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Accuracy Assessment of Geoeye-1 Satellite Images for Updating Large-Scale Maps in Iran

Momeni E[1]*, Fard FSN[2] and Haghi H[2]

[1]*Department of Earth Sciences, The University of Memphis, USA*
[2]*National Cartographic Center, Iran*

Abstract

Urban planners and decision-makers always demand the most updated maps in order to model urban dynamics and make an optimized plan for the city. Conventional mapping techniques in Iran are still based on the use of traditional panchromatic aerial photos. Keeping maps up-to-date is a challenge for National Cartographic Center, as the main producer of maps in Iran. This paper examines the ability of GeoEye-1 high-resolution satellite images to update large-scale topographic maps of Iran considering Iranian national mapping standards. Extractable urban features from GeoEye-1 images and their geometric accuracy were studied and compared with aerial photos. The study found GeoEye-1 images as a practical alternative for aerial photogrammetry for updating large-scale topographic maps in Iran. Maps at a scale of 1:3,000 with 1 m contour interval can be extracted from GeoEye-1 images based on Iranian standards. Also, the study found that cost of map updating using GeoEye-1 images is less than the cost of map updating using conventional aerial photogrammetry.

Keywords: GeoEye-1; Aerial photogrammetry; Accuracy assessment; Map updating; Iran

Introduction

Rapid growth of urbanized area and changes in the urban patterns in developing countries, such as Iran, calls for an efficient technique for map production. Availability of high-resolution satellite imagery has increased the interest of scholars in use of remote sensing for large-scale topographic maps production [1-3]. In comparison with traditional aerial photos, satellite images not only provide a larger coverage, higher temporal resolution and multi-spectral data, they are usually more cost-effective than aerial photogrammetry and land surveying [4,5]. Conventional mapping techniques in Iran are still based on the use of panchromatic aerial photographs and field works. Most of the large-scale topographic maps are produced by aerial photos acquired between 1981 and 2008. Many maps produced in the early 1980s and 1990s are out of update now, and there is a need to re-map or update them. Therefore, National Cartographic Center (NCC, *hereafter*), Iran's national mapping agency, decided to find an alternative for the aerial photos to revise and update the topographic maps of the country.

NCC has separated databases for topographic maps in different scales including small-scale, medium-scale and large-scale topographic databases. This paper addresses the potential of GeoEye-1 high-resolution satellite images to update large-scale topographic maps considering the Iranian national mapping standards. Extractable features from GeoEye-1 images, geometric accuracy, and precision of them, in addition to an estimation of cost for updating large-scale maps are discussed in this paper.

Related works

Even though scholars in many disciplines have tried to extract information from different kind of images, the science of photogrammetry has been used for many decades as the main technique for producing topographic maps and extracting geometric information [6]. NCC, the main producer of topographic maps in Iran, has been using traditional aerial photogrammetry for producing coverage maps of Iran in different scales. Nowadays, the main task of NCC is revising and keeping those maps up-to-date [7]. During the past years, several researchers at NCC studied different alternatives for aerial photos in order to update maps at different scales.

In 2011, comprehensive studies on using IRS-P5 and ALOS-Prism imagery for updating 1:25,000 maps were done by NCC's researchers [8]. In other research, Momeni et. al. investigated potential of ZY3 satellite images for updating medium-scale maps of Iran [9]. The main purpose of those studies was to find a proper alternative of aerial photos to update medium-scale maps of Iran. The conclusion of both studies showed that IRS-P5 images can reach a higher precision and accuracy for updating 1:25,000 maps of Iran, based on Iranian standards. Based on those conclusions, NCC provided an instruction for updating medium-scale maps using IRS-P5 satellite imagery and started revision of medium-scale maps [10].

In addition to the medium-scale maps, updating large-scale maps of Iran is a challenge for NCC. In 2006, IKONOS images of more than 400 cities of Iran were obtained and orthorectified to produce or update large-scale maps of Iran. Those IKONOS images are used to update 1:10,000 urban 2D maps. Even though many of 1:10,000 maps of Iran were produced or updated using IKONOS image, those maps are 2D and the third dimension (elevation) of the features is missing. The current study investigates the potential of GeoEye-1 satellite image to produce or update the large-scale topographic maps of Iran, based on Iranian national mapping standards.

