

Algorithms for Enhancing Satellite Imagery to Discover Archaeological Finds Covered by Shadow

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Abstract. Very high-resolution (VHR) images proved to be an invaluable source of information even in the archaeological domain, but sometimes shadows hinder their full exploitation. To overcome such limitation, this research proposes a workflow able to analyze shadowed zones, by processing Pléiades and World-View 2 images. The case study is the archaeological site of Maltai, in the Iraqi Kurdistan Region, which presents shadowed areas to be detected. Applying de-shadowing workflow has been tested over multispectral and panchromatic images, with different invariant color spaces. The proposed methods exploit the techniques of automatic thresholding and spectral ratio in the detection of shadow regions. This approach shows a clustering of shadow pixels for an enhanced images visualization and proves its suitability for archaeological settings.

Keywords: VHR imagery · Pléiades · World-View 2 · Multispectral images · Panchromatic images · Shadow algorithms · Archaeological area

1 Introduction

Remote sensing (RS) represents a useful tool for the analysis and evaluation of changes in environmental and urban processes, and not only. In fact, RS becomes a useful approach for investigation, documentation and planning also in the archaeological field. The new possibility offered by the processing of data collected remotely allows to analyze sites of particular interest and to discover the signs of ancient population activities on the land surface [1]. In particular, satellite imagery provides a high detailed resolution of land cover mapping [2]. The technological evolution of acquisition devices and the continuous refinement of data processing algorithms offer new possibilities for classification and extraction of information on the ground. For these reasons, RS is an effective technique to monitor the dynamics due to anthropogenic and natural actions [3], thanks to the processing of high or very-high resolution (VHR) multitemporal and multispectral satellite images [4]. The use of the VHR satellite systems represents an

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extremely valid tool for the monitoring of change detection of the terrestrial surface with a sub-millimetric accuracy, based on the definition of time series (TS) of satellite radar images [5]. However, thanks to the recent technological progress, different satellites have been launched such as IKONOS, QuickBird, Pléiades, GeoEye, RapidEye, Skysat-1, WorldView-2, WorldView-3, Jilin-1 and Kompsat [6]. The abovementioned satellites are able to acquire different images by several multispectral and panchromatic VHR sensors are used. In the use of satellite RS, a challenge is to detect and/or classify shadowed targets, where shading results in the decrease or total loss of spectral information [7], such as in mountain areas covered by vegetation [8]. The problem arises when the presence of shadowed areas in such archaeological sites may prevent their correct view and identification of the area that will be the subject of the archaeological expedition. In order to overcome this problem, various algorithms have been implemented to reduce or remove shadow pixel imagery [9].

The research work presented in this paper aims to exploit VHR images for the recognition of objects in hard-to-reach areas and to allow an accurate mapping of the archaeological area. After an initial analysis about related works, the article is setup as follows. The paragraph on the methodology of work starts with a brief description of the archaeological case study. Then the work performed to test the de-shadowing technique according to the type of image used is illustrated: first on multispectral images and then on panchromatic ones. This is followed by a summary of the results obtained and, in conclusion, comments on these approaches are discussed.

2 Related Works

In literature there are not many applications of satellite remote sensing for the identification and monitoring of archaeological areas [10]. Using multispectral and/or panchromatic satellite imagery, the monitoring process of archaeological sites can be effectively supported in a reliable, repetitive, non-invasive, fast and cost-effective manner [11]. The satellite sensors offer more advantages with spectral imagery in comparison with aerial photogrammetry [12]. Nowadays, the employment of multispectral sensors allows measuring each pixel imagery carried out usually derived between 3 and 10 different bands [13]. In addition, in areas where the work of archaeologists has been blocked, due to, for example, the outbreak of civil war or the occupation by militias [14], the inaccessibility of the sites is overcome by the use of satellite RS. In fact, with RS it is possible to acquire a time series of images to monitor and map all the archaeological sites and artistic heritage.

