. أظهرت النتائج تفوق فضاء الوان HSL لدمج الصور على باقي الفضاءات، حيث سجلت أعلى نسبة SNR وأقل معدل تحول اللون. لم تتأثر جودة الصور المدمجة باستعمال فضاء الوان Lab بنوع الخوارزمية الوسيطة المستعملة لفضاء XYZ ، على عكس فضاء الوان LUV تأثرت نتائج الصور المدمجة بنوع خوارزمية XYZ المستعملة والتي سجلت بشكل عام أسوأ النتائج. ويلاحظ أن الوقت الحسابي الذي يستغرقه زاد بشكل كبير مع الاختلاف في الدقة المكانية بين الصور المدمجة.

1. Introduction

In digital remote sensing imagery, using mathematical techniques, the fusion images of varying spatial resolution sensors have become a significant process of integrating relevant information for two or more images of the same geographic region. One of the fusion technique's goals is to enhance the spatial resolution of multispectral images [1] [2].

The basic idea of the technique is to produce a better land cover interpretation, which can be achieved in two ways. The first way is combining a panchromatic and multispectral image since the panchromatic image has a higher spatial resolution than the multispectral image. The panchromatic image replaces the achromatic information of the multispectral image in one of the perceptual color spaces while preserving the original image's spectral completeness. Landsat-7 and Landsat-8 satellites consist of both types of images. The information contents (spatial and spectral) are combined to produce a high spatial resolution multispectral image that contains the best information of the two input images [3] [4].

The second way is to combine the two satellite images (different sensors), which do in different parts of the electromagnetic spectral range (microwave, visible light, and near-infrared), with the different image information, characteristics (contrast, brightness, and standard deviation), and statistics of the image to improve the quality of the images and produce the distinct images for the same scene [4].

This technique provides an effective method to compare and analyze multi-sensor data having complementary information about a certain region and reducing increasing information by extracting valuable information from original images [2].

Landsat data have been utilized widely for global monitoring due to unrestricted availability and regular revisit efficiency. The temporal coverage of Landsat data is unsuitable for monitoring rapid changes, which revisits the same region every 16 days. The captured Landsat data for certain regions can be polluted by smoke, cloud, and shadow, so obtaining one clear image in a month is challenging. Spatial and spectral fusion techniques have been developed to obtain more recurrent Landsat images for timely monitoring [5].

Two satellites are used in this research; Orbview-3 and Landsat-7 images. The Orbview-3 image contains significant features with high contrast and details, which are absent in the multispectral Landsat images with low contrast and details. In this research, the spatial and spectral image characteristics are improved by two image fusion techniques to overcome the image data fusion problem for different sensors acquired for the same region.

For the spatial part, the low-resolution multispectral image is up-sampled using the bilinear interpolation method to match the spatial resolution of the panchromatic image. In contrast, for the spectral part, the multispectral image is transferred after the upsampling process into a perceptual color space using four-color spaces (HSL, HSV, LAB, and LUV).

The quality of the fusion image was calculated using fidelity criteria for each color space, including Signal Noise Ratio (SNR) for the achromatic part and the mean color-shifting parameters that compute the ratio of chromatic information loss of compound (RGB) inside each pixel after comparing the multispectral image with fusion image. Then recording the computational time of fused images for each color space [6].

1.1. Previous Studies

The fusion technique occupied an extensive field of research, such as;

Al-Rubiey [2] implemented six fusion techniques between panchromatic and multispectral images: Ehlers, color normalize, Gram-Schmidt, local mean and variance matching, Daubechies of rank two, and Symlets of rank four wavelets transform, using two different sensors, Landsat-8, and world view-2. Different fidelity metrics like MSE, RMSE, PSNR, Cc, ERGAS, and RASE are used to compare fusion techniques. She showed that the Daubechies wavelet (db2) transform method was better for fusion images with the best statistical values.