The paper is organized as the following: Section Two discusses the quality of maps based on Iranian national mapping standards; Section Three is dedicated to the study area and data; Section Four is about the

***Corresponding author:** Momeni E, Department of Earth Sciences, The University of Memphis, Memphis, Tennessee, USA, Tel: +1-901-206-614, E-mail: Hsn.momeni@gmail.com

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methodology of large-scale map updating; Section Five contains data processing and feature extraction; Section Six shows the results and accuracy assessment of map updating using GeoEye-1 images. Lastly, Section Seven is the conclusion.

The Quality of Maps based on Iranian National Mapping Standards

In this section, feature status and three different quality indicators based on Iranian national map standard (the unified specifications for surveying and mapping -volume II aerial photogrammetry-general) are discussed. Those three indicators are geometric accuracy, attribute accuracy and completeness of the map [11].

Feature status

Iranian national mapping standards define each feature as either a well-defined or an ordinary feature. A well-defined feature is a fixed feature with precise and clear borders, which can be recognized by the specialist easily and accurately. The intersection of walls is an example of a well-defined point that the specialist can detect it clearly [12]. In contrast, ordinary features do not have very clear, sharp, fixed or precise borders. Grasslands are examples of the ordinary features [12]. While a feature can be considered as a well-defined feature for a certain purpose at a certain scale or at a certain kind of image/photo, it can be considered as an ordinary feature for other purpose, other scale or other kind of image/data. Ordinary features are not proper for accuracy assessment [12].

Geometric accuracy criteria

Iranian national mapping standards seperated the geometric accuracy into planimetric and altimetric accuracies.

Planimetric accuracy criteria: Iranian standards define a planimetric error as the planimetric (horizontal) difference between the observed location of a feature and its actual location.

Based on the Iranian national mapping standards for the planimetric accuracy, the planimetric error of 90% of the well-defined features should be less than 0.3 mm × n_s, while n_s is the scale number of the map. In addition, the maximum planimetric error should be less than 0.5 mm × n_s. Furthermore, the same features in the overlapping area of images should have a planimetric error less than 0.2 mm × n_s [11].

Altimetric accuracy criteria: Iranian standards define an altimetric error as the vertical difference between the observed elevation of a feature and its actual elevation.

Based on the Iranian national mapping standards for altimetric accuracy, the altimetric error of 90% of the well-defined features should be less than 1/3 × CI, while CI is the contour interval. In addition, the maximum altimetric error should be less than 1/2 × CI [11].

Standards defined contour intervals, planimetric and altimetric accuracies for a large-scale map as Table 1 [11].

Attribute accuracy criteria

The Iranian standards define attribute accuracy as the rate of consistency between the extracted attributes of a feature and its actual attributes. These attributes include all kinds of attributes such as symbology and names [11].

Based on the Iranian national mapping standards for attribute accuracy, 90% of the extracted attributes of all features should be matched with the actual attributes of them at a 99% confidence interval [11].

Completeness criteria

The Iranian standards define completeness as the rate of consistency between the amount of extracted features from an image and the amount of existing features in the real world of the area [11].

Based on the Iranian national mapping standards for the completeness accuracy, 95% of all features in an area (with a confidence interval of 99%) should be mapped [11].

Study Area and Data

In order to update large-scale maps using GeoEye-1 images, a region in the west of Tehran, Iran, was selected as the study area (Figure 1). The study area is located between (35°46' 41"N, 51°04'22"E) and (35°42'12"N, 51°17'41"E) and covers an area of 138 sq. km. The area contains urbanized and unurbanized areas with different land covers, such as developed, water, agricultural, and barren. Also, different urban zones, including residential, commercial and industrial, are located in the study area.

The available GeoEye-1 images of the study area include one stereo pair of images; Image A and Image B, were acquired on June 30, 2009. Because of technical limitation at transferring and storing high-resolution images, Image A and Image B were available in some sub-images. Figure 2 shows a schematic view of the raw GeoEye-1 sub-images.

Image A was available in 3 different sub-images. While sub-image 1 had a unique Rational Polynomial Coefficients (RPCs), sub-images 2a and 2b had the same RPCs. Therefore, Image A was obtained by mosaicking of sub-images 1, 2a, and 2b using adequate RPC files. Image B was also available in 4 different sub-images; sub-images 3a and 3b had the same RPCs and sub-images 4a and 4b had the same RPCs. Therefore, Image B was obtained by mosaicking of sub-images 3a, 3b, 4a and 4b using adequate RPC files. Images A and B are pan-sharpened stereo pair with a spatial resolution of 0.5m at RGB true color channels.

