Automatic Coastline Extraction Using Radar and Optical Satellite Imagery and Wavelet-IHS Fusion Method

Hasan Mirsane[1*], Yaser Maghsoudi[2], Rohollah Emadi[3], Majid Mostafavi[1]

[1] Hydrography M.Sc., North Tehran branch, Islamic Azad University, Tehran, Iran; hasanmirsane@yahoo.com
[2] Faculty of Geodesy and Geomatics Engineering, Khaje Nasir Toosi University of Technology (KNTU), Tehran, Iran
[3] Department of Geomatics Engineering, South Tehran branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO	ABSTRACT
	The coastline is defined as an edge or land margin by the sea. Managing such ecological environments in terms of continuous changes requires monitoring at different intervals. To do this, it is necessary to use remote sensing techniques to detect and analyze coastline variations. Two study areas located on the coast of the Persian Gulf (South part of the Qeshm Island and the port of Tien to Asaluyeh) have been studied by two types of optical and radar images and wavelet edge detection algorithm for coastline extracting. In this study, the coastline is extracted in two ways, firstly the coastline extracts from both optical and radar images separately, then by images fusion using wavelet-IHS method. The accuracy obtained in Qeshm area in 2009 from optical, radar and fused images was 3.4, 5.5 and 3.2 respectively, and in Asaluyeh region in 2007, 2.1, 3.4 and 2.98 respectively.

1. Introduction

Coastlines are one the most important linear phenomena on the earth's surface, which have dynamic nature and usually a fragile ecosystem [2]. They have also tremendous value in economical and natural resources. Coastline changes are often the result of coastal erosion or sedimentation, as well as human activities (such as dredging, making breakwaters and ports, etc.). Monitoring and assessing coastal areas for the sustainable planning and predicting coastal behavior also safe navigation could be considered as an important factor in national development and natural resource management [4]. Coastline detection using manual and surveying methods are mainly hard and costly, the non-automatic coastal detection methods by the visual interpretation of high-resolution aerial photos are also time consuming and require tedious process skills and massive attention to details. Therefore, automated and remote sensing methods for monitoring coastal area seems to be necessary. In this study we firstly extract coastlines in study areas using Optical and Radar data separately then extract it from a fused image of these data and evaluate all results by high resolution IRS images. Finally, we estimate the coastline displacement in different times of study.

The extraction of shorelines are well known issue in satellite remote sensing and have been discussed in many publications [8][23][7][15] . Mason, D. C and Davenport, I. J., 1996 suggested the use of a contrast ratio filter together with an active contour model (snake algorithm) as edge detector. S. Mallat *et al.* (1992a and 1992b) suggested a method to detect all edges above a certain threshold. Niedermeier, A., *et al.* (2000) used a Wavelet based edge detection method coastline detection by SAR images. Liu, H and Jezek, K, C., (2004), used thresholding technique on Landsat and Radarsat data. Wang Y. and Allen, R. T., (2008) applied an edge-filtering model with Sobel filter. Ouyang, Y., *et al.* (2010) applied two enhanced Level Set Algorithm (LSA) on Radarsat imagery. Chen, K. S., *et al.* (2011) developed an algorithm for costal changes monitoring from ERS data. They also fallowed morphological filter to refine the boundaries. Acar, U., *et al.* (2012) improved an automatic algorithm to detect coastline using from ALOS/PALSAR data at the coastline of the Black Sea in the north-west part of Turkey.

Optical data makes coastline detection easier while differentiate between water and land and interpretation of coastline observations due to color differences is more distinguishable. Basic techniques, which use optical data, make detection and extraction of a continuous coastline with precision at pixel level

measurement possible. Main issue of optical systems is its dependence on cloud cover, sunlight and generally meteorological conditions, which significantly limits its effectiveness [4]. The similarity of shadows on surface with water bodies (especially in deep water) could also make mistakes in water pixels' classification. In addition, in coastal areas with less than one-meter depth, it is difficult to find threshold values in 5 or 7 bands due to sea-floor reflections to the sensor. The presence of particles in water and its pollution in coastal areas is another problem that makes coastal areas detection (using only one band) difficult. Hence, many researchers have suggested the use of the indexes (which calculated using more than one bands) [15]. The return of light from the sea floor near beaches (shallow waters) is also another weakness in optical images that could be eliminated by fusion. Since, in the event of precipitation or the presence of clouds during optical imaging, the use of a radar image (that does not depend on weather conditions) could be a good solution.