Abduljabbar [7] proposed new fusion techniques to fuse multiple satellite images acquired through different electromagnetic spectrum ranges to create a single grayscale image based on wavelet transform by pyramid and packet bases. He performed the fusion technique by two different fusion rules. First, the low-frequency part is remapped through PCA analysis based on the covariance and correlation matrix. Second, the high-frequency part is fused using different fusion rules (adding, selecting the higher, replacement). He obtained the restored image by applying the inverse discrete wavelet transform. He displayed the accuracy of the proposed method to fuse images with a similar representation compared with the general wavelet fusion technique that only fuses high-frequency parts.

Abduljabbar [4] presented a new approach based on the principal component analysis (PCA) fusion method for the fusion of satellite images acquired in different electromagnetic wave ranges, which showed the ability to make one of the image characteristics a few superior to other without decreasing the quality of the resultant fused image.

Hamed et al. [8] proposed a new technique to fuse panchromatic and multispectral satellite images based on combining IHS perceptual color space and Haar wavelet transform. They evaluated results using different fidelity criteria like Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR).

Sabti [9] used four perceptual color spaces, H, Lab, and LUV, to implement a new steganographic method. He analyzed the effects of the quantization and encoding process on the quality of the cover image and the color spaces components.

1.2. Up-Sampling Using Bilinear Interpolation technique

Image interpolation is a mathematical technique designed to predict calculations of measured points with known values in a specific region to estimate values at other unknown points and create a vector surface with estimated values [10]. This technique based on multi-resolution is essential due to its various applications such as medical, geographical, and space information. There are different interpolation techniques such as the nearest neighbor, Bilinear, Bicubic, B-spline, Lanczos, global polynomial, local polynomial, inverse distance weight (IDW), Discrete wavelet transform (DWT), and Kriging [11]. In this research, the bilinear interpolation technique was applied to the multispectral image to up-sample it. Bilinear interpolation is implemented to determine the unknown gray level values at the random position from the weighted average of the four nearest pixels to the specified input coordinates and assign these values to the output coordinates [12]. The Niblack bilinear interpolation is used in this research in the upsampling process [13].

1.3. Color space

Color space indicates a color coordinate system as a three-dimensional space in which the pixel value of a color image is represented. Different color spaces are used for various applications because some devices have specific factors that describe the size and type of color space used. The RGB color space is the most commonly used in computer technology, which was established by The International Commission on Illumination (CIE) in 1931 as a basic color system [14]. The RGB color space consists of three primary colors: Red, Green, and Blue; each color has a numerical value ranging between (0 and 255). The mixing of Red, Green and Blue color values in different ratios displays 16777216 colors [15] [16] [17].

The perceptual color spaces implemented are HSL, HSV, Lab, and LUV. The characteristic of the color spaces is the ability to split the chromatic information from the achromatic to match the nature of human perception.

1.4. Color Spaces Classification

In digital image processing, many color spaces are implemented. The color spaces can be divided according to The International Commission on Illumination (CIE) into [16] [17] [18]:

1. Basic color space (RGB).
2. Human visual system (HSV).
3. Perceptual color space:

a. Perceptual uniform color space, such as; (CIE LUV and CIE Lab).

b. Perceptual nonuniform color space, such as; (HSL Triangle, HSV hexagonal, and HSL Double.

The CIE LUV and CIE Lab color spaces depend on the human vision system (HVS); these color spaces can be used through intermediate color space XYZ. The XYZ color space is the origin of all visible colors that determine the positive values from this space and is used to evaluate the difference in colors [16] [19] [20].

1.5. Study Site Description and the Used Data

The selected study region is located in Al-Anbar province, western side of Iraq. The study region falls in the Landsat 7 satellite scene in path 168 and row 37 and the Orbview-3 satellite scene in path 41 and row 3 (see Figure 1).

