Mapping Contents Analysis of WorldView-2 VHR Satellite Imagery Using Cadastral Information

Mehmet Alkan[1], Okan Yilmaz[1], Gurcan Buyuksalih [2], Cem Gazioglu [2], Karsten Jacobsen [3]

[1]Department of Geomatics Engineering, Yıldız Technical University - alkan@yildiz.edu.tr
[1]Department of Geomatics Engineering, Yıldız Technical University - yilmaz@yildiz.edu.tr
[2] Institute of Marine Sciences and Management, Istanbul University - gurcanb@istanbul.edu.tr
[2] Institute of Marine Sciences and Management, Istanbul University - cemga@istanbul.edu.tr
[3] Institute of Photogrammetry and GeoInformation, Leibniz Universität Hannover, Germany - jacobsen@ipi.uni-hannover.de

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ABSTRACT:

Very High-resolution (VHR) optical satellites with a ground sampling distance (GSD) of 1m and less for nadir view began with IKONOS in 1999. There are now several VHR optical satellites. A WorldView-2 image compared the advantage of higher-resolution space images for mapping purposes with some lower-resolution VHR images. The orbit altitude of WorldView-2 (WV2) was changed from 767km to 680km in 2011, reducing the GSD in the nadir view from 0.46m to 0.41m. The WV2 image was taken at an incidence angle of 33.3°, resulting in a GSD of 0.49 m times 0.59 m, or 0.54 m on average.

The information content analysis confirmed the generally required production scale of 0.05 to 0.1 mm GSD at map scale. This corresponds to a topographic map scale of 1:10,000 for 1 m and 1:5000 for 0.5 m GSD images. This is also based on test fields in İstanbul, Adalar district. The required mapping detail that could be identified using with the VHR space images is dominated by the ground resolution available as the ground sampling distance (GSD). WV2 imagery has proven to help update the GIS and cadastral database.

1. INTRODUCTION

A new era of Earth observation has recently begun with the global launch of very high-resolution (VHR) optical satellites (Alkan et al., 2013; Li, 1998). This study partially used a ground-projected 50 cm GSD WorldView-2 image covering the Sea of Marmara (SOM). The image covers only a tiny part of the land, but some islands in the SOM. These islands are known as the Prince's Islands, such as Büyükada and Heybeliada, and include built-up areas. Because of their historical importance, the mapping authorities constantly monitor changes in these islands. The projected imagery was georeferenced using ground control points (GCPs) digitised from Google Earth. We digitised key map details, such as buildings, using QGIS software and compared this dataset with cadastral maps of the area. It turned out that the WV-2 images could be used to detect changes in such critical areas and update the map content.

Over the past thirty years, very high-resolution (VHR) optical satellite imagery has been increasingly utilised across various application domains. One of these domains includes object extraction, change detection, topographic mapping, and developing and updating Geographic Information Systems (GIS). Depending on national specifications, VHR optical satellite imagery has also been used for cadastral databases. A primary application involves creating and updating GIS databases through topographic mapping, depending on the representation scale (Jacobsen, 2002; Jacobsen et al., 2008; Ahmadi et al., 2010; Mondino & Chiabrando, 2010). Geographic Information Systems (GIS) and remote sensing have become crucial by leveraging VHR optical satellite data as object extraction components. The production of topographic maps is a significant application. Aerial imagery or very high-resolution optical satellite images can be used to create or update GIS databases, depending on the required accuracy and mapping detail (Alkan et al., 2010; Jacobsen et al., 2008; Topan et al., 2009; Topan et al., 2005; Aquilar et al., 2008). The number and capacity of very high-resolution optical satellites have continuously increased, making access to high-resolution space imagery no longer an issue (Alkan et al., 2013; Jacobsen et al., 2008; Topan et al., 2005). Due to the very high resolution of optical satellite imagery, it can be used as an alternative to aerial imagery, depending on the required information content and accuracy (Jacobsen et al., 2008; Topan et al., 2005; Alkan et al., 2010; Topan et al., 2009; Aquilar et al., 2008).