The problem arises when the presence of shadowed areas in such archaeological sites may prevent their correct view and identification of the area that will be the subject of the archaeological expedition. The presence of the shadow in images may have a dual effect. The first one shadow is considered as a support of information through a semantic process, while secondly it can cause distortions to return of the shape of objects in the image, for their recognition [15]. In order to overcome this problem, it has been used correction and analysis methodologies applied in contexts differing from the one under examination, such as urban and natural environments [16–18]. During the recent decades, different algorithms has been developed in order to improve the identification

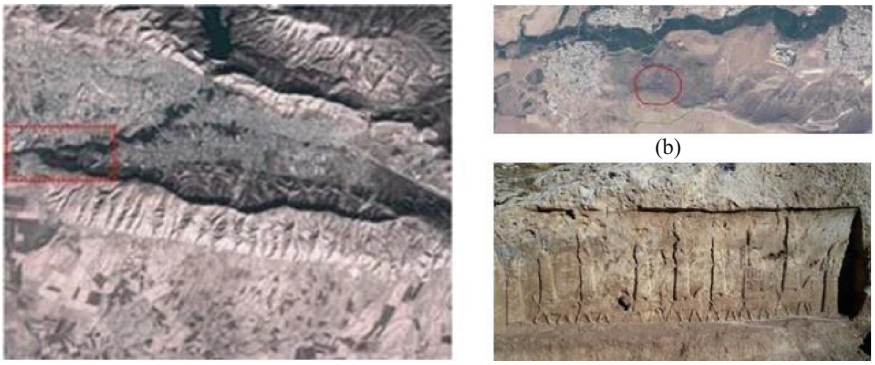
and detection of shadow pixels in color aerial images. Among these we can find Tsai [19], considering the multispectral images, describes the relationship between hue and intensity in order to identify the difference between shadow and non-shadow pixels, separating the shadow masks from the map with an Otsu threshold (1979) [20].

The set of de-shadowing processes allow the creation of raster images, being used by archaeologists for the generation of a basic map in GIS (Geographic Information System). This enables a thematization and the development of a predictive model that bases its roots both on the geometries of the non-shadowed entities present in the study area and on other types of data such as topographical, historical, geological, etc. [21].

3 Materials and Methods

3.1 Description of the Study Area

Traces of the Assyrian empire, which dominated ancient Mesopotamia in the first millennium B.C., were found in northern Iraq (Iraqi Kurdistan Region), thanks to an archaeological expedition led by the University of Udine. After research campaigns, almost 500 archaeological sites have been discovered, of which about 200 from the Neo-Assyrian period, consisting of ancient towns and rural villages, caves and wells, quarries, canals and ancient roadways. These sites are located in the "Land of Nineveh" (http://www.terradininive.com), an area straddling the provinces of Mosul (the ancient land of the Nineveh) and Dohuk. In these sites, bas-reliefs carved into the rock have been found, including the Maltai rock reliefs (Fig. 1), selected as a case study for this work. In this area these bas-reliefs were observed for the first time in the 70's and investigations on the site began in 2012. But the archaeological work was abandoned and hidden when ISIS became active in the region in 2014. In 2018, during the archaeological expedition led by Prof. Morandi Bonaccorsi, in collaboration with the archaeologists of the Duhok Antiquites Directorate, they discovered ancient rock carving dating almost 3000 years [22].



(a) (b) (c)

Fig. 1. (a) Individuation of the archeological area of Maltai (satellite image). (b) Core and buffer zone of Maltai. (c) One of the panels of Assyrian carvings unearthed.

3.2 Methodology Workflow

The methodology of research is based on the analysis of VHR satellite images, which can provide useful data about the archaeological area located along the rocky slope of the mountain. The satellite images examined are those given by the Pléiades and World-View 2 satellites, which include both multispectral and panchromatic images. The satellite imagery has been acquired in two different time. World View 2 imagery have been collected in four color scales each for band (R, G, B and NIR) and the panchromatic image have been captured on 7th September 2014. Pleiades imagery have been surveyed four in multispectral images (R, G, B and NIR) and the panchromatic one has been acquired on 18th November 2014. For this purpose, it has been used several algorithms, already known by literature, reporting in this paper the best results obtained compared to ground truth, also shown by processed images, as shown below.