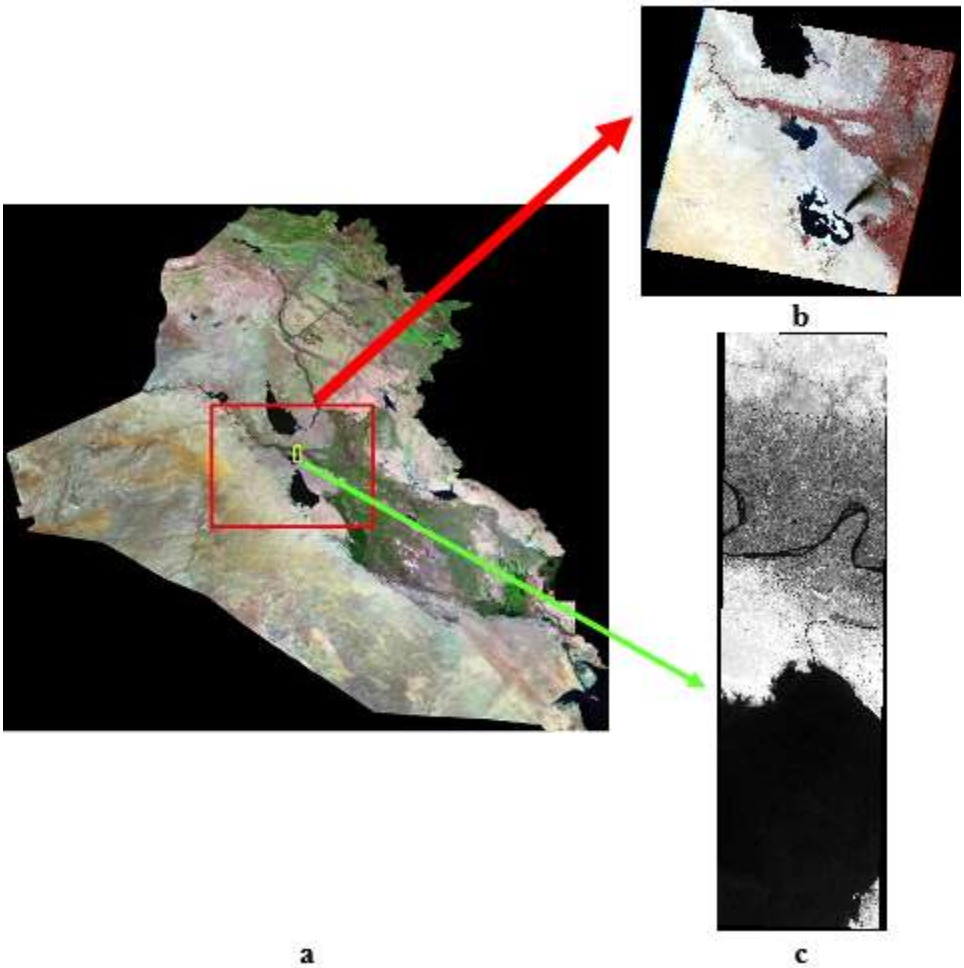
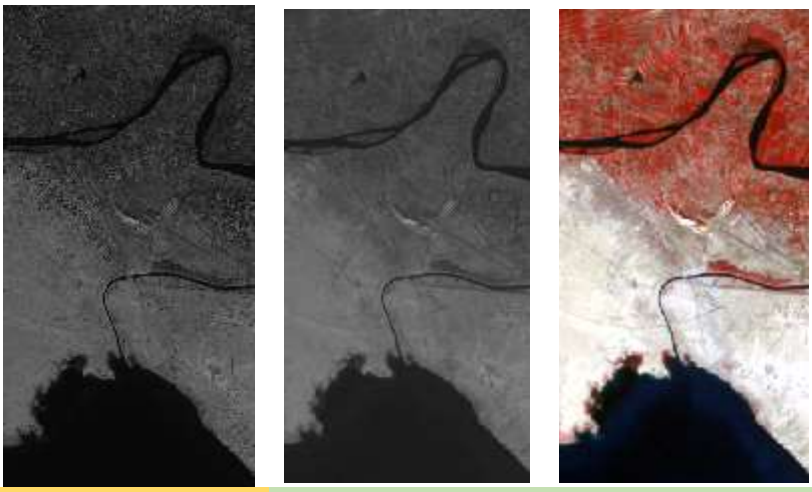


Figure 1-a. Iraqi country map with two scenes for study region (b. Pseudo-false color of Landsat-7 ETM+ and c. Orbview-3)