Istanbul, Turkey, was selected for the acquisition of WorldView-2 imagery. WorldView-2 images are available for this region and have been utilised for topographic mapping in Istanbul’s renowned “Adalar area.” Information content and geometric accuracy are crucial for large-scale topographic mapping.

Istanbul and its districts were chosen for this study due to their diverse topographic structures, which can be classified as flat, sloped, coastal, lake, and lakeshore areas.

The study area used in this research consists of an archipelago located south of Istanbul. This region is also known as the famous "Islands area." As shown in Figure 1, Büyükada was selected as the pilot area. The studies conducted here are presented in the following sections.

VHR satellite images such as WorldView-1, -2, and -4, IKONOS, and QuickBird have recently been widely used. Traditionally, topographic and cadastral mapping relied on aerial photographs. However, due to legal classification restrictions in Turkey, aerial photography was challenging. Today, the availability of very high-resolution space imagery with a ground sampling distance (GSD) of up to 0.5 m enables the use of space imagery instead of aerial imagery. These images offer the advantage of easy accessibility and are not restricted by classification regulations (Büyüksalih et al., 2008; Jacobsen et al., 2008).

Currently, high-resolution space imagery with a GSD of up to 0.3 m makes it possible to use space imagery as an alternative to aerial images. These images, similar to aerial photographs in Turkey, offer the advantage of easy acquisition and are not subject to classification restrictions.

In the context of this paper, the generally required image GSD of 0.05 to 0.1 mm in the map scale was confirmed. It is required to correspond to a topographic map scale of 1:10,000 for 1 m GSD and 1:5000 for 0.5 m GSD images. In this study, images from Worldview-2 were used for topographic mapping. For this reason, the İstanbul test fields are an important area for applying high-resolution imagery. In this study, high-resolution imagery was tested depending on the GSD and according to the map scales for updating the GIS database.

Figure 1. In this study, a test site from Istanbul (Islands area) on Worldview-2 pan-sharpened VHR satellite imagery

2. STUDY AREA AND DATA

The Worldview-2 VHR image belongs to the family of very high-resolution sensors as it has a panchromatic ground resolution of 0.46 m, or 0.54 m for the 33.3° angle of incidence and a multispectral resolution of 1.84 m, or 2.16 m for the direction of view used. It will fly at an altitude of 680 km along a sun-synchronous orbit with a descending node at 10:30 a.m. and an average orbital period of about 1 day. On 14 April 2023, the WV-2 image was acquired over the SOM, including the Princess Islands in the centre of the image. The image has 16-bit radiometric resolution and has been processed to LV2A product level, Ortho-Ready Standard (ORS) imagery ready for GIS applications, corresponding to a projection onto a horizontal reference plane. ORS2A images are radiometrically corrected. These images are provided with Rational Polynomial Coefficients (RPCs) that relate only to the projection plane and do not consider object heights that differ from the projection plane. The area covered by the image is approximately 208 km2 (16x13) with a central latitude and longitude of 40.87º and 28.96º, respectively. Based on direct sensor orientation, the WV-2 ORS2A imagery is specified at 2.3 m RMSE and 5.0 m CE90 (circular error at 90% probability) (DigitalGlobe, 2020). It is georeferenced to the World Geodetic System 1984 (WGS84) using the Universal Transverse Mercator (UTM) datum at zone 35.

It is necessary to check the direct orientation of the sensor, as any initial deviation will affect all subsequent products. Ground Control Points (GCPs) can be used to check the geometric accuracy of satellite imagery. GCPs can either be measured on the ground or digitised from reference aerial photographs or large-scale maps (Dial et al., 2003). In this study, we used GCPs collected from Google Earth, which, in our experience, have a root mean square accuracy of about 1.5 m. Another paper submitted to this workshop (Büyüksalih, G., Gazioglu, C., Jacobsen, K., Geometric Evaluation of GeoTIFF Worldview-2 Image Data Acquired Over Sea of Marmara) gives a geometric evaluation of the WV-2 image. So the detailed information can be found there. However, it can be said that the better standard deviation of X and Y of 1.30 m and 1.23 m is obtained by the 3D-affine transformation, which corrects the influence of the tilted viewing direction as a function of the object height.

