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Implementing Geomatics Techniques for the Increase of Resolution of Satellite Images

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ABSTRACT

Image enhancement is the process of improving the quality of a digital image. Improved image quality is one of the goals of the ongoing effort to improve the information content and interpretability of satellite images. Two sets of remote sensing data were collected for this region: one from the SPOT-4 (2018) satellite and the other from the Enhanced Thematic Mapper Plus (ETM+) Landsat 7 (2020) satellite. This study used two images taken at various spatial resolutions of the same location. Two images are shown here: one with a 30 m spatial resolution and the other with a 5 m resolution with multispectral processing. The results indicate that integrating spatial and spectral resolution using geomatics techniques significantly benefits various applications. Before merging the images, it was root mean square error (RMSE) 11.55 Easting, 5.77 Northing and became 1.52 Easting, 1.45 Northing after merging the images. After implementing the approach, the resulting fusing image exhibits enhanced spatial resolution, and the resulting multispectral image has excellent spatial as well as spectral resolution. Finally, the improved combined image with great spatial and spectral resolution is prepared for analysis and classification.

Keywords: geomatics techniques, remote sensing, spatial resolution, spectral resolution.

INTRODUCTION

The data collected by a device that is not physically present with the thing, place, or thing under study may provide a wealth of information about it; this process is known as remote sensing. One common purpose of image merging, or image fusion or unification, is to increase the spatial and spectral resolution of images (Jensen, 2005). Improving satellite images and other forms of remote sensing data via image processing allows for more accurate geographical analysis and interpretation (Aqeel, 2012). Combining data from many images of the same area captured by different sensors with different spatial resolutions is a common practice in mathematically based digital remote sensing imaging (Al-Jasim et al., 2022). Improving the spatial resolution of multispectral images is one objective of the fusion approach (Al-Rubiey, 2017). The importance of remote sensing in geographic information systems (GIS) has increased significantly in the last several years owing to developments in image processing and remote sensing software (Merchant and Narumalani, 2009; Al-Saedi et al., 2023). Image fusion is an effective method for several GIS and remote sensing applications requiring high spectral and spatial resolution. Satellites collect various image data, including panchromatic images with high spatial resolution but poor spectral resolution and multispectral images with lower spatial resolution but better spectral resolution (Kadhum et al., 2023; Jasim et al., 2024a).

The comprehensive view of Earth's surface manifestations made possible by satellite images has made them useful instruments or methodologies for several scientific and practical studies. GIS software and digital image processing methods may illustrate spatial connections, locations, patterns, clusters, and distances as well as extract much information. Removing any aberrations from imagery increases its value. It may be accessed by connecting to the main geodetic network as a base map. Environmental protection, geographical planning, change monitoring, and military applications are typical uses for satellite imaging (Karwowska and Wierzbicki, 2022a). In-land mapping applications, in particular, several publications have acknowledged the value of combining high spectral and spatial resolution images. Spectral, geographical, and temporal resolution are three factors that significantly impact the use of remote sensing data, especially the images taken by Earth observation satellites (Rahmawati, 2020).

Small satellites are gaining popularity because of their smaller size and simpler design. It opens the possibility of launching more satellites into orbit, allowing for more regular monitoring of specific locations on Earth (Karwowska and Wierzbicki, 2022b). The Union of Concerned Scientists reports that more than 3.000 active satellites were in Earth's orbit on January 1st, 2021 (Pollpeter and Barrett, 2021). Some methods have been suggested for creating multispectral images with higher spatial resolution by combining many high-resolution images of the same subject (Rocchini, 2007). Image fusion methods were discussed in this study to enhance the data use. The current methods that maintain spectral properties while improving spatial resolution are the primary focus of this work. Multispectral images with high spatial and low spectral resolutions may be obtained by combining the adopted images using these techniques.

