Spectral Image Analysis and Visualisation of the Khirbet Qeiyafa Ostracon

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Abstract. The article reports the research conducted to enhance the readability of Khirbet Qeiyafa ostracon using the spectral image analysis combined with image processing. The spectral imaging carried out in the visible and IR range facilitated the detection, improvement in readability of characters, and better interpretation of the history. Analysis of the spectral data using principal component analysis and independent component analysis showed better ink visibility and gave further support to archaeologists and historians. The proposed techniques resulted in an improvement compared to earlier interpretations.

Keywords: multispectral imaging, cultural heritage imaging, principal component analysis, independent component analysis, proto