3. INFORMATION CONTENTS

Space imagery is widely used in many fields today. One of these is the significant use of GIS. Ortho-images are among the most commonly used geoinformation products utilised for various purposes. A simple rule for this usage is that ortho-images should have at least 8 pixels/mm, corresponding to a publication scale 1:4000 for WV-2 images. However, the relationship between GSD and the publication scale of topographic maps is more complex for vector maps. Topographic maps have a fundamental rule of 0.1 mm GSD at the publication scale, which also depends on imaging conditions (Jacobsen, 2006). Based on the required GSD with WV2 satellite imagery, a publication scale 1:5000 is feasible for maps. The standard deviation of coordinates at the publication scale should not exceed 0.25 mm, corresponding to 1.25 m. With WV-2 images, a relative accuracy of 1 pixel, equivalent to 0.5 m, can be achieved for well-defined objects. The limiting factor, of course, is identifying details required for the publication scale. Naturally, this is not entirely fixed but depends on the area and the details represented on the maps. Additionally, imaging conditions are crucial. The sun's height and the resulting shadows are particularly critical when digitising map details on the image.

We manually extracted the main map details, e.g., buildings and roads, over the Worldview-2 image of Princess Islands using digitisation tools in the QGIS software. Particular attention was paid to details located at different elevations. The digitised information was superimposed on the cadastral maps of the area, and statistical analysis was performed to determine the contribution of VHR satellite images to updating the cadastral map contents.

WorldView-2, since September 2011, has been flying at an altitude of 680km, corresponding to a Ground Sampling Distance (GSD) of 0.46 m for the nadir view. The image used was taken at a nadir angle of 30.03°, corresponding to an incidence angle of 33.6°. The angle of incidence is the nadir angle from the ground to the satellite, which is larger than the nadir angle from the satellite to the ground due to the curvature of the Earth. The GSD of 0.46 m for the nadir view and at the incidence angle of 33.3°, resulting in a GSD of 0.49 m times 0.59 m, or 0.54 m on average. This should be verified for operational use. It was done by edge analysis using the Hannover EDGE program (Jacobsen 2009). The edge analysis gave a factor of 1.13, resulting in an effective resolution for the nadir view of the available ORS2A image with 0.50m GSD * 1.13 = 0.56 m, which is very close to the theoretical value of 0.54 m. For inclined view direction, the GSD increases across the view direction to the nadir GSD by division with cos(incidence angle) and in the view direction to 0.50 m /cos²(incidence angle). Of course, for the optimal GSD also optimal atmospheric conditions are required, so the effective GSD of 0.56 m is satisfying close enough to the theoretical value of 0.54m.

The Ground Sampling Distance is the distance between the centres of neighbouring pixels in object space. Neighbouring pixels may be over-sampled or under-sampled. The smaller the GSD, the more detailed information can be extracted. For example, the high-resolution WorldWiew-2 images show more object detail than IKONOS images with 1 m GSD. In IKONOS images, only large buildings are visible, whereas WorldView-1 images show details of small buildings. Similar details as in WorldView-2 images can be seen in Worldview-1 scenes.

The nominal ground resolution is not identical to the effective ground resolution; in particular, space images with staggered CCDs (50% oversampling) may have a lower image quality, resulting in a reduced effective ground resolution. Table 1 shows the result of the edge analysis; the nominal resolution for these satellites corresponds to the effective resolution of the images used.

	Nominal pixel size from the Imageries (m)	Adequate pixel size from the Imageries (m)
IKONOS VHR imagery	1	1
Quickbird VHR imagery	0.6	0.6
Worldview-1 VHR imagery	0.5	0.5
Pleiades 1 &2 VHR imagery	0.5	0.5
Worldview-2 VHR imagery	**0.5**	**0.5**
Worldview-4 VHR imagery	0.31	0.31

Table 1. Effective and Nominal GSD have been determined by edge analysis of different space images

4. INFORMATION CONTENT - MAPPING

The section explaining the simple comparison of different space images gives a good idea of the information content. The critical issue is geometric resolution with topographic mapping for object identification.