In this case, the most effective tool is the Synthetic Aperture Radar (SAR), which ensures good spatial resolution observation throughout the day and any weather conditions. Although coastline extraction based on SAR still remain challenging, because: 1) the presence of speckle noise in SAR images, which interferes the interpretation of these images. 2) Lack of difference between land and water properties to the sensor, which depend on the sea conditions and geological materials on surface [4]. One of the main source of errors in radar images is the speckle. Major changes in the gray levels of adjacent pixels in a SAR image is calling speckle. These changes create a granular texture in the image. This noise, have more effects in wavy coast conditions it cause reduction of distinction between water and land. Due to the presence of noise in the images some holes on edges and especially on the coastline area will appear, when using Mallat algorithm for edge detection. Filling these holes requires knowing the prior information about the edges' behavior in images. The Kanizsa triangle shows that eliminating such holes in the edges is done by the human visual system [11]. Consequently, for first time a Wavelet-IHS method was applied in this study for optical and radar images fusion to extract coastline at the study area. For coastline extraction we used Mallat algorithm for edge detection which is based on Wavelet transformation. The advantage of using this method is its high accuracy in edge detection from images.

In fusion techniques, the most significant problem is color distortion. In this study, a fusion method for high-resolution SAR image with medium-resolution multispectral (MS) images was applied to simplify SAR images interpretation. This method is based on IHS (Intensity, Hue, Saturation) fusion method and wavelet transformation, while each of these methods could not produce satisfactory results of SAR and MS images fusion standalone (due to the significant difference in gray value between SAR images and MS). The proposed wavelet-IHS method is to benefit from IHS ability in conserving the spatial resolution and from wavelet, the ability of intensity preserving. So a combination of Wavelet-IHS techniques was proposed to utilize the benefits of Wavelet and IHS techniques for SAR image and multivariate image fusion and to address the shortcomings of these two methods standalone. In this method, IHS was used to integrate multifunctional color information with low spatial resolution with high resolution SAR information and details to achieve a smooth injection of spatial and color features. Wavelet transform is used to produce a new image that has high image intensities and includes spatial details of the original SAR image [6].

A discrete wavelet transform is a fragmentation in spatial-frequency domain that present a flexible multivariate analysis of image [19]. This analysis can reveal the characteristics of a signal or image that other analytical techniques, such as drives, disclose points, discontinuities in higher and similar derivatives will lose out. Wavelet analysis could also filter and reduce noises in signal without any significant data loss. In IHS method, panchromatic (PAN) and MS images are combined, and the RGB space with red, green, and blue colors transforms from a MS image to the IHS space. The intensity (I) is replaced by a PAN image, then the invers transformation is used to obtain the RGB image. A commonly used IHS transformation is based on a triangular color model [18]. In this study we used Haar-Wavelet edge detection and Wavelet-IHS fusion method simultaneously which could lead to better results while this method could have more relative capabilities than any above mentioned reasons.

2. Study Areas and Dataset
2.1 Study area
Qeshm is the largest island in the Persian Gulf and is located in the southern part of Bandar Abbas. This island has three types of sandy, rocky, and muddy beaches that are affected by sea currents, including tides, so that the island's area is changing around 195 km² from the highest to the lowest tide level. Our first study area is the southern part of the island, which includes the Salach port, and has a sandy beach. The geographical coordinate of this studied area are between 22.65° (E) to 22.68° (E) longitude and 55.64° (N) to 55.70° (N) latitude, which cover about 12 km of island's coastline. Sea level changes is differing between 2 and 4 meters depend on tidal periods around Qeshm Island. The waves altitude is maximally up to 1 meter in the south coastal area of Qeshm and will reach up to 3 ~ 5 meters. There are

Table 1: Satellites' specifications comparison

Specification	ALOS	Sentinel-1	CartoSat-1	Landsat-7	Landsat-8
Altitude (km)	691.65	693	617	705	705
Inclination (°)	98.26	98.18	97.87	98.21	98.22
Period (min)	98	98.7	94.72	98.83	98.8
Repeat cycle (days)	46	12	116	60	16
Radar Sensor	PALSAR	C-band	N/A	N/A	N/A
Band	L-band (1.27 GHz)	C-band (5.405 GHz)	Pan	Red, NIR,SWIR1	Red, NIR,SWIR1
Wavelength	236 (mm)	555 (mm)	0.5-0.8 (µm)	0.6-1.7 (µm)	0.6-1.6 (µm)
Incidence Angle	8° to 60°	20° to 45°	N/A	N/A	N/A
Spatial Resolution (m)	10	5 (40)	2.5	15 (30)	15 (30)
Swath (km)	70	20 (400)	25(30)	185	185

sea streams affected by sea waves on the margin near the shores of Qeshm, as well as tidal flows, especially in the sea channel between the island and the motherland. In addition to waves effects, sea flows, have an effective impact on coastal erosion and displacement of sediments and land-bed changes, especially for sea canals between the island's Hara forests. The second study area is the westernmost part of the coast in Bandar Abbas province with a geographic coordinate of 27.21° (E) to 27.31° (E) longitude and 52.67° (N) to 52.82° (N) latitude. This area includes the port of Tien (eastern part of Asaluyeh) which has mostly rocky beaches.