In addition to the GeoEye-1 images, existing topographic maps at a scale of 1:2,000 were available at NCC. These large-scale maps are used for geometric corrections of GeoEye-1 images and aerial photos, as well as for accuracy assessment of the extracted features. These large-scale maps of the study area were produced in 2005 by NCC.

Furthermore, 37 aerial photos of the study area at a scale of 1:8,000 that were acquired in 2002 were available at NCC and are

Scale	RMSE(m) CMAS/1.517	Planimetric accuracy CMAS=0.3 mm × ns	CI (m)	Altimetric accuracy 1/3 × CI
0.3888889	0.1	0.15	0.25	0.1
1:1,000	0.2	0.3	0.5	0.16
1:2,000	0.4	0.6	1	0.33
1:5,000	1	1.5	2.5	0.84
1:10,000	2	3	5	1.67

Table 1: Geometric criteria of large-scale maps based on the Iranian standards.

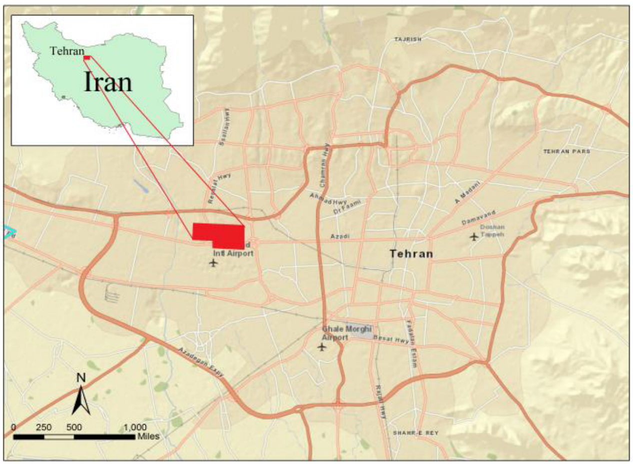

Figure 1: The study area.

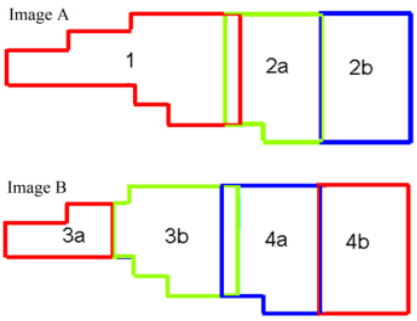

Figure 2: Schematic view of the raw GeoEye-1 images.

used as the reference data for the assessments to avoid mapping and photogrammetrists' errors.

Methodology

The GeoEye-1 satellite was successfully launched in September 2008. With a spatial resolution of 0.41 m for panchromatic and 1.65 m for multispectral channels, and temporal resolution of 3 days, it is considered as a proper source of data for mapping applications [13]. Using a stereo pair of GeoEye-1 images, a topographic map of an area in Tehran was produced. Using aerial photos, another topographic map of the same area was produced. Then, the accuracy, precision, completeness and cost of both those maps were compared. To avoid human-based errors, the same specialist was employed to capture features from both the GeoEye-1 images and the aerial photos. The main steps of the study are as the following (Figure 3):

1) Geometric orientation of satellite images using refined Rational Polynomial Coefficients (RPCs): GeoEye-1 satellite images have an RPCs file correspond to each image. To reach a higher precision, each initial RPCs file, that contains geometric orientation of the corresponding image, were geometrically corrected using precise Ground Control Points (GCPs). Also, the accuracy of correction was evaluated using Check Points (CPs) [14].

2) Geometric orientation of aerial photos: After a precise internal orientation of the aerial photos, they were oriented externally using precise GCPs.