Objects	**Required pixel size from the imageries**	**To Create a Possible Map Scale**
Roads and buildings	0.31m GSD (maybe lower is possible)	1:2.500
Railways	0.31m GSD (maybe lower is possible)	1:2.500
Roads and buildings	0.6m GSD (maybe lower is possible)	1:5.000
Railways	0.6m GSD (maybe lower is possible)	1:5.000

Table 2. To create topographic and cadastral mapping based on panchromatic images which is required GSD

5. GEOMETRIC ANALYSIS OF WORLDVIEW-2 IMAGERY

Büyükada on the island of Istanbul was chosen as the pilot region for this study. In the study, manual building extraction was carried out in two different regions.

In the region, 1/1000 scale topographic cadastral data was produced using Global Navigation Satellite System (GNSS) surveying. The comparison of this data with the data obtained from the Worldview 2 image in the two main regions of this study is presented visually (Figures 2 and 3). Here the results obtained from Worldview-2 with a GSD of 0.50m in the context of buildings are compared with 1/1000 scale topographic cadastral data. As seen from this application, it was possible to achieve conformity with the cadastral data in terms of building extraction in two different ways (in two different regions).

The results obtained from the Worldview-2 image with a GSD of 0.50 m showed a high level of resolution in the context of buildings. In the context of parcels, it was found that it was not easy to obtain high extraction results in the residential area. The main difficulty here is determining the plot corners. This is the main factor that complicates the extraction of parcel objects. On the other hand, vegetation and trees are other factors that make this process difficult.

It is considered easier to determine the parcel corner points when the evaluation and inference is carried out in rural areas. This is because the parcel corner points can be seen more clearly for parcels that are fields.

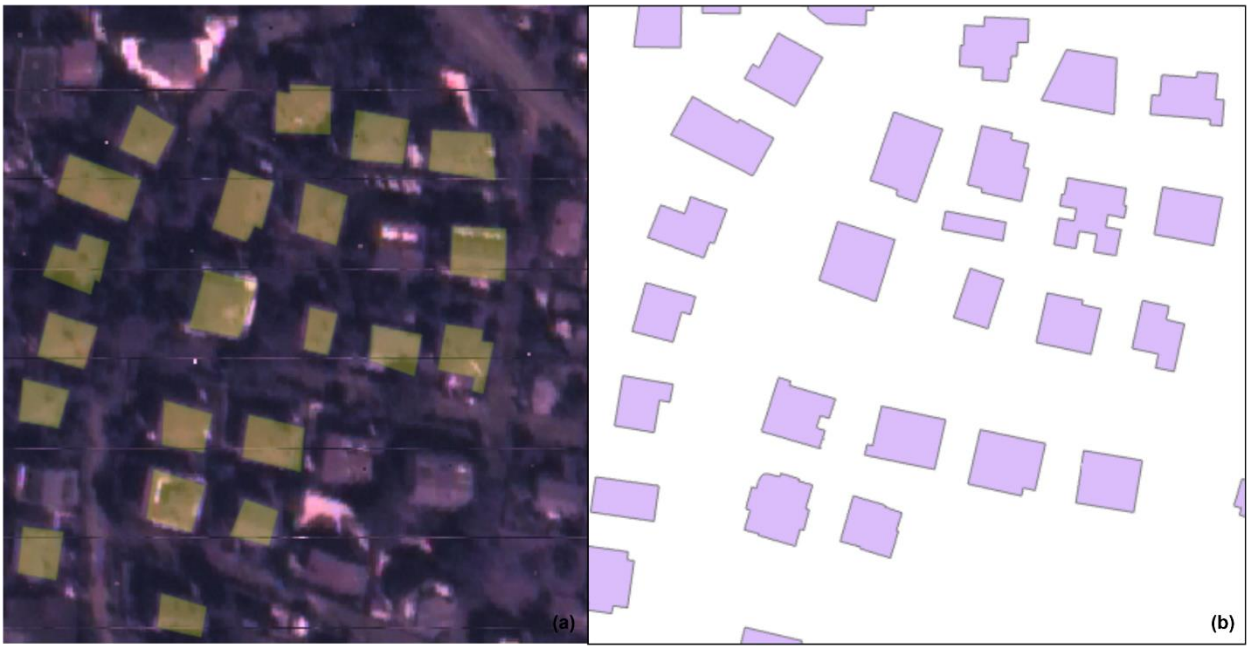

Figure 2. Object comparison with left image (Worldview-2) and 1/1000 scale Cadastral map (right figure) in the area study area-1