2.2 Dataset

In order to detect and extract the coastline, radar and optical satellites data have been used in the regions. Radar images are extracted from the PALSAR sensor of ALOS satellite (in 2007 and 2009) also Sentinel-1 satellite (in 2016). For optical data Landsat-7 (in 2007 and 2009) and Landsat-8 (in 2016) were used. The images of these satellites are roughly in same dates as radar images, and have 3, 4, and 5 bands with a resolution of 30 meters, as well as a pan-chromatic band with 15-meter resolution. The high-resolution image of CartoSat-1 (IRS-P5) satellite is used for results evaluation and to determine the accuracy of coastline detection. For this purpose, a panchromatic band of IRS images with spatial resolution of 2.5 was considered. In the southern part of Qeshm Island, images of three different periods were used. For the years 2007 and 2009, the ALOS images and for the year 2016, Sentinel-1 images were used. The ALOS

images are descending and have HH and HV dual polarimeter. The Sentinel-1 image is also in single-polar VV mode. Table 1 shows specifications of used satellites in this study. In second study, two different periods of images have been used. The ALOS and Sentinel-1 images, which has a VH and VV polarimetry. Table 2 indicates the data acquisition date and time in different study areas and for different sources of data.

The PALSAR sensor operates in the L band, which creates waves about 10 cm. It has a multi-polarimetric and a ScanSAR mode. Therefore, it is expected that the collected data by this system will contribute to a new research lines. While the Sentinel-1 mission includes C-band imaging and operates in four unique imaging modes with different resolutions (less than 5 meters) and different coverage (up to 400 kilometers)

3. Methodology

To distinguish the edges and body, the scale of the object must also be considered, this will lead to image wavelet analysis. The edges can be defined as the maximal absolute value of the image wavelet spectrum. In order to reveal edges, the Haar-Wavelet analysis was applied using the algorithm provided by the Mallat, S. G., (1989). Automated coastline extraction was used by MATLAB in three images (radar, optical and fussed image) in this study. A Wavelet-IHS model was applied for image fusion. Due to using two sensors for fusion, the images must be in a same coordinate system before processing. In addition, a sensor is rotated slightly away from its

Table 2: Acquisition date and time of satellite images

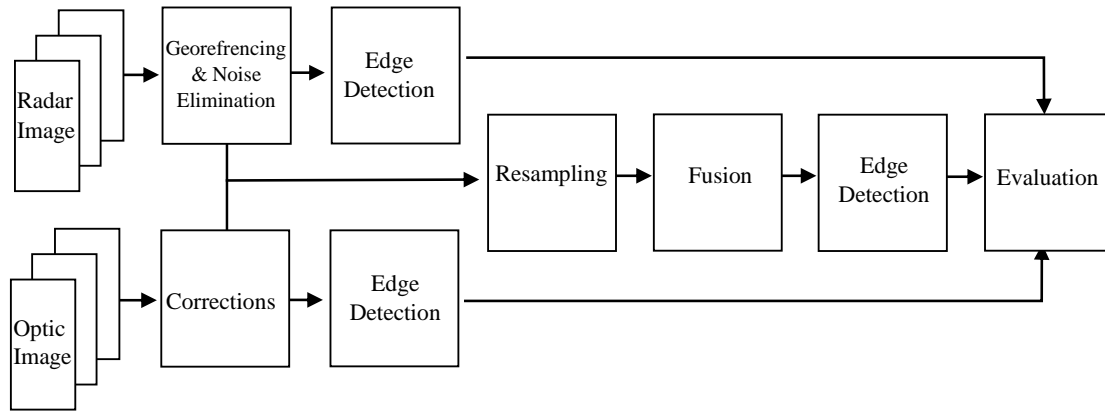| Region	Radar Image		Optic Image		IRS Image
Qeshm	ALOS	19/7/2007 18:50	Landsat-7	10/7/2007 06:35	N/A
	ALOS	24/7/2009 18:52	Landsat-7	15/7/2009 06:36	10/06/2009 6:56
	Sentinel-1	31/8/2016 06:39	Landsat-8	27/8/2016 06:45	N/A
Asaluyeh	ALOS	12/7/2007 19:01	Landsat-7	8/7/2007 06:48	18/02/2007 7:11
	Sentinel-1	13/11/2016 17:29	Landsat-8	13/11/2016 06:58	N/A

Figure 1: Schematic diagram of applied methodology

orbit every time, and therefore for comparison of images in different years we also need to co-register the images. In order to find the coastline displacement over the course of several years, we have to do the co-registration two times. Finally, the coastline displacements were identified using these images fusion. Below diagram (Figure 1) illustrated applied methodology of our study.

3.1 Pre-processing
Pre-processing for Radar images include speckle noise reduction and geo-referencing of the images. Landsat images should then be co-registered with radar images, the pre-processing steps are mentioned as below:

3.1.1 Speckle Noise Reduction
To reduce and eliminate speckle noise in radar images, the Refined-Lee filter was applied by NEST software for all ALOS and Sentinel-1 radar images in different years and in both HH and HV bands.