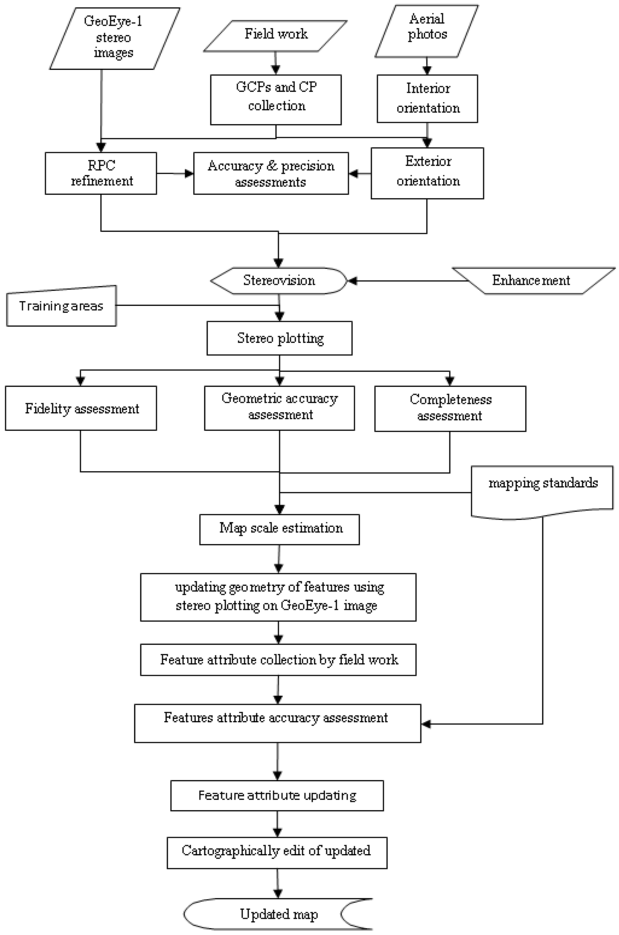

Figure 3: The methodology for updating large-scale maps using GeoEye-1 images.

3) Radiometric correction of GeoEye-1 images and aerial photos: Using steriovisioning, the radiometric characteristics of oriented GeoEye-1 images and aerial photos were enhanced to help the specialist in recognizing features clearly.

4) Defining training areas: Areas containing well-defined and unchanged features were detected and defined as the training areas for the planimetric accuracy assessment. In addition, some random points in unurbanized areas were collected for the altimetric accuracy assessment.

5) Stereo mapping: Capturing and mapping of features was done by a photogrammetrist who is a specialist in high-resolution aerial photogrammetry and remote sensing.

6) Planimetric and altimetric accuracy assessment: Well-defined features and random points of maps driven from the GeoEye-1 image and aerial photos were compared to estimate the geometric accuracy.

7) Completeness assessment: Identifiable features in the training areas on the satellite images were used to evaluate the completeness of the map.

8) Map scale estimation: Statistics of the deriven maps were compared with criteria of Iranian mapping standards.

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9) Updating the existing maps: The features with a change were updated in the existing maps using GeoEye-1images.

10) Updating the attributes: Features' attributes were collected and updated by field work.

11) Cartography: After updating the geometry and attributes of all features, cartographical modification was applied on the updated maps as the last step.

Data Processing and Feature Extraction

Geometric orientation of GeoEye-1 images and accuracy assessment

For each GeoEye-1 image at the oriented level, an initial RPCs file is provided. The initial RPCs file contains radiometric corrections, as well as the justification of the sensor and the earth curvature. The initial RPCs should be corrected geometrically to improve the geometric accuracy of the image [15]. In most cases, the initial RPC file can be refined with a zero or first order polynomial adjustment. A zero order polynomial requires at least 1 GCP to computes the translation in the horizontal and vertical directions. A first order polynomial requires at least 3 GCPs to computes the wraps in the image. While PCI Geomatics, one of the world leaders in geo-imaging products, pointed out that refinement of a GeoEye-1 image requires at least 6 GCPs, they mentioned that using more than 20 GCPs does not significantly improve the accuracy for most of the models [16,17].

In this study to refine the RPC files and accuracy assessment of geometric correction, 20 precise GCPs and 5 CPs were selected using stereoscopic models. Those GCPs and CPs were selected at well-defined points including building corners, wall intersections, and curb corners. Figure 4 illustrates the density and distribution of GCPs and CPs on the GeoEye-1 images.

Each Initial RPCs was refined separately, using affine equations, and a parallax-free model was created. The accuracy assessment of RPCs correction showed that the Root Mean Square Error (RMSE) for GCPs and CPs are 0.76 m and 0.56 m, respectively (Table 2).