The study region includes different urban areas, agricultural areas (irrigated lands and rice fields) considered agricultural lands and pastures, mineralization areas (gravel and sand areas), river levee soils, river basin soils, and silted soils phase, gypsum desert land, and mixed gypsiferous desert land. This region contains lands suitable for agriculture and lands not suitable for agriculture, so it is considered good lands for grazing and forests. The groundwater types are chloride (C_l) and Bicarbonate - sulfate (HCO_3 – SO_4). Salinity of groundwater classified as freshwater < 1000 (mg/l) and brackish water (3000-10000) (mg/l). It contains alternation of sand, silt, clay, gypcrete, alternation of sandstones, pebbly sandstones, and limestones. This region's structural-denudational, evaporitic, and fluvial origins are plateaus, gypcrete, terraces (Euphrates River), flood plains, water reservoirs (Al-Habbaniyah, AL-Thirthar, and Razzaza lakes), and infilled depressions, which represents the surface water regions.

The descriptions of the study region were obtained from the exploratory soil map of Iraq by dr p. Buringh, 1957 [21]; the hydrogeological Map of Iraq by Juma A. Al-Wasity, 1990 [22]; the land use map of Iraq by Kanaan Lotfi Ali Hafiz, et al. 1993 [23]; the geomorphological map of Iraq by Nouri M. Hamza, 1997 [24].

The study region is located between (33°19'22.03"- 33°25'41.94") of latitude and (43°30'33.85" - 43°34'39.33") of longitude with an area of (74) $km^{2,}$ and it contains part of the Al-Habbaniyah lake, Malhama city, Al-Habbaniyah city, Al-Habbaniyah airport, Al-Taqaddum airport, and part of the Euphrates river, (see Figure 2).



Panchromatic Orbview-3	Panchromatic Landsat-7	Pseudo-false color (NIR, R & G)

Figure 2-The clipped original images for Landsat-7 and Orbview-3 satellites by QGIS 3.12 program

Two satellite scenes in which three images were used in this research as listed in table 1; the satellite scenes were downloaded from the United States center for Earth recourses, observation, and science [25].

Table 1-Information on the used satellite images

Satellite	**Band Combinations**	**Spatial Resolution**	**Date**	Scene Dimensions
Landsat 7 (ETM+)	ETM+_4 (NIR), ETM+_3 (Red), and ETM+_2 (Green)	30 m	4 October 2004	207 × 394
Landsat 7 (ETM+)	ETM_8 (Panchromatic)	15 m	4 October 2004	413 × 789
Orbview-3	Panchromatic	1 m	3 October 2004	6279 × 11966

2. Methodology

Four perceptual color spaces are used in this research: HSL, HSV, LUV, and Lab. In this research, the mathematical models of the IRO group company are presented on their website [26]. Two XYZ color space algorithms are used to calculate Lab and LUV color spaces, where the D65/2° standard illuminant (CIE 1931) for the reference values of the XYZ are used (Daylight), the two algorithms of XYZ are the standard, and the adobe 1998 algorithms [26], Figure 3 illustrates the transformation between the color spaces that used in research work.