3.1.2 Geo-referencing
After the speckle noise reduction in radar images, we must do geo-referencing. Their coordinate system is the UTM WGS84 and should be referenced using ground control points which include in image's file.

This process was also performed using the Nearest sampling method by NEST software.

3.1.3 Co-registration
In the next step, optical and radar images should be co-registered. So the Landsat images get co-registered based on radar images, but before that, they should be resampled. The spatial resolution of the panchromatic band of Landsat is 15 meters and the other bands are 30 meters. Considering the spatial resolution of the ALOS images is 12.5 meters, Landsat images get resampled to 12.5 meters then they get stacked together using Envi software. The spatial resolution of the Sentinel-1 image is also 10 meters and the final resolution of Landsat image considered the same (10 meters). In next step Landsat images get co-registered based on radar images using ArcGIS.

3.1.4 Tidal effect
The tidal effects could make changes in position of the coastline at different hours in a day. In this study, the tidal data of nearest tide gauge close to our study area were considered. Tidal effect at the moment of shooting two optical and radar images (7:00:00 – 19:00:00) have almost equal effect in the region according to the 12 hours' interval (Figure 3) which was considered the same.
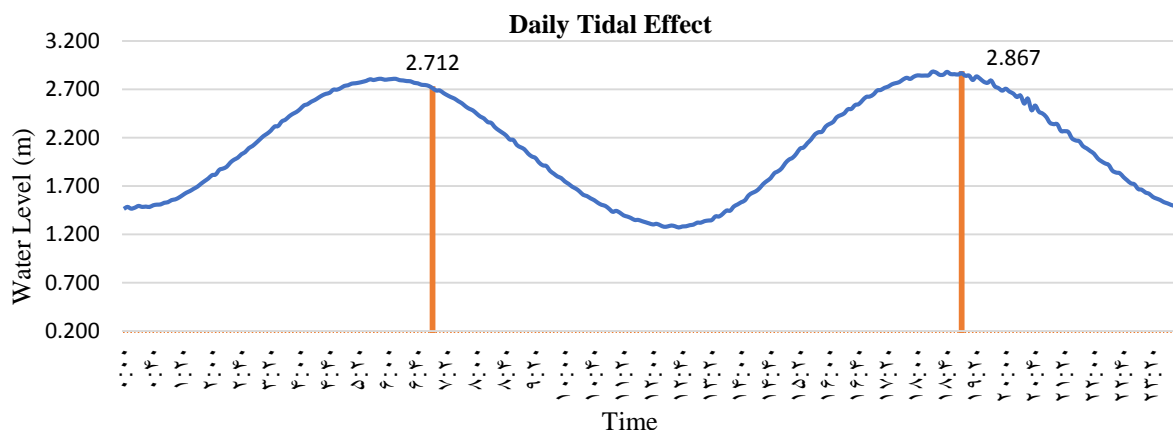

Figure 2: Daily tidal effect over study area

3.2 Coastline extraction

We applied two methods in order to detect the coastline. Firstly, we extracted the coastline from each Landsat image and the radar separately using the wavelet method. then we did the fusion of Landsat and Radar images using the Wavelet-IHS method and then extract the coastline from the fussed image with the wavelet method. Then we compare the lines obtained from the three images and interpret the results.

3.2.1 Coastline extraction using Landsat and Radar Image

After images pre-processing, we extracted the coastline from each Landsat and radar images separately. For optical image, Landsat Panchromatic Band was used for coastline extraction. In radar images, there are two HH and HV bands, multiply of this two bands were used to increase the distinction between water and land. The implementation algorithm process using MATLAB are described as below:

1. Wavelet algorithm was applied in order to extract the edges in both images
2. The Isodata method was used to binary images. The remaining noises is removed using morphology analysis.
3. The detected edges in output image contains all available edges in study area and our goal is to extract the coastline from them. The binary image was segmented by Watershed method. Using this method, the segments larger than 8 pixels are labeled as a single segment.
4. In the segmentation result, the water and land regions are the largest components of image. We used the maximum likelihood method to convert the image to an image that only contains two pieces of water and land regions.
5. At this point, the coastline was extracted from the image. From the existing edges, the coastline was assumed to be the edge that one side is water and other side is land.
6. Finally, in order to have a better shape, we have made the coastline smoother using morphology analysis.