Figure 5 shows the difference between initial RPCs and the refined RPCs on georeferencing of the GeoEye-1 image [18].

The geometric accuracy is not the only important factor in map updating using GeoEye-1 images. The interpretability of images by a photogrammetrist is also an important factor [7].

Geometric orientation of aerial photos and accuracy assessment

All 37 available aerial photos of the study area were used in this study to compare them with GeoEye-1 images. Internal orientation of aerial photos was carried out by calculated affine equations using a calibration report. 101 aerial triangulated GCPs and 9 CPs were used (Figure 6). To reach to a more precise matching result, 511 tie points were selected automatically and all of them were transferred to the corresponding overlapped images. After precise external orientation of aerial photos, accuracy assessment of the geometric orientation was

Point type	No. of points	RMSE (m)			
		X	Y	Z	Overall
GCP	20	0.49	0.36	0.45	0.76
CP	5	0.36	0.29	0.32	0.56

Table 2: Accuracy assessment of RPCs correction for GeoEye-1 images.

Figure 4: The density and distribution of GCPs and CPs on the GeoEye-1 images.

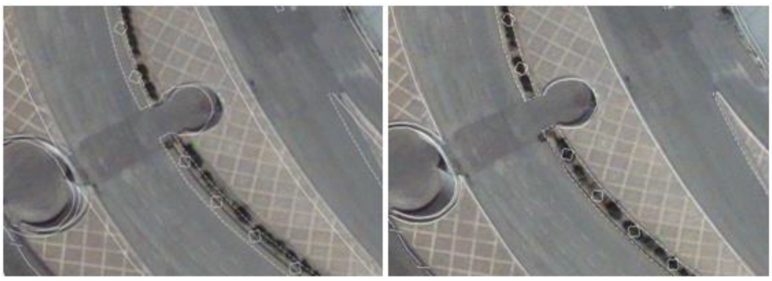

Figure 5: Existing vector maps on the GeoEye-1 image: using initial RPCs (left), using refined RPCs (right).

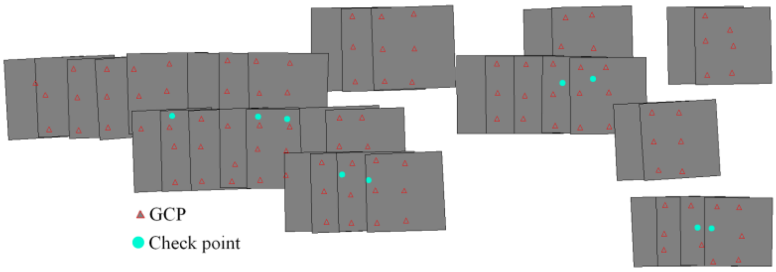

Figure 6: The density and distribution of GCPs and CPs on 37 aerial photos.

Point type	No. of points	RMSE (m)			
		X	Y	Z	Overall
Control	101	0.26	0.22	0.34	0.48
Check	9	0.21	0.24	0.23	0.39

Table 3: Accuracy assessment of geometric orientation for aerial photos.

done. The accuracy assessment showed that the RMSE for GCPs and CPs are 0.48 m and 0.39 m, respectively (Table 3).

Feature extraction

To determine whether the GeoEye-1 image is suitable for topographic mapping, the extracted features on the oriented GeoEye-1 images were compared with the extracted features on the oriented aerial photos. All features were extracted by an NCC photogrammetrist who is familiar with capturing spatial information from high-resolution aerial photos and satellite images. Figure 7 shows an example of training areas where features were extracted from both GeoEye-1 images and aerial photos.

For orientation, visualization, and mapping, Leica Photogrammetry Suite (LPS) module at ERDAS IMAGINE9.2 software by PRO600 software was used, and all the features in the training areas were captured on both satellite images and aerial photos, as well as heights of random points.

Results

To compare mapping using GeoEye-1 images and aerial photos, geometric fidelity, planimetric accuracy, altimetric accuracy and completeness of the maps were analyzed.

Geometric fidelity

All the features in the training areas were captured on both GeoEye-1 images and aerial photos. Figure 8 illustrates captured maps of a training area from GeoEye-1 images and aerial photos. As Figure 8 shows, all the features extracted from the GeoEye-1 image are similar to the features extracted from aerial photos. A visual evaluation by an expert photogrammetrist of NCC concluded that shapes and alignments of all mapped features from the GeoEye-1 images and aerial photos are the same. The few differences between them are because of changes that had happened between 2002 and 2009. As already mentioned in section 3, aerial photos were captured in 2002, while GeoEye-1 images were captured in 2009, while urban dynamic has changed within that time span.