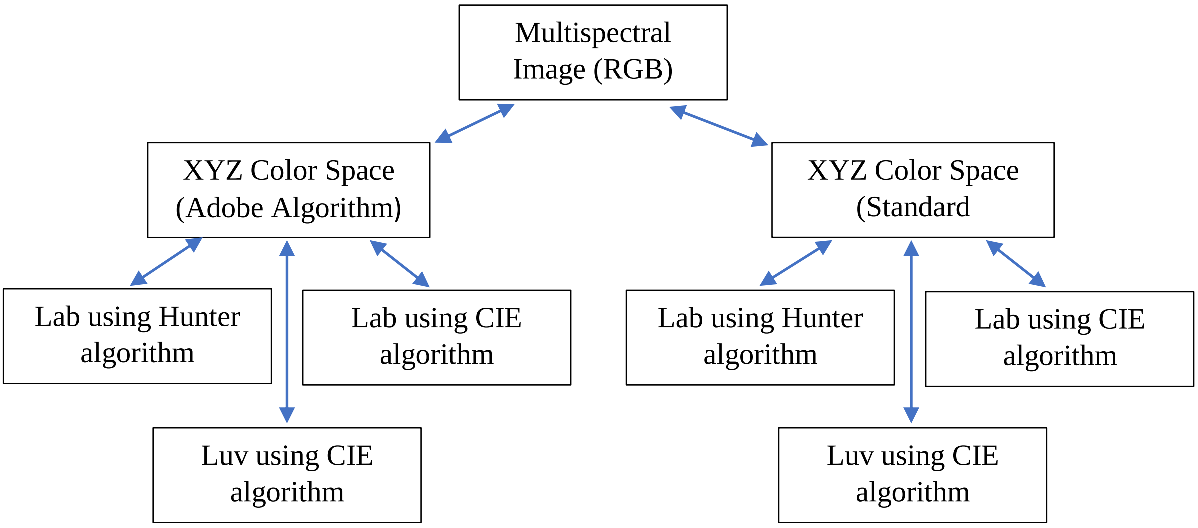


Figure 3-Transforming algorithm between the RGB color space and the Lab and Luv color spaces.

Different image quality criteria are used to calculate the quality of the fused image, like; Signal to Noise Ratio (SNR) for each color space, to estimate the quality of the fused image and achieve the comparison among the color spaces. The mean color-shifting parameters are computed, and the elapsed time for each color space is recorded.
The fusion process is illustrated in Figure 4, in which the achromatic part of the multispectral image is replaced by one of the panchromatic images in one of the perceptual color spaces.