To evaluate coastline extraction visually, the obtained automated coastline was compared with the original image. The Figure 3 through Figure 7 confirm that mostly the extracted coastline form Landsat image has better agreement with the original image, and obtained line from the ALOS image shows some errors mainly due to the speckle noise. The obtained edge (which assumed to be the coastline) has discontinuities and holes. A mathematical morphology technique has been applied to interpolate it, which would eliminate the existing dock (in ALOS 2007) and will make errors in some parts of the coastline. As shown in Figure 4 (b) the extracted coastline using radar image has dislocation in three parts compare to the actual coastline, which is caused by applying the morphology.
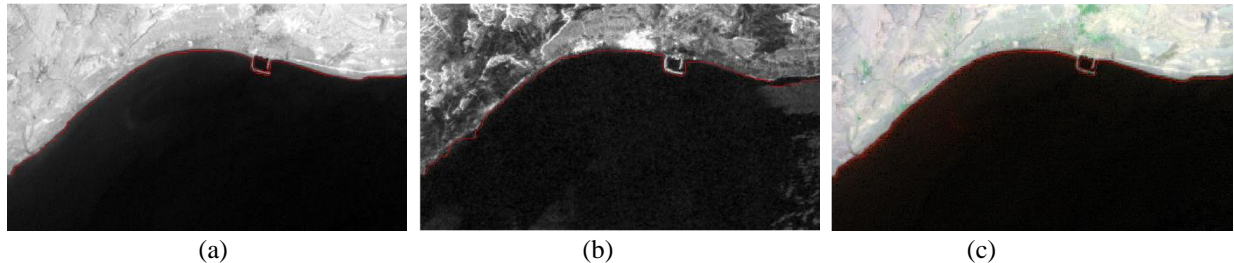

| (a) | (b) | (c) |

Figure 3: Extracted coastline in 2007 using a: Landsat-7 b: ALOS c: Fused images in Qeshm area
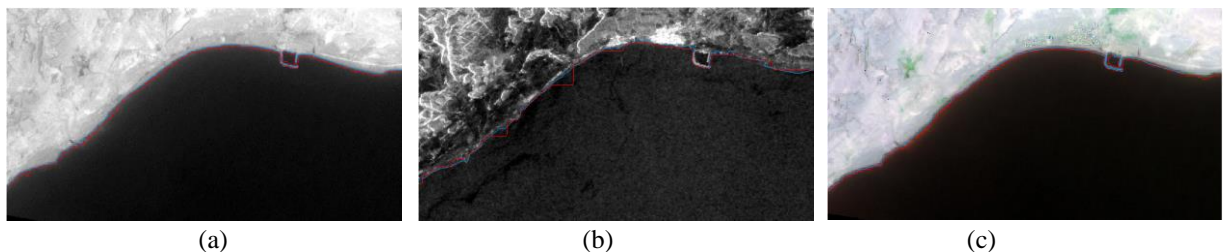

| (a) | (b) | (c) |

Figure 4: Extracted coastline in 2009 using a: Landsat-7 b: ALOS c: Fused (red line) images in Qeshm area compare to hand drawn line (blue line)
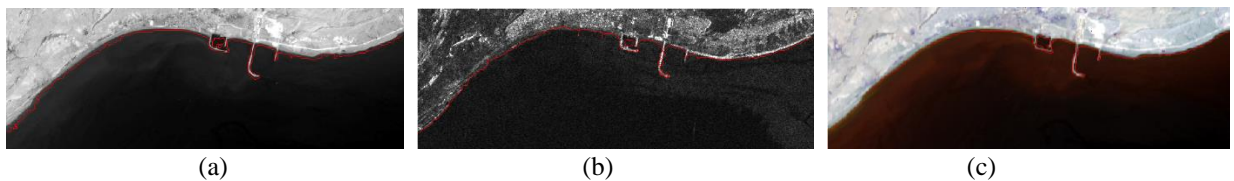

| (a) | (b) | (c) |

Figure 5: Extracted coastline in 2016 using a: Landsat-8 b: Sentinel-1 c: Fused images in Qeshm area

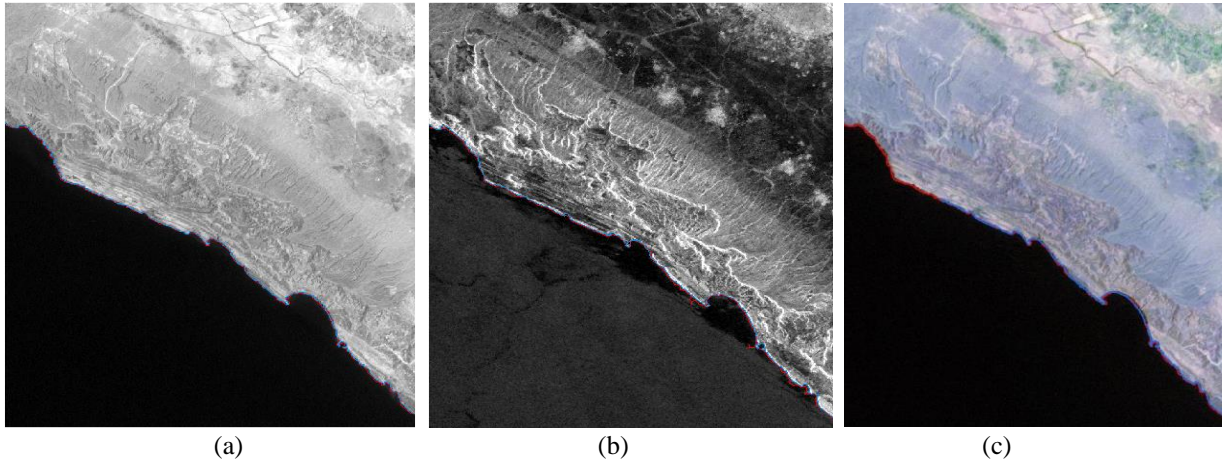(a)   (b)   (c)