Planimetric accuracy assessment

To examine the planimetric accuracy of GeoEye-1 images in comparison to the aerial photos, an evaluation was performed by comparing 2D coordinates of 188 corners of well-defined features.

Figure 7: An example of selected random points (left) and training area (right).

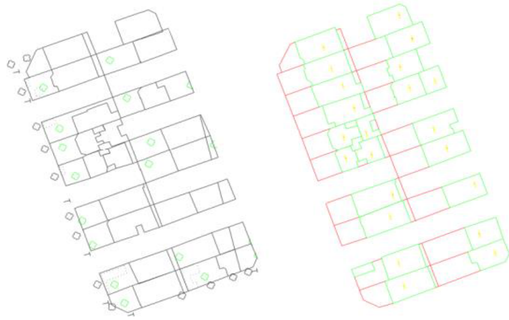

Figure 8: Captured features from the GeoEye-1 images (right) and the corresponding features from aerial photos (left).

No. of points	RMSE (m)			
	Minimum	Maximum	Mean	Std. Deviation
188	0.03	1.11	0.52	0.22

Table 4: Planimetric errors between GeoEye-1 images and aerial photos.

Extracted coordinates from GeoEye-1 images were compared with extracted coordinates from aerial photos and planimetric errors of them were calculated. Table 4 summarizes the statistics of planimetric errors.

According to the Iranian national mapping standard for the planimetric accuracy, the following conditions should be satisfied:

1) The planimetric error of 90% of the well-defined features should be less than 0.3 mm × n_s, while n_s is the scale number of the map [11]. In order to produce a map at a scale of 1:3,000, 90% of planimetric errors should be less than 0.9 m. The statistical comparison in the study shows that 92% of planimetric errors (173 out of 188 features) are less than 0.9 m.

In order to produce a map at a scale of 1:2,000, 90% of planimetric errors should be less than 0.6 m, while the statistical comparison in the study shows that only 78% of planimetric errors (164 out of 188

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features) are less than 0.6 m. Therefore, GeoEye-1 images failed to satisfy this criterion for a map at a scale of 1:2,000.

2) The maximum planimetric error should be less than 0.5 mm × n_s [11]. In order to produce a map at a scale of 1:3,000, the maximum planimetric error should be less than 1.5 m. As Table 4 shows, the maximum planimetric error was 1.11 m.

3) The same features in the overlapping area of images should have a planimetric error less than 0.2 mm × n_s [11]. In order to produce a map at a scale of 1:3,000, all the same features in the overlapping area of images should have a planimetric error less than 0.6 m. There were 19 points in the overlapping area of images and the maximum planimetric error of them is 0.178 m.

Based on the above assessments, the planimetric accuracy of GeoEye-1 images is proper to produce maps at a scale of 1:3,000 or smaller (including 1:5,000). Based on the planimetric assessment, the GeoEye-1 image cannot satisfy planimetric criteria of maps at a scale of 1:2,000.

Altimetric accuracy estimation

To examine the altimetric accuracy of GeoEye-1 images in comparison to the aerial photos, an evaluation was performed by comparing elevation of 132 random points in the unurbanized areas. Extracted elevations from GeoEye-1 images were compared with extracted elevations from aerial photos. Table 5 summarizes the statistics of altimetric errors.

According to the Iranian national mapping standard for the altimetric accuracy the following conditions should be satisfied:

1) The altimetric error of 90% of the well-defined features should be less than 1/3 × CI, while CI is the desired contour interval [11]. In order to produce a map at a scale of 1:2,000, CI is 1 m (Table 1). Therefore, the altimetric error of 90% of the well-defined features should be less than 0.33 m. The statistical comparison in the study shows that 95% of altimetric errors (126 out of 132 features) were less than 0.33 m.

2) The maximum altimetric error should be less than 1/2 × CI [11]. In order to produce a map at a scale of 1:2,000, CI is 1 m (Table 1). Therefore, the maximum altimetric error should be less than 0.5 m. As Table 5 shows, the maximum altimetric error was 0.47 m.