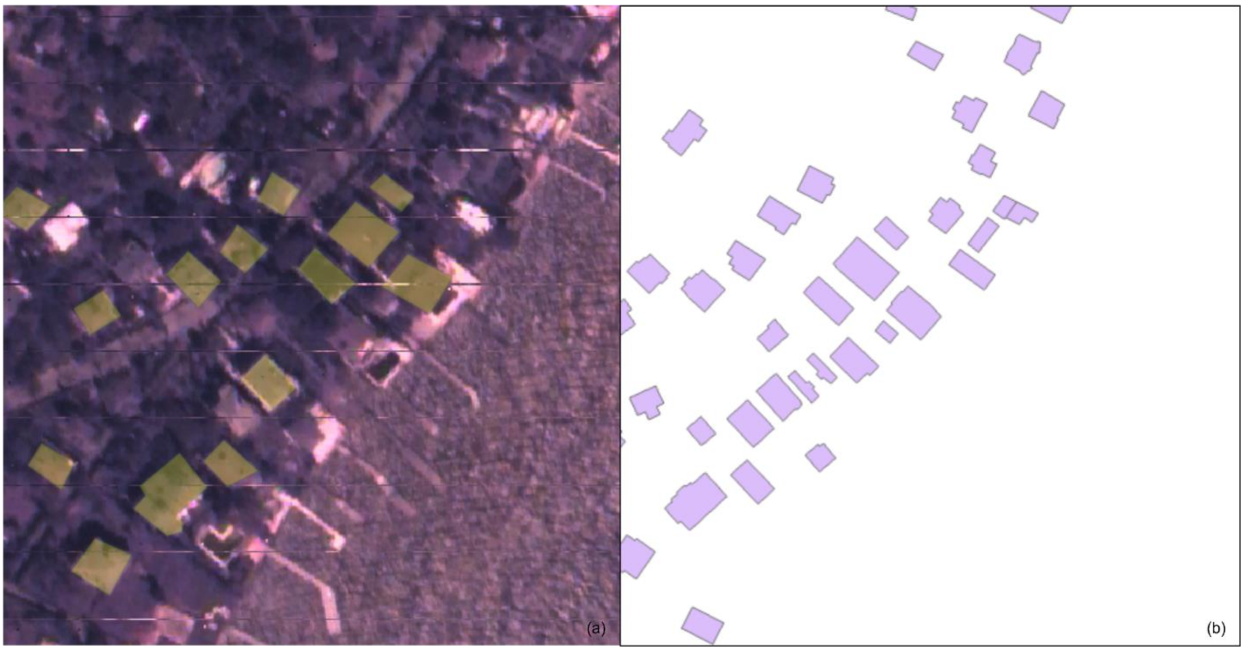

Figure 3. Object comparison with left image (Worldview-2) and 1/1000 scale Cadastral map (right figure) in the area study area-2