Figure 6: Extracted coastline in 2007 by a: Landsat-7 b: ALOS c: Fused images (red line) in Asaluyeh area compare to hand drawn coastline (blue line)
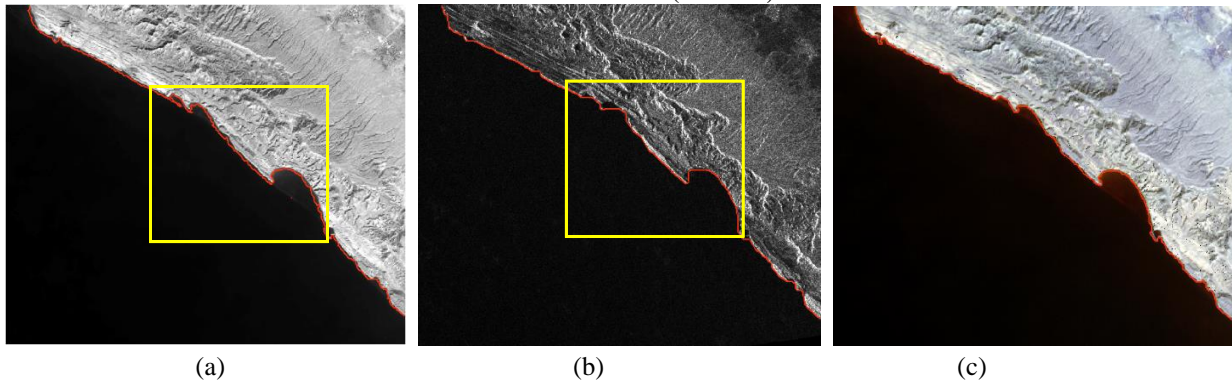

(a)   (b)   (c)

Figure 7: Extracted coastline in 2016 by a: Landsat-8 b: Sentinel-1 c: Fused image in Asaluyeh area

3.2.2 Coastline extraction using fused image

In this study, an intermittent image fusion method has been applied for SAR images and low-resolution optical images fusion to enhance the interpretation capability of SAR images, which was also described by Hong, G., *et al.* (2009). The goal is to keep the high resolution of SAR images while the spectral information of the optical image remains unchanged. To achieve this goal, The Wavelet-IHS methods has been developed for fusion while:

1. Wavelet transformation method can maintain the spectral information of optical image, but artifacts are visible in results [22].
2. IHS method could saves the spatial information of high-resolution images well, but the color quality strongly depends on sampling of high-resolution image and the image of intensity of low-resolution optical image [20].
3. The Wavelet-IHS fusion method is more desirable than each of the unique methods as it avoids the above mentioned issues.

After coastline detection by each of the Landsat and radar images, the coastline detection is also done by image fusion. To do this, HH and HV bands firstly fused by Wavelet algorithm in order to gain the advantage of polarimetry, and then the image is fused using Wavelet-IHS with bands 3, 4, and 5 of Landsat image.

The fusion results showed that the proposed integration method could display spatial data from SAR images and spectral information from optical image well in a single fused image. The colors in all compilation results are close to the original MS images and the details are similar to the SAR image. Compared to the original SAR data, it can be seen that the coatings are interpreted in a simpler and more accurate image than original data.

The IHS fusion method stand alone could save the spatial information of the SAR image, but there will be color distortion in comparison with the MS image [6]. The standalone Wavelet method can enhance spatial information, however, severe color distortion is also created in the result and the whole image looks gray as SAR image is evenly injected into each of multiple bands of MS image. In Wavelet-IHS fused image, the coastline is better interpreted due to color combination and spatial details. For example, in SAR data, we have difficulties in objects interpreting in parts of the image, but in output fused image, the objects could be easily interpreted cause of their color and clarity. The colors in the fused image is very close to Landsat main image, and are also clear as the original SAR data. This shows that MS and SAR images are well fused. The final extracted coastline in 2009 and 2016 for the Qeshm area as well as the years 2007 and 2016 for the Asaluyeh region was shown in Figure 3 through Figure 7. In

Figure 8 (sub-section of Asaluyeh 2007) and Figure 9 (sub-section of Qeshm 2009) the difference between the extracted coastline by optical and radar images is distinguishable.

4. Results and Discussions

Manually drawn coastlines on radar and optical images was used for evaluation and precision estimation of automated extracted coastline. Also for fused images evaluation we used manually drawn coastline on high resolution IRS images in Qeshm 2009 and Asaluyeh 2007. Thus, difference between the lines derived from the algorithm and the hand drawn line is calculated and considered as final precision (Table 3).