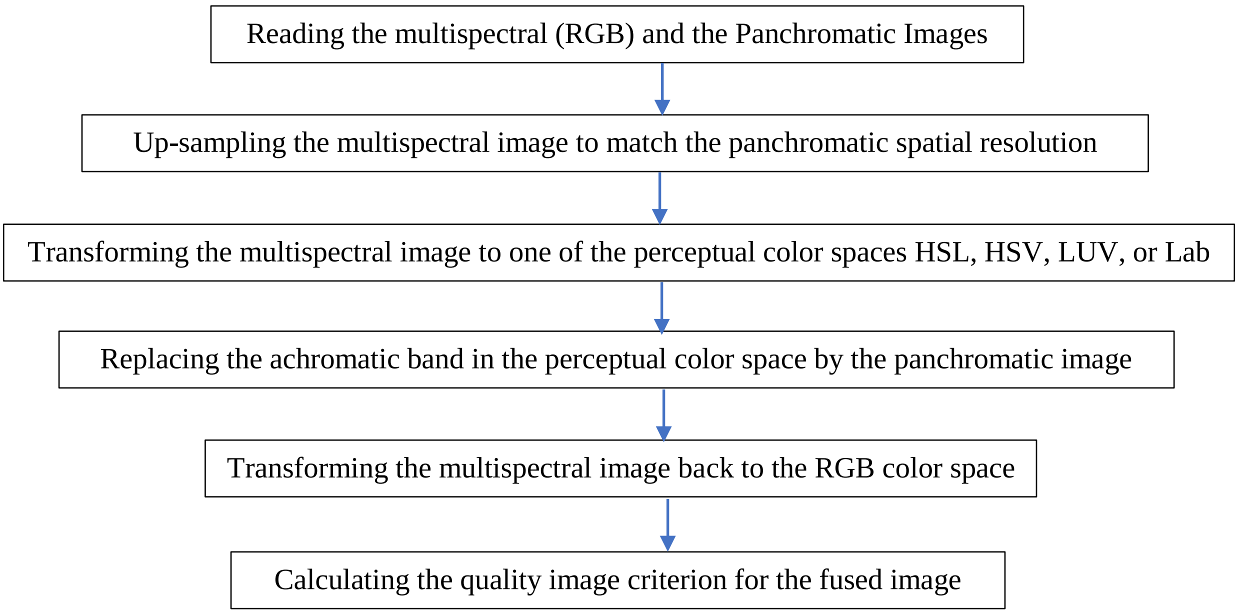
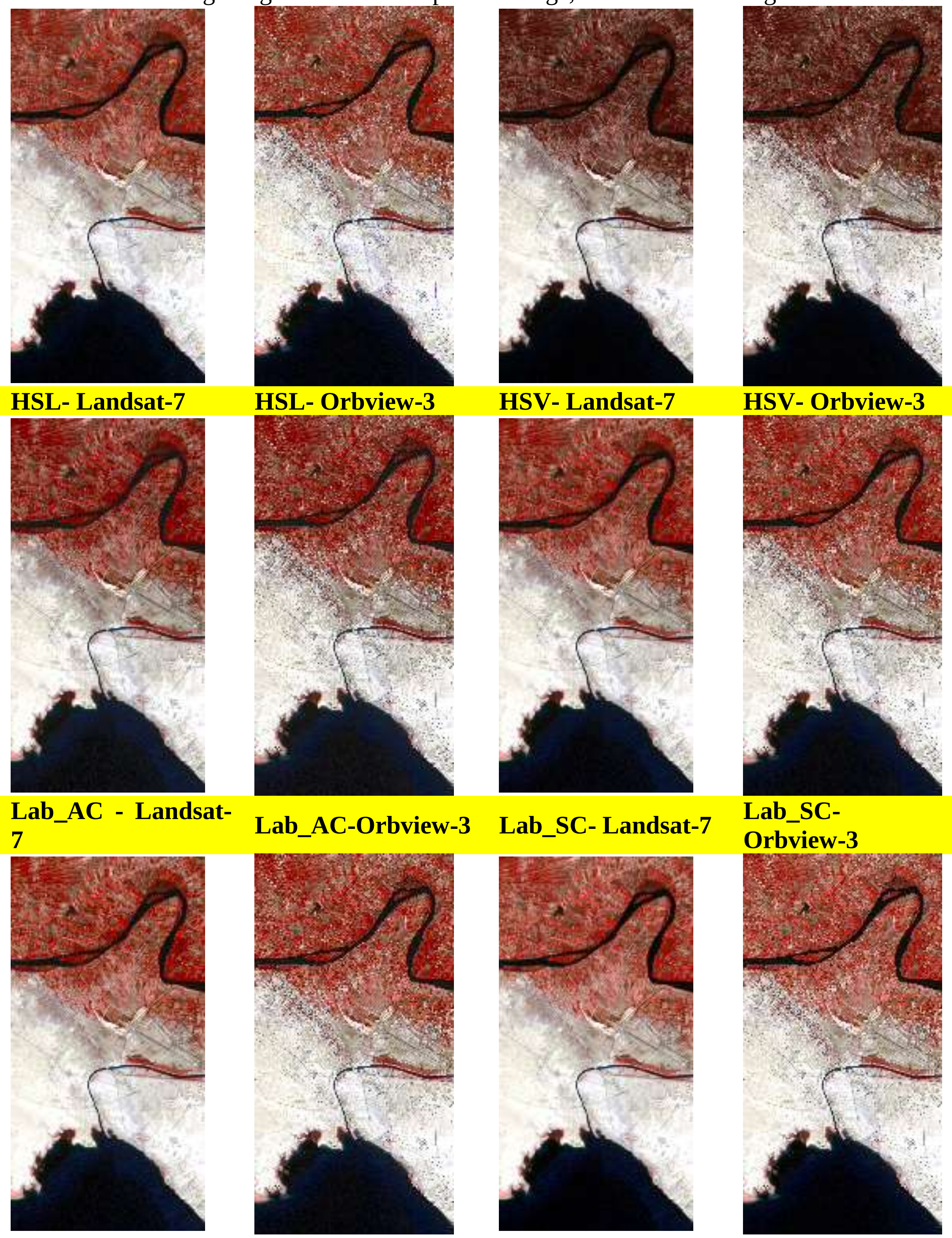