STUDY AREA

The Babylon Governorate is situated around 100 kilometres south of Baghdad, the Iraqi capital, and is therefore geographically in the center of the country, between the longitudes of 44°2'43" and 45°12'11" East, as well as the latitudes of 32°5'41" and 33°7'36" North. Abu Gharq District is one of the districts affiliated with Hilla District in Babil Governorate in central Iraq. It is located 10 km northwest of the center of Hilla District, and the main road that connects the governorate to Karbala Governorate passes through it. There is a lot of agricultural and industrial activity; its area is 191 km^2, it was founded in 1920, and its population is 108,212 people. Abu Gharq consists of the center of the district and several villages. The Al-Kawthar residential complex was recently established in the district, which contains (1058) residential units according to horizontal construction, and this project will serve different segments of society. In the district, there is the Technical Institute, the shrines of Idris bin Musa al-Kadhim, Ahmed bin Musa al-Kadhim, Yasoub al-Din bin Musa al-Kadhim, and the shrine of Alawiyah Sharifa, daughter of Imam al-Hasan. Although the city is agricultural, no large river passes through it, and what is strange is that it depends on the Euphrates and Shatt al-Hilla rivers for irrigation because it is mediated between the two rivers. The cultural levels are diverse in Abu Gharq, as there are farmers, workers, teachers, police, soldiers, engineers, doctors, as well as other liberal professions and employees. The study area was chosen for the availability of digital data and access to field monitoring points for the stations to be monitored.

THEORETICAL BACKGROUND

Multispectral sensors available for acquisition are increasing in quantity and quality, as is the data they provide. However, when a higher level of feature discrimination is required, high spectral resolution is more important than high spatial resolution, and vice versa for the applications requiring a high level of detail (Mora et al., 2012). Panchromatic (PAN) images have a better spatial resolution than multispectral (MS) images. However, both types of satellite data might have different spectral and geographical resolutions (Ahmed and Salih, 2022). Image fusion merges images of different spectral and spatial resolutions based on a certain algorithm (Ahmed and Salih, 2022). Image fusing or sharpening is merging relevant data of several images into a single, more detailed one; the final product will have more spatial and spectral information than the individual input images combined (Kaittan, 2018). Each step of applying this treatment to a digital image changes the digital optical characteristics, which in turn impact the value of measurements obtained from them; hence, the stages and sequencing of this treatment are essential for obtaining correct findings in practical studies of digital processing. The Brovey transform, also known as color-normalized fusion, and the chromaticity transform are required for the intensity function. The Brovey method's mathematical methodology is as follows (Vrabel, 1996):

$$CN_i = \frac{3 \times (A_i + 1) \times (B + 1)}{\sum_i A_i + 3} - 1 \quad (1)$$

where: A is the multispectral image, B is the panchromatic image, and CNi is the output color normalized band, the results fusing the image by applying the Brovey (color normalize) method.

According to the following formula, root-mean-squared error (RMSE) may be used to ascertain the difference between fused and original images (Jasim et al., 2024a) (Jasim et al., 2024b) (Melissa et al., 2008):

$$RMSE = \sqrt{\frac{\Sigma_x \Sigma_i (A_i(x) - F_i(x))^2}{n \times m \times d}} \quad (2)$$

where: x is the pixel, i is the band number, (n, m) are image coordinates, and d is the band number.

AVAILABLE DATA

The suggested target outlined in this article is believed to be achievable using various types of data accessible in the chosen field of investigation. The available data can be classified into:

1. Satellite image with a spatial resolution of 5 meters, panchromatic image, 2020, as in Figure 1.
2. Satellite image with a spectral resolution of 30 meters, multispectral image, 2018. as in Figure 2.
3. Ground control points (GCPs) 27 monitoring stations use the field navigation device for ground monitoring, as shown in Table 1.