Figure 4. General seen of the Büyükada application area of the image

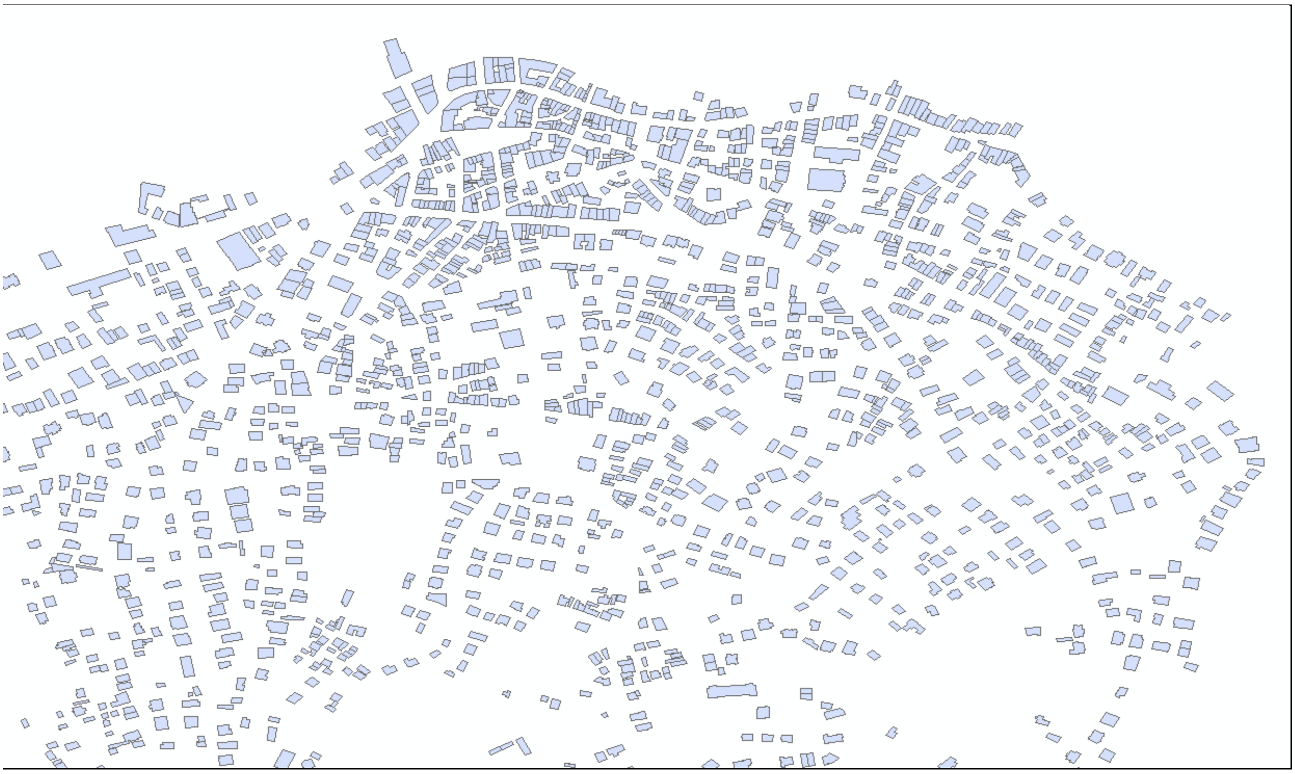

Figure 5. General seen of the Büyükada application area of the cadastral database

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6. CONCLUSION

From this study results, the exclusive element of this study is to present the results to be obtained from object extraction from VHR images. In this context, the mapping and updating of the GIS database are very important components. Also, mapping and updating of the GIS is limited by the information content of the imagery used. Due to the very high ground resolution of the optical space imagery used, aerial imagery can be dispensed with map scales of 1:5000 and smaller. The rule of thumb for GSD of 0.05 to 0.1 mm at map scale has been confirmed for the panchromatic imagery used. Colour images are relatively more straightforward to interpret but do not provide as much detail. The main limitations of mapping are image resolution and image quality. The required accuracy of 0.25mm at the publication scale is easily achieved.

Experience with the production of topographic maps based on high and very high-resolution space imagery (Jacobsen, Büyüksalih 2006) led to the requirement of 0.1 mm GSD in the map scale. This results in a possible map scale of 1:6900 with an effective GSD of 0.69 m. This is only an approximate relationship. At a map scale of 1: 5000 it is possible that some of the required objects will not be correctly identified. Conversely, at a map scale of 1: 10 000, it should be possible to identify all the necessary details. Identification and classification are more complicated than the correct geometry of the objects.

Finally, this study used WorldView-2 VHR images to extract the buildings and update GIS and cadastral data. It was found that object extraction and database updating can be difficult in residential and built-up areas on slopes, partially caused by the high incidence angle of the image used. One can also say that maps at a scale 1:5000 can be used here. In non-residential areas, it has been determined that object extraction can be performed more accurately and with more detail using WorldView-2 VHR images. In this context, the updating of the cadastral database will be more obvious. Furthermore, it has been observed that field boundaries in rural areas can be determined more clearly and faster using VHR satellite images than with aerial images.

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