Panchromatic images provide only intensity information. To avoid difficulties in recognizing shadow and non-shadow zones, the algorithm adopted is the one presented by Liu et al. [4]. This operation consists of two phases. In the first phase the sampling operation is limited to shadow regions, while in the second phase the selected pixel values of the previous sampling are processed with the algorithms. After the sampling phase, the image normalization was carried out in the range [0, 1] by 255 (for 8-b quantization) and the optimal automatic Otsu threshold [20] was applied as no further investigation is required (Fig. 2, Fig. 3).

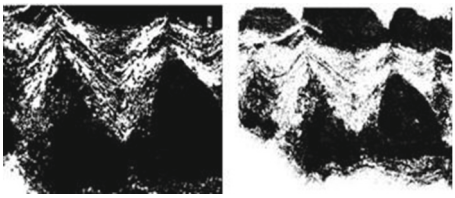
Multispectral images were first analyzed, adopting the same approach for both Pléiades and World-View2. Basing on the characteristics of VHR satellite imagery and using multispectral bands, shadow regions are distinguished from non-shadowed ones [23]. For multispectral images, the parameters of chromaticity (hue component) and luminance (intensity component) in the invariant color space were considered, as well as the reflectivity of the bands themselves to highlight the shadow zones. For these reasons, it has been started with the application of Mixed Property-Based Automatic Shadow (MSPI) [24]. The processed image will then have higher values in shadow pixels than in non-shadow ones and the vegetation cover in non-shadow areas, applying the optimal shadow index threshold recommended by Otsu [20]. The subsequent algorithms used are functions already implemented in Matlab (R2019b version), which include: hue-intensity-saturation (HSI) [25], hue-saturation-value (HSV) [26], hue chroma value (HCV) [27], Luma-in phase-quadrature (YIQ) [28], Luma Chroma Blue Chroma Red (YCbCr) [29]. The choice fell on them, as the de-shadowing approach [19] was adopted, which exploits the properties of shadows in luminance and chromaticity applied in different invariant color spaces. This operation consists of four phases: color transformation, shadow segmentation, shape preservation and shadow compensation. Results of these processes highlight the distinction between shadow and non-shadow regions (Fig. 4, Fig. 5).

The application of these models aims to divide the pixels of an image into categories based on spectral properties. The ground truth has been defined manually, identifying parts of shadow zone from non-shadow ones, that is a time consuming. The confusion matrix, obtained by comparing each pixel of the ground truth and the images generated by the de-shadowing operations, is used as objective evaluation of the accuracy of the shadow images and is based on values of different metrics [24].These metrics are: the

producer accuracy (PA), omitted error (EO), specificity (SP), error committed (EC), and overall accuracy (OA). They are calculated as follow:

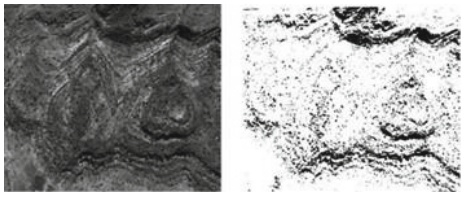
$$PA = \frac{TP}{(TP + FN)}; EO = \frac{FN}{(TP + FN)}; SP = \frac{TN}{(TN + FP)}; EC = \frac{FP}{(TN + FP)};$$
$$OA = \frac{TP + TN}{(TP + TN + FP + FN)}$$

they are based on the confusion matrix calculating pixel by pixel. Thus, it has been obtained a set of indexes (TP, TN, FP, FN) with the purpose to estimate the output of methods applied to satellite imagery of this case study.



(a) (b)

Fig. 2. Panchromatic Pléiades images. (a) The original image. (b) The de-shadowing result by Liu et al. (2011) [4]



(a) (b)

Fig. 3. Panchromatic World-View 2 images. (a) The original image. (b) The de-shadowing result by Liu et al. (2011) [4]