Table 1. Field monitored points to evaluate the improvement process

Station	Easting (m)	Northing (m)
1	436908	3600637
2	436884	3600775
3	436955	3600834
4	437057	3600875
5	437198	3600850
6	437285	3600792
7	437342	3600623
8	437339	3600492
9	437324	3600446
10	437255	3600446
11	437144	3600438
12	437087	3600404
13	437030	3600388
14	437011	3600467
15	437099	3600530
16	437011	3600599
17	437126	3600666
18	437212	3600576
19	437212	3600710
20	437125	3600731
21	437023	3600803
22	436963	3600847
23	436961	3600767
24	436935	3600804
25	437247	3600349
26	436965	3600321
27	436886	3600343

Figure 1. A satellite image with a spatial resolution of 5 meters (SPOT-4 satellite)

Figure 2. A satellite image with a spatial resolution of 30 meters (Landsat 7 ETM+ satellite)

METHODOLOGY

Several image quality criteria are used to assess the quality of the fused image, estimate its quality, and compare the color spaces. One of the perception color spaces substitutes the achromatic portion of the multispectral image with a panchromatic image. Because the digital optical characteristics are controlled by the steps of this treatment and sequencing, the value of measurements produced from them is affected by each stage, making it essential to obtain correct findings in the practical studies of digital processing. It can be achieved in the following steps (Kaittan, 2018):

1. A resolution match between the high-resolution panchromatic image and the low-resolution multispectral image is required.
2. The R, G, and B components of the original image are converted to the HVS color space.
3. A better spatial resolution panchromatic band stands for the low-resolution Intensity component V.
4. Acquiring the fused image by converting it to RGB color space while keeping the original values of H and S.
5. Evaluating the improved map based on ground control points. Figure 3 illustrates the methodology flowchart.

RESULTS AND DISCUSSION

Implementing geomatics techniques to combine the spatial and spectral resolution of satellite images significantly improves the quality and utility of the resulting images. This section presents the main findings based on applying the previously discussed methodology. By combining data with varying spatial resolutions, better spatial resolution may be achieved without compromising spectral resolution by using many methods. Sharpening images aims to increase spatial resolution without affecting their spectral variety in multispectral images. Therefore, the RMSE metric and some statistical results have been used to compare fused image results. The investigation used the following computer hardware and software specifications: ENVI 5.3 and GIS 10.8. Land use and land cover mapping are the only potential study domains that might benefit from

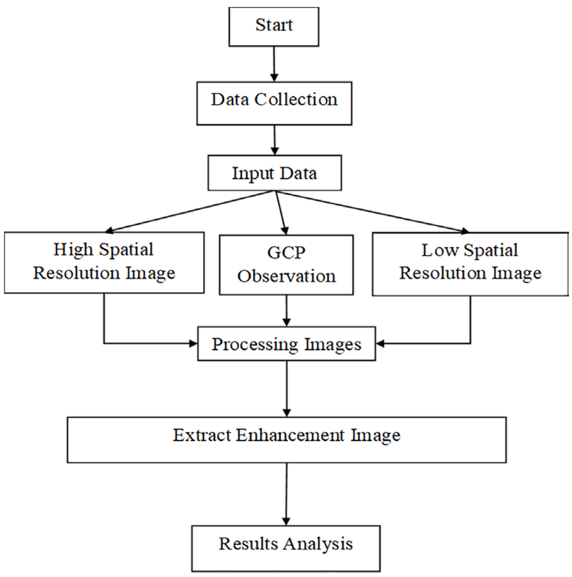

Figure 3. The methodology

high-resolution (HR) satellite imagery. Figure 4 shows the final merged images after using the fusion procedures.

Table 2 provides a detailed look at the changes in the geographical coordinates of the measuring stations due to the merger and is a valuable tool for analyzing the accuracy and efficiency of this process. This data can improve future operations and reduce unwanted variations in spatial locations. Change in eastern coordinates: variations range from -310 m to 227 m. Some stations had very slight changes in the eastern coordinates (e.g., station 20 with a change of 1 m). Other stations experienced relatively large changes (e.g., station 4 with a change of -310 m). Change in northern coordinates: Variations range from -40 meters to 100 meters. Some stations had slight changes in north coordinates (e.g., station 21 with a change of -40 m). Other stations had relatively large changes (such as station 11 with a change of 100 m).

Improving the accuracy of geographic images after the merging process is necessary for multiple purposes, such as mapping, geographic analysis, and GIS applications. Because there are fewer disparities after merging, the images are more reliable for various practical applications. Ground control points are precise references used to compare coordinates extracted from images. The merging process should improve the correspondence between these points and images.