Based on the above assessments, the altimetric accuracy of GeoEye-1 images is proper to produce maps at a scale of 1:2,000 or smaller (including 1:3,000 and 1:5,000).

Completeness assessment

To determine completeness of driven data from the GeoEye-1 image, the stereo pair of GeoEye-1 were analyzed by a team of well-trained and expert photogrammetrists in the stereo plotting and land surveying sections of NCC. All the features in different zones including dense urban, industrial, rural-agricultural and floodplain, were examined according to five different map scales of 1:500, 1:1,000, 1:2,000, 1:5,000 and 1:10,000. These five map scales are standard large-scale scales, based on Iranian national mapping standards [11]. Examined features including buildings, walls, roads, railways, paths, curbs, vegetation limits, water features, field boundaries, power lines, stairs, pedestrian bridges, canals, trenches, fences, hedges, patios, weirs, rocks, monitoring towers, and silos. Table 6 summarizes the results of completeness assessment for GeoEye-1 images. The column named "scale" indicates the mapping scales at which each feature could be mapped.

No. of points	RMSE (m)			
	Minimum	Maximum	Mean	Std. Deviation
132	0	0.47	0.17	0.11

Table 5: Altimetric errors between GeoEye-1 images and aerial photos.

Estimated cost

Cost always plays an important role in defining a project. When the project is nation-wide, such as updating large-scale maps of a country like Iran, the role of the cost is even more important. In order to have a comprehensive study of the potential of GeoEye-1 for updating maps, costs of updating a map using GeoEye-1 images were compared with the cost of updating the same map using aerial photos. Based on the results of accuracy assessment in sections 6.1 to 6.4, considering the Iranian national mapping standards, GeoEye-1 images are proper to update the maps at a scale of 1:3,000 (or smaller). To update maps at the same scale of 1:3,000, aerial photos at the scale of 1:8,000 is used. The total inevitable cost of map updating using GeoEye-1 images of a region with 50% to 80% of urbanization was estimated 2,350 USD/sq. km (Table 7) [19].

Meanwhile, the total inevitable cost of map updating using aerial photos for the same region with the same conditions was estimated 2,382 USD/sq. km (Table 8) [19].

Office operations in Table 7 refers to the preprocessing of satellite images including radiometric and geometric corrections, mosaicking different patches of an image and transferring collected GCPs on the images. Moreover, in Tables 7 and 8, field works refer to the insitu clarification of ambiguous features on the image/photo. Field works also includes collecting required attributes about features.

Tables 7 and 8 show that updating maps using GeoEye-1 satellite images is cheaper than using aerial photos. The difference between cost per sq. km of GeoEye-1 and the aerial photo is not significant, but for updating maps of a large country such as Iran, with an area of 1.648 million sq. km, the difference is significant (up to 53 million USD for the high-scale coverage maps of the whole country). Considering more than 1100 cities in Iran, the cost saving of high-scale map generation in urbanized areas of Iran using GeoEye-1 images would be considerable.

Conclusions

The results of this study show that the stereo pan-sharpened images of the GeoEye-1 satellite with a spatial resolution of 0.5 m can be used as a main source of data for updating large-scale topographic maps in Iran. These images are a proper alternative for aerial photos to update maps at a scale of 1:3,000 or smaller. Even though contour maps with 1 m interval can be extracted from GeoEye-1 images, but the planimetric accuracy of GeoEye-1 images cannot satisfy the Iranian standards for maps at a scale of 1:2,000. This limitation probably comes from the image processing step, where pan-sharpened applied. Manipulation of pixel values make some linear features, such as narrow walls, curbs, light poles, stairs, and ditches, blurry and difficult to capture them precisely. Meanwhile, expert photogrammetrists are able to extract some city furniture, such as dustbins and billboards, based on empirical analyses of feature's placement and its surroundings.