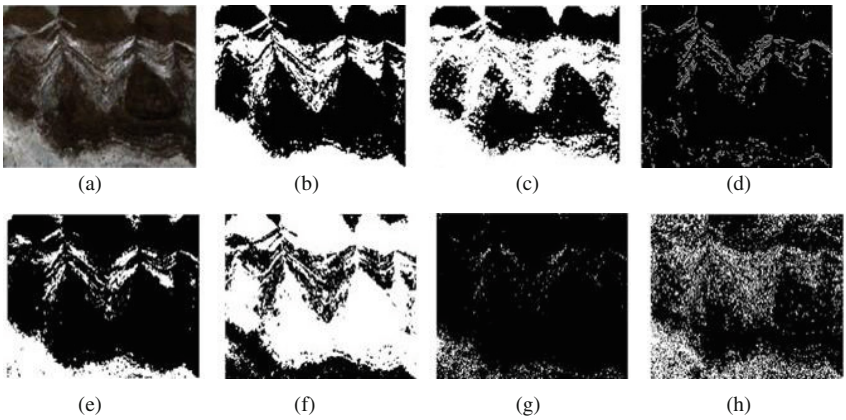


Fig. 4. Multispectral Pléiades test images. (a) The original image. (b) The reference shadow image. (c) Shadow image by MSPI based approach [24]. (d) Shadow image by HSI model [25]. (e) Shad-ow image by HSV model [26]. (f) Shadow image by HCV model [27]. (g) Shadow image by YIQ model [28]. (h) Shadow image by YCbCr model [29]

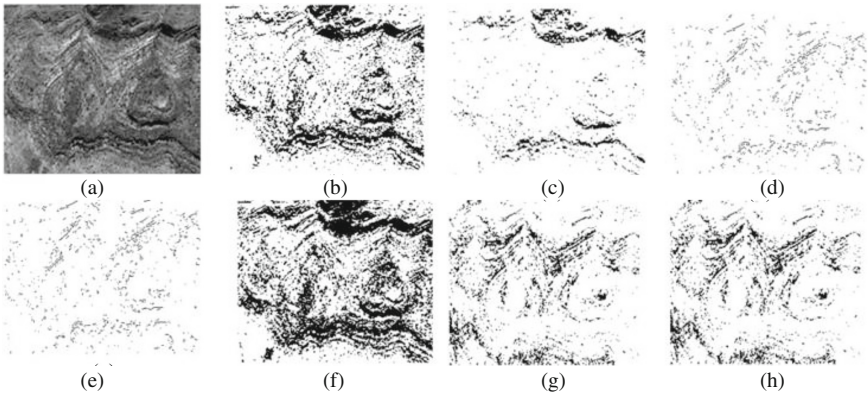


Fig. 5. Multispectral World-View 2 test images. (a) The original image. (b) The reference shadow image. (c) Shadow image by MSPI based approach [24]. (d) Shadow image by HSI model [25]. (e) Shadow image by HSV model [26]. (f) Shadow image by HCV model [27]. (g) Shadow image by YIQ model [28]. (h) Shadow image by YCbCr model [29]

4 Result Assessment

In the tables below, are listed the results of the workflow explained above, where the values of the evaluation metrics are reported. The accuracy data for shadow de-tection of the methods applied both to multispectral Plèiades images (Table 1) and for panchromatic ones (Table 2) is tested. Same operations for the results obtained on World View 2 multispectral (Table 3) and panchromatic (Table 4) images. The effectiveness of the various models for shadow detection has been evaluated. Among the methods applied to multispectral images, with pixel size 2.0 m, the optimal values of OA for HCV and PA

for MSPI have been obtained. But a better accuracy has been achieved with the method used for panchromatic models, with pixel size 0.5 m, both in terms of OA and PA. On the basis of these results, the algorithms are applied very well for high resolution images, recognizing small areas of shadow and avoiding distortions as geometrical distortion, thanks to the type of natural environment analyzed which is free of vegetation and ponds.

Table 1. Display of the accuracy data for shadow detection from test panchromatic Pleiàdes images (Fig. 2).