Figure 4-The general fusion algorithm flowchart

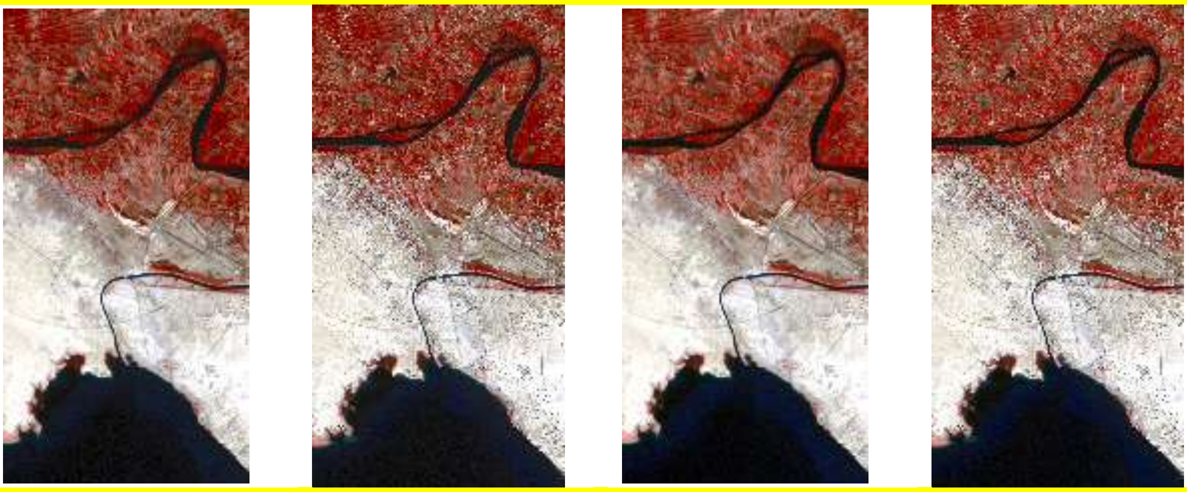
3. Results and Discussions

The computer hardware and software specifications used in this research are; ENVI 5.3, QGIS 3.12 program, and MATLAB R2020a language.

The resultant fused images of applying the fusion techniques are illustrated in Figure 5. The quality of the achromatic part of the fused image was estimated via the signal-to-noise ratio (SNR) by comparing them with the panchromatic images. In contrast, the quality of the chromatic part was estimated by calculating the mean color-shifting by comparing each pixel between the resulting image and the multispectral image, as illustrated in Figures 6 and 7.



Lab_AH- Landsat-7	Lab_AH-Orbview-3	Lab_SH- Landsat-7	Lab_SH - Orbview-3



Luv_AC- Landsat-7	Luv_AC- Orbview-3	Luv_SC- Landsat-7	Luv_SC- Orbview-3

Figure 5-The fused images for Landsat-7 and orbview-3 satellites using (HSL, HSV, Lab_AC, Lab_SC, Lab_AH, Lab_SH, LUV_AC, and LUV_SC) color spaces