Table 3: Coastline extraction precisions in pixels

Region	Year	Optical Image	Radar Image	Fused Image
Qeshm	2007	2	5.5	-
	2009	3.4	5.5	3.2
	2016	4.6	3.3	-
Asaluyeh	2007	2.1	3.4	2.98
	2016	4.6	4.3	-

In Qeshm area, difference between the drawn coastline on IRS image and extracted line by algorithm in Landsat and radar images in 2009 stand alone are respectively 3.4 and 5.5 pixels (Figure 4). Given the precision of fused image, which is 3.2, it can be concluded that the image fusion improved accuracy. Considering the extracted coastline in 2009, radar image is comparable in some parts of the coast and also has a large difference in another area, we choose a part of the image that has good agreement (Figure 9), then calculate the extraction accuracy for all three Landsat, radar and fused images.

In Asaluyeh area (2007), the difference between the drawn coastline and extracted coastline in Landsat, radar and fused images are respectively 2.1, 3.4 and 2.98 pixels (Figure 6). In this area, we select two smaller parts of the original image and calculate the accuracy of extracted coastline for each of the three images (Figure 8). In sub-section (1-1) of this region, the precision of Radar, Landsat and Fused images are respectively 2.55, 2.30 and 2.52 pixels, which indicates improvement in precision of extraction after
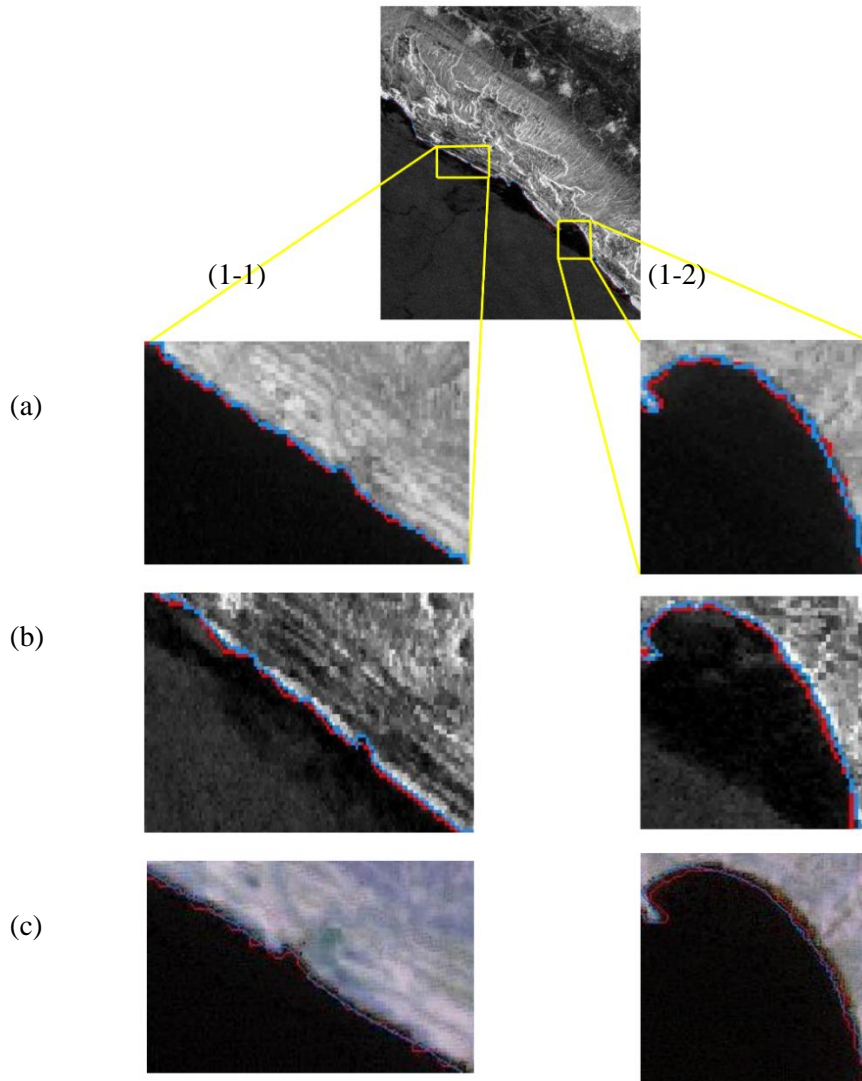