Method	PA (%)	SP (%)	EO (%)	EC (%)	OA (%)
Liu *et al.* (2011) [4]	99.09	0.91	64.12	35.88	82.46

Table 2. Display of the accuracy data for shadow detection from for test panchromatic World-View 2 images (Fig. 3)

Method	PA (%)	SP (%)	EO (%)	EC (%)	OA (%)
Liu *et al.* (2011) [4]	88.19	11.82	90.32	9.68	90.01

Table 3. Display of the accuracy data for shadow detection from test multispectral Pleiàdes images (Fig. 4)

Method	PA (%)	SP (%)	EO (%)	EC (%)	OA (%)
MSPI [23]	99.33	0.67	63.90	36.10	81.05
HSI [24]	84.13	15.87	78.09	21.91	83.95
HSV [25]	88.81	11.20	99.85	0.14	89.59
HCV [26]	97.20	2.79	96.41	3.58	96.94
YIQ [27]	82.89	17.11	97.56	2.43	83.01
YCbCr [28]	66.45	33.55	76.42	23.59	74.16

Table 4. Display of the accuracy data for shadow detection from shadow detection from test multispectral World-View 2 images (Fig. 5)

Method	PA (%)	SP (%)	EO (%)	EC (%)	OA (%)
MSPI [23]	98.41	1.59	83.96	16.03	84.93
HSI [24]	23.99	76.01	78.55	21.45	76.83
HSV [25]	23.86	76.10	78.55	21.45	76.89
HCV [26]	60.13	39.87	99.18	0.82	85.55
YIQ [27]	82.90	17.11	97.57	2.43	83.01
YCbCr [28]	0.00	100.00	78.13	21.87	76.87

5 Conclusion

In this paper, different approaches to shadow detection based on the properties of shadows (luminance, chromaticity and spectral reflectivity) have been applied to obtain a set of images separated from shadows. The proposed methods exploit the techniques of automatic thresholding and spectral ratio in the detection of shadow regions. For the objective evaluation, Pléiades and World-View 2 satellite imageries are used. Analyzing the results, best data were obtained from the World-View 2 images, where the geometric shape of the shadows and the surface area of the rock profile are better defined. The same cannot be said from the Pléiades ones, because the shadow zone is too wide and covers almost the entire site under study. The set of operations carries out false pixels deleting that are associated with non-shadow regions and allow users to have a greater understanding of the territory, seen from above. The basis of this study will serve to evaluate the advantages and disadvantages of the results in the use of de-shadowing algorithms. As future work, a geo-referenced database will be created, where all the information related to the rock finds of the Assyrians will be stored, integrating the data acquired during the different expeditions and surveys and ensuring their interchange between the several archaeological institutes.

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References

1. Malinverni, E., Pierdicca, R., Bozzi, C., Colosi, F., Orazi, R.: Analysis and Processing of nadir and stereo VHR pleiadés images for 3D mapping and planning the land of nineveh. Iraqi Kurdistan. Geosciences. **7**, 80 (2017). https://doi.org/10.3390/geosciences7030080
2. Tolt, G., Shimoni, M., Ahlberg, J.: A shadow detection method for remote sensing images using VHR hyperspectral and LIDAR data. In: International Geoscience and Remote Sensing Symposium (IGARSS), pp. 4423–4426 (2011). https://doi.org/10.1109/igarss.2011.6050213
3. Aplin, P.: Remote sensing: ecology. Prog. Phys. Geogr. **29**, 104–113 (2005)