Figure 5 displays the differences between the horizontal coordinates obtained from ground

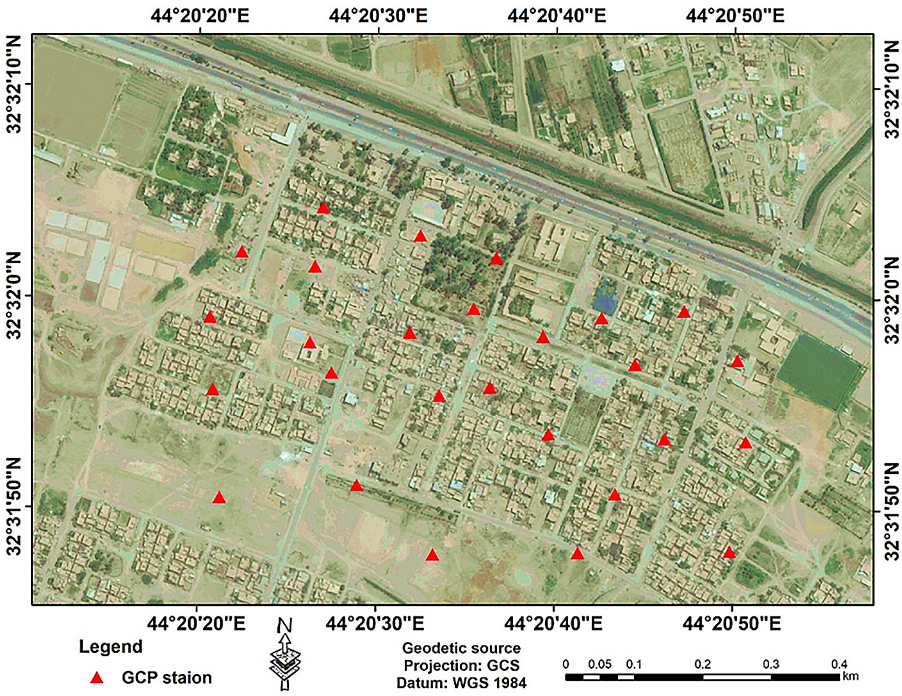

Figure 4. A map showing the locations of field monitoring stations

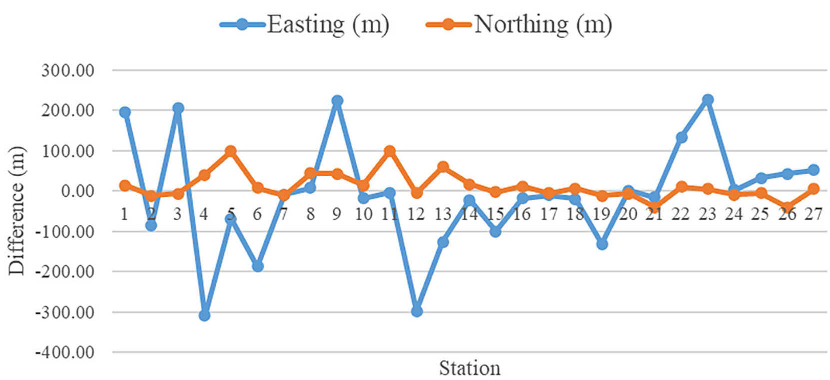

Figure 5. Difference between the horizontal coordinates taken from GCP and the images before the merging process

Table 2. The difference between the observed points GCP and those taken from the image before the merging process