Figure 8: Two sub-section of extracted coastline in Asaluyeh 2007 by a: Landsat-7 b: ALOS c: Fused images (red line) compare to hand drawn coastline (blue line)
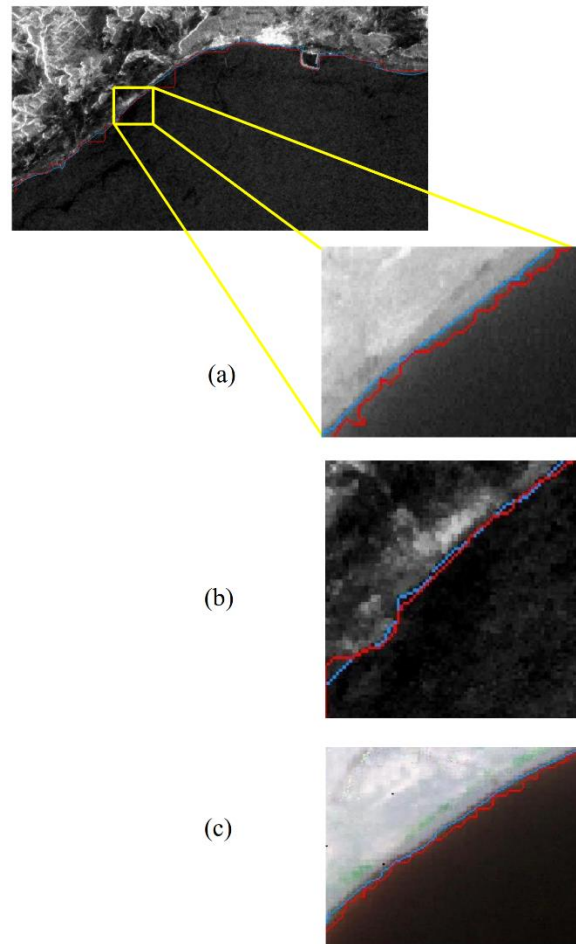
Figure 9: Sub-Section of extracted coastline in Qeshm 2009 using a: Landsat-7 b: ALOS c: Fused (red line) images compare to hand drawn line (blue line)

fusion. Also, in sub-section (1-2), the precision of extraction in Radar, Landsat and Fused images are respectively 2.96, 2.66 and 2.58. In this part of image, extraction accuracy in fused image is slightly same as Landsat and ALOS images.

In Figure 9, the obtained accuracy for sub-section (2) in Qeshm area (2009) by Landsat image is 4.86 pixels, for radar image is 1.66 pixels and fused image is 3.54 pixels. These accuracies yield a contradicting result with the precision obtained from the whole image. Here the radar image accuracy is better than the optical image One of the error factors in coastline extraction by optical images is light reflection of the sea bed in coastal area where there is shallow water. This caused a lower accuracy in extraction of coastline using Landsat 8 (Figure 6 (a)) image in 2016 compare to Landsat 7 2007 (Figure 7 (a)) image. This problem is completely removed in fused image (c parts of same figures) and the obtained coastline by images fusion has a better agreement compare to any radar or optical images stand alone. As showed in Figure 7 (yellow squares) the sea bed reflections was detected as coastline using Landsat image.

4.1 Conclusion

Generally, with one exception (Qeshm-2016) the results approved that the coastline detection using optical images (Landsat- Pancreatic Band) is more accurate than Radar images. The results of visual assessment show that, the detected coastline by optical images is more in line with the original image. However, in radar images for some reasons, the 2009 ALOS image in Qeshm there were some abnormalities caused by use of morphology analysis. If we ignore these types of errors in radar images, in other parts of radar image we could see good alignment of extracted coastline compare to original image. This is also clearly visible in radar images of Asaluyeh area. Considering that good agreement was find using optical images in 2007 and 2009 also using radar images in 2016, it can be concluded that applied method in this study for image fusion will improve coastline extraction precision. In fact, using fusion method, if not even increasing precision, will increase the accuracy of output information.

4.2 Coastline Changes Monitoring

In order to obtain coastline movements during the study period, we used the Near tool in ArcGIS (Figure 10). Thus, the displacement i.e. the average distance between the coastlines in 2007 and 2009 in

Figure 10: Coastline displacement over Qeshm (a) and Asaluyeh (b) area between 2007 (blue line) and 2016 (red line) by automated coastline extraction

the Qeshm area is 32 meters, and average distance between the coastlines in 2007 and 2016 is 37 meters in this region. In Asaluyeh area, this displacement between 2007 and 2016 is 33 meters. Coastline changes in the Qeshm area did not follow a general trend while coastline displacement in Asaluyeh region is depending on the type of beach. The coastline changes in the south of this area, which has a sandy beach, is generally up to the coast, and in the north, which has a rocky coast, it does not show any significant changes. Considering the accuracy of co-registration in this study is around 17 on average, it cannot be said that the mentioned numbers show precise coastline displacement, as they are also including co-registration errors.

4.3 Proposal
The following is recommended for future studies:
1- Use of polarimetric analysis in radar images with full polarimetric data (HH, HV, VH and VV). This method increases the ability of distinction between water and land due to the nature of the transmitted and received waves as well as the type of beach.
2- Use of ground control points to improve the accuracy of image co-registering in the pre-processing stage for fusion and monitoring the changes in different years.
3- Using meteorological and waves data to determine the effect of sea waves on the accuracy of coastline extraction.
4- Choosing a better way for continuity instead of using morphology
5- Coastline detection using different bands (C, L, and P) to determine the best frequency for extracting coastline from radar images on beaches with different classifications and types.

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