It should be emphasized that multispectral channels of GeoEye-1 images aid interpretation and contribute to the qualitative data extraction such as land cover classification and feature detection. While greyscale aerial photos cannot contribute to such a qualitative data extraction. In addition, cost analyses show that map updating

Features	Description	Scale				
		0.388888889	1:1,000	1:2,000	1:5,000	1:10,000
Buildings	All buildings and their edges are quite distinct. Floating point tangent on tar layer roof is hard since image pixels are shiny.	×	×	✓	✓	✓
Walls	Easy to identify, middle of the wall is captured, floating point tangent on thin walls is difficult.	×	×	✓	✓	✓
Roads	All roads can be identified. Edge of freeways and asphalt roads can be captured accurately. Edge capturing of carriageways depend on photogrammetrist. White lines visible and road slope and alignments clear.	×	×	✓	✓	✓
Railways	Individual tracks and alignments of railway visible and axis line of tracks can be captured.	✓	✓	✓	✓	✓
Curbs	Curbs altitude is the diagnosis. The distinction between curbs and ditches are difficult.	×	×	m	✓	✓
Fences- Hedges	In most cases easy to identify. Generally interpretation base on shadow status, altitude, irregular shapes and neighbor features such as garden, park, railway aim separation between fences and hedges.	×	×	m	✓	✓
Field Boundaries- Vegetation Limits	Such as green areas, agriculture, garden, outdoor parking, terminal, cemetery, sports fields, garbage fields and gas station easy to identify. Interpretation plays an important role.	×	×	✓	✓	✓
Canals	Regular shapes and altitude of structure assistance identification. If full of watercolor contrast appears. Bridges on canal intersection with other features easy to recognize.	×	×	✓	✓	✓
Water features	Ravine, river coast, island and even streams clear to identify and capture. Color images aid to identification and capturing.	×	×	✓	✓	✓
Ditches	The depth of ditches aims identification. Two separate lines captured in More than 1-meter width.	×	×	m	✓	✓
Weirs	Clear to identify.	×	×	✓	✓	✓
Trenches	Trenches alignment and slope clear to identify. Artificial trenches easier to capture.	×	×	✓	✓	✓
Pit and pile - Rock	Alignment and slope clear to identify. If rock slope is positive, contours were captured otherwise low and high attitude of rocks were drawn.	×	×	✓	✓	✓
Silos	Obvious to identify. Type of silos such as cereals and cement is identified by field collection.	×	×	✓	✓	✓
Light poles	Using the intersection of the shadow of poles and body poles aid identification. In cases that poles aren't hidden, identification and capturing is possible.	×	×	m	-	-
Light lamp	Light lamps in parks can be identified using their cap, shadow rod and their contrast with around environment.	m	m	-	-	-
Patios	Most cases easy to identify.	×	×	✓	-	-
Dustbins	Interpretation based on feature texture, placement such as the end of an alley in featureless places possible identification.	m	-	-	-	-
Stairs	Difficult to identify. Small altitude differences of stairs impossible to identify, so white area appear in the image. Only stairs beside autobahns and in front of towers should be captured. Photogrammetrist experience assists identification.	×	×	m	-	-
Pedestrian bridges	Very easy to identify. Edge blurring makes capturing difficult.	×	×	✓	✓	✓
Billboards	Only big ones in superhighways easy to identify.	✓	✓	-	-	-
Monitoring towers	Identification possible by placement beside walls of open military areas, rod shadow, and regular shape of roof.	×	×	✓	✓	✓

[Note: √ means the feature can be captured; m means in some circumstances the feature maybe captured; × means the feature cannot be accurately captured; - means the feature does not exist in the scale specification].

Table 6: Analyses extractable features from GeoEye-1 stereo pair images.

Steps	Unit Price (USD/sq. km)
Purchasing image	69.23
GCPs data collection	1.87
Office operations	18.11
Capturing features	2003.66
Field works	103.53
GIS modification	154.13
Total cost	2350.53

Table 7: Cost estimation of large-scale map updating using GeoEye-1 satellite images.

Operational steps	Unit Price (IRR/sq. km)
Aerial photograph capturing	36.36
Field works	165.53
Aerial triangulation	22.4
Capturing features	2003.66
GIS modification	154.13
Total cost	2382.08

Table 8: Cost estimation of large-scale map updating using aerial photos.

using GeoEye-1 images are more cost-effective than aerial photos. Lastly, NCC has some limitations for aerial photography in the regions close by the borders of Iran, while satellite images are free of those limitations.

Even though aerial photogrammetry is more self-sufficient and photos can be taken any time even under a cloudy sky, but GeoEye-1 satellite image is a proper alternative for updating large-scale maps in Iran, especially for maps at a scale of 1:3,000 or smaller.

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