Specification	GCP		Before marge image		Easting (m) difference	Northing (m) difference
Station	Easting (m)	Northing (m)	Easting (m)	Northing (m)		
1	436908	3600637	436712	3600623	196.00	14.00
2	436884	3600775	436970	3600787	-86.00	-12.00
3	436955	3600834	436749	3600841	206.00	-7.00
4	437057	3600875	437367	3600835	-310.00	40.00
5	437198	3600850	437267	3600751	-69.00	99.00
6	437285	3600792	437472	3600784	-187.00	8.00
7	437342	3600623	437351	3600634	-9.00	-11.00
8	437339	3600492	437331	3600448	8.00	44.00
9	437324	3600446	437099	3600404	225.00	42.00
10	437255	3600446	437274	3600432	-19.00	14.00
11	437144	3600438	437148	3600338	-4.00	100.00
12	437087	3600404	437385	3600410	-298.00	-6.00
13	437030	3600388	437157	3600328	-127.00	60.00
14	437011	3600467	437034	3600450	-23.00	17.00
15	437099	3600530	437200	3600533	-101.00	-3.00
16	437011	3600599	437029	3600588	-18.00	11.00
17	437126	3600666	437137	3600671	-11.00	-5.00
18	437212	3600576	437232	3600570	-20.00	6.00
19	437212	3600710	437343	3600722	-131.00	-12.00
20	437125	3600731	437124	3600738	1.00	-7.00
21	437023	3600803	437039	3600843	-16.00	-40.00
22	436963	3600847	436830	3600837	133.00	10.00
23	436961	3600767	436734	3600762	227.00	5.00
24	436935	3600804	436933	3600813	2.00	-9.00
25	437247	3600349	437215	3600355	32.00	-6.00
26	436965	3600321	436922	3600361	43.00	-40.00
27	436886	3600343	436834	3600338	52.00	5.00

control points and the images before merging. These differences indicate the extent of discrepancy between the actual locations of the ground control points and the locations extracted from the images before the merging process was performed. This format helps understand the accuracy and reliability of images before further processing. Typically, large discrepancies in this context reflect that raw images may contain distortions or inaccuracies in localization.

Table 3 shows slight to moderate changes in the coordinates after image processing. The differences in the eastern coordinates range between -4 and 5 meters. The differences in the northern coordinates range between -5 and 5 meters. Some stations have large variances, such as Station 4 and Station 27. The data indicate that the overall accuracy is acceptable if the variances are within the permissible limits in the respective geographical applications.

The accuracy of the merging may be affected by multiple factors, such as the accuracy of ground control points, the quality of the images, and the method used in the merging process. Figure 6 displays the differences between the horizontal coordinates from ground control points and the images after the merging process. The goal of the merging process is to improve the accuracy of the images and coordinate them with the actual locations of ground control points. If the merger succeeds, spreads are expected to be significantly lower. This figure provides a measure of the effectiveness of the fusion process in improving the spatial resolution of images.

Table 4 shows the difference in the east coordinates: It shows a significant deviation in the values, as the maximum error reached 227 meters and the minimum error reached -310 meters, with an average error of -11 meters and a high

Table 3. The difference between the observed points GCP and those taken from the image after merging

Specification	GCP		After marge image		Easting (m) difference	Northing (m) difference
Station	Easting (m)	Northing (m)	Easting (m)	Northing (m)		
1	436908	3600637	436909	3600632	-1	5
2	436884	3600775	436883	3600774	1	1
3	436955	3600834	436957	3600833	-2	1
4	437057	3600875	437053	3600877	4	-2
5	437198	3600850	437197	3600849	1	1
6	437285	3600792	437286	3600793	-1	-1
7	437342	3600623	437343	3600624	-1	-1
8	437339	3600492	437336	3600497	3	-5
9	437324	3600446	437323	3600447	1	-1
10	437255	3600446	437253	3600447	2	-1
11	437144	3600438	437142	3600439	2	-1
12	437087	3600404	437089	3600401	-2	3
13	437030	3600388	437031	3600386	-1	2
14	437011	3600467	437014	3600466	-3	1
15	437099	3600530	437095	3600527	4	3
16	437011	3600599	437012	3600598	-1	1
17	437126	3600666	437123	3600665	3	1
18	437212	3600576	437215	3600573	-3	3
19	437212	3600710	437211	3600711	1	-1
20	437125	3600731	437129	3600730	-4	1
21	437023	3600803	437022	3600804	1	-1
22	436963	3600847	436960	3600848	3	-1
23	436961	3600767	436962	3600766	-1	1
24	436935	3600804	436934	3600802	1	2
25	437247	3600349	437248	3600351	-1	-2
26	436965	3600321	436966	3600323	-1	-2
27	436886	3600343	436881	3600340	5	3