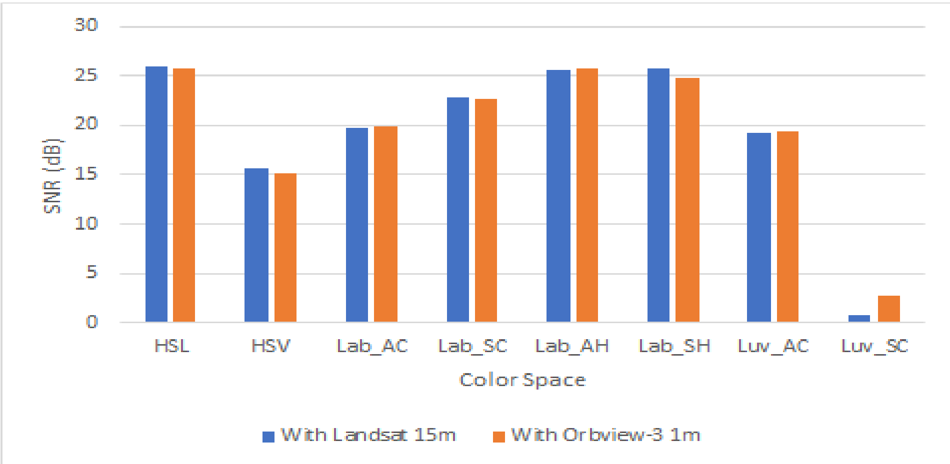


Figure 6-The SNR of the achromatic part of the fused images

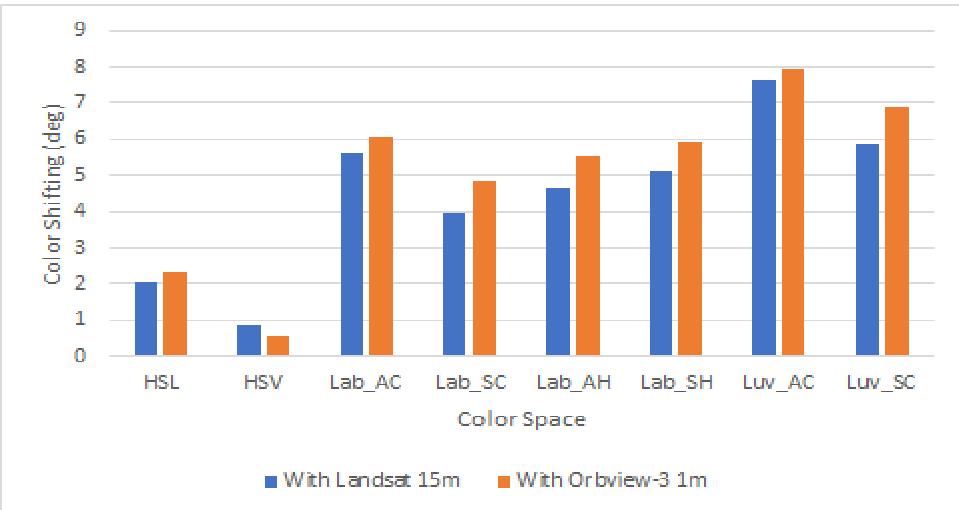


Figure 7-The mean color-shifting of the fused images

By examining the results, the HSL space could fuse the achromatic information with the chromatic information and maintain the quality of the chromatic and achromatic parts. The Hunter algorithm for lab color space revealed better results than the Adobe algorithm, while using different algorithms for intermediate XYZ space did not show significant results. As for the LUV color space, using different algorithms in XYZ intermediary space significantly impacted the quality of the fused image, as it was the worst result with the LUV space and standard XYZ space.

In general, the results did not show a difference in the quality of the achromatic part when using panchromatic images with different spatial resolutions, except that a deterioration in the quality of the chromatic part (mean color-shifting) with an increase in the difference in spatial resolution between the fused images. The quality of the color parts is due to the the-saturation of the chromatic part, diagnosed by other researchers such as Abdulabbar [27].

Based on the results, the over-saturation increases with an increase in the difference in spatial resolution between the fused images. The effect of increasing the difference in spatial resolution between images to be fused and the computational time taken to complete the fusing process is apparent in Table 2, as the increase in the computational time takes on an exponential nature with the increase in the difference in spatial resolution.

Table 2-The computational time of applying the fusion techniques

Color Space	**Computational time (sec)**	
	Landsat (15 m)	**Orbview-3 (1 m)**
HSL	3.8	854.1
HSV	2.4	566.1
Lab_AC	6.9	1450.8
Lab_SC	5.8	1330.6
Lab_AH	5.0	959.7
Lab_SH	4.2	970.3
LUV_AC	4.4	1120.8
LUV_SC	4.5	987.1

4. Conclusions

Depending on the results obtained, the following conclusions could be reached:

- The best results obtained for the fused image quality were for the HSL perceptual color space regardless of the difference in the spatial resolution of the fused images for both parts (chromatic and achromatic).
- Changing the spatial resolution between fused images does not affect the achromatic quality of the resulting image for given perceptual color space.
- Increasing the difference in spatial resolution between fused images reduces the chromatic quality of the resultant fused image due to the over-saturation of a particular perceptual color space.
- The quality of the chromatic part of the image resulting from the fusion process using Lab perceptual color space changing the algorithm adopted for XYZ intermediate color space does not affect the quality of the resulting image; unlike the LUV perceptual color space, the Adobe algorithm was better than the standard algorithm for XYZ intermediate color space.
- A significant (exponential) increase follows an increase in the spatial resolution of the fused images in the time required to complete the fusing process.

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