4. Liu, J., Fang, T., Li, D.: Shadow detection in remotely sensed images based on self-adaptive feature selection. IEEE Trans. Geosci. Remote Sens. **49**, 5092–5103 (2011). https://doi.org/10.1109/TGRS.2011.2158221
5. Solano Correa, Y., Bovolo, F., Bruzzone, L.: An approach for unsupervised change detection in multitemporal VHR images acquired by different multispectral sensors. Remote Sens. (2018). https://doi.org/10.3390/rs10040533
6. Deilami, K., Hashim, M.: Very high resolution optical satellites for DEM generation: a review. Eur. J. Sci. Res. ISSN **49**, 542–554 (2011). ISSN 1450-216
7. Reiche, J., Verhoeven, R., Verbesselt, J., Hamunyela, E., Wielaard, N., Herold, M.: Characterizing tropical forest cover loss using dense sentinel-1 data and active fire alerts. Remote Sensing. **10**, 777 (2018). https://doi.org/10.3390/rs10050777
8. Shahtahmassebi, A., Yang, N., Wang, K., Moore, N., Shen, Z.: Review of shadow detection and de-shadowing methods in remote sensing. Chin. Geogra. Sci. **23**, 403–420 (2013). https://doi.org/10.1007/s11769-013-0613-x
9. Arellano, P.: Missing information in remote sensing: wave-let approach to detect and remove clouds and their shadows. Enshede, the Netherlands: International Institute Geo-Information. Science and Earth Observation (2003)
10. Malinverni, E.S., Fangi, G.: Comparative cluster analysis to localize emergencies in archaeology. J. Cult. Heritage **10**, e10–e19 (2009)
11. Parcak, S.H.: Satellite Remote Sensing for Archaeology. Routledge, London (2009)
12. Alexakis, D., Agapiou, A., Hadjimitsis, D., Sarris, A.: Remote sensing applications in archaeological research. Remote Sens.-Appl. 435–462 (2012)
13. Pavlidis, L.: High resolution satellite imagery for archaeological application (2005)
14. Casana, J., Laugier, E.J.: Satellite imagery-based monitoring of archaeological site damage in the Syrian civil war. PloS One **12**(11), e0188589 (2017)
15. Jin, X., Davis, C.H.: Automated building extraction from high resolution satellite imagery in urban areas using structural, contextual, and spectral information. EURASIP J. Appl. Sig. Process. **14**, 2196–2206 (2005)
16. Polodorio, A.M., Flores, F.C., Imai, N.N., Tommaselli, A.M.G., Franco, C.: Automatic shadow segmentation in aerial color images. In: Proceedings of XVI Brazilian Symposium on Computer Graphics and Image Processing, pp. 270–277 (2003)
17. Abraham, L., Sasikumar, M.: An efficient shadow detection method for high resolution satellite images. In: 2012 Third International Conference on Computing, Communication and Networking Technologies (ICCCNT 2012), pp. 1–5. IEEE (2012)
18. Zhang, H., Sun, K., Li, W.: Object-oriented shadow detection and removal from urban high-resolution remote sensing images. IEEE Trans. Geosci. Remote Sens. **52**(11), 6972–6982 (2014)
19. Tsai, V.: A comparative study on shadow compensation of color aerial images in invariant color models. IEEE Trans. Geosci. Remote Sens. **44**, 1661–1671 (2006). https://doi.org/10.1109/TGRS.2006.869980
20. Otsu, N.: A threshold selection method from gray level histograms. IEEE Trans. Syst. Man Cybern. **SMC-9**(1), 62–69 (1979)
21. Orlando, P., de Villa, B.: Remote sensing applications in archaeology. Archeol. Calcolatori **22**, 147–168 (2011)
22. Orazi, R.: The archaeological environmental park of sennacherib's irrigation network. Recording, Conservation and Management of the Cultural Heritage of the Northern Region of Iraqi Kurdistan. Italian Archaeological Mission to the Kurdistan Region of Iraq. Monographs 1, Forum, Udine (2019)
23. Kadhim, N.: Building assessment using shadow analysis for the architectural documentation. Int. Arch. Photogr. Remote Sens. Spat. Inf. Sci. (2019)

24. Han, H., et al.: A mixed property-based automatic shadow detection approach for VHR multispectral remote sensing images. Appl. Sci. **8**, 1883 (2018). https://doi.org/10.3390/app8101883
25. Pratt, W.K.: Digital Image Processing, 2nd edn. Wiley, New York (1991)
26. Smith, A.R.: Color gamut transform pairs. In: Proceedings of SIGRAPH, Atlanta, GAvol. 3, pp. 12–19. ACM (1978)
27. Smith, H.J.: Putting colors in order. Dr. Dobb's J. **1993**, 40 (1993)
28. Xiao, F., Miao, S., Guo, L.: Color image enhancement on YIQ color space. Appl. Mech. Mater. **631–632**, 478–481 (2014). https://doi.org/10.4028/www.scientific.net/AMM.631-632.478
29. Basilio, J., Torres, G., Sanchez-Perez, G., Medina, L., Perez-Meana, H.: Explicit image detection using YCbCr space color model as skin detection, pp. 123–128 (2011)