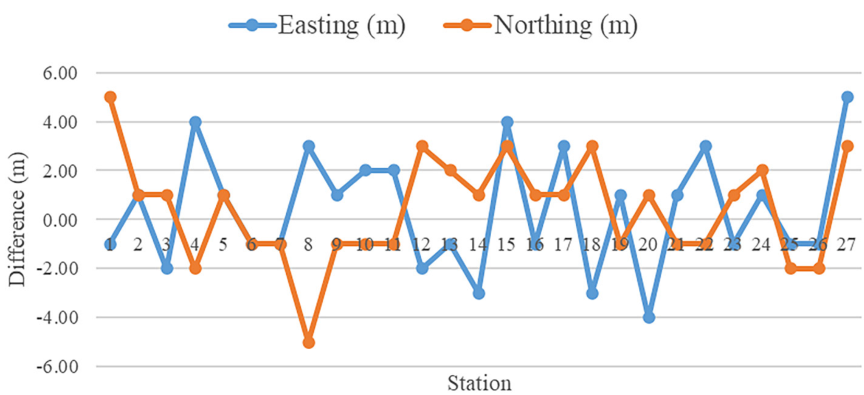

Figure 6. Difference between the horizontal coordinates from GCP and the images after merging

Table 4. Summary statistics before merge image

Horizontal coordinates	RMSE	Mean error	Max error	Min error	SDT error
Easting (m) difference	11.55	-11	227	-310	133.41
Northing (m) difference	5.77	12	100	-40	33.29

Table 5. Summary statistics after merge image

Horizontal coordinates	RMSE	Mean error	Max error	Min error	SDT error
Easting (m) difference	1.52	2	5	-4	2.31
Northing (m) difference	1.45	2	5	-5	2.09

standard deviation. North coordinate difference: It also shows a clear skew, with a maximum error of 100 m and a minimum error of -40 m, with an average error of 12 m and a relatively lower standard deviation than the east coordinate difference.

Table 5 shows the difference in east coordinates: The error values decreased significantly, with the maximum error reaching 5 meters and the minimum error reaching -4 meters, with an average error of 2 meters and a much lower standard deviation. North coordinate difference: Error values also decreased, with a maximum error of 5 m and a minimum error of -5 m, with an average error of 2 m and a much lower standard deviation. After merging the images, the differences were greatly reduced. The analysis shows that image merging significantly improved the accuracy of horizontal coordinates, as the variances and errors were reduced considerably after merging compared to the values before. It shows the importance of integrations in improving data quality and accuracy.

This statistical analysis provides a comprehensive view of the differences and emphasizes the practical benefit of using image fusion processes to obtain more accurate data. Standard deviation refers to the dispersion of data around the mean. Before merging, the large deviations indicated high dispersion and heterogeneity of the data. After consolidation, the standard deviation decreased significantly, indicating improved homogeneity and reduced dispersion around the actual values. The data shows that the image fusion process significantly improved the accuracy of horizontal coordinates. These improvements are reflected in all statistical metrics, including RMSE, mean error, maximum and minimum error, and standard deviation. These improvements indicate that image merging has reduced discrepancies and errors and improved data quality.

CONCLUSIONS

The researchers in this study merged the multispectral image with a low spatial resolution (30 meters) with the panchromatic image with a high spatial resolution (5 meters). It reduced errors in the horizontal and vertical coordinates taken from the final result image. The standard deviation error of the coordinates before the image merging process was (133.41 E, 33.29 N), while after the image merging process, the standard deviation error became (2.31 E, 2.09 N). in the novelty of this study is that the researchers used field observations to compare with the results of the image merging process, while previous research did not use field observations to compare the produced work, and thus coordinate errors were not evaluated when deriving them from the final image. New prospects will be obtained when using this method to increase the spatial accuracy of old satellite images with modern images that contain details that others need in their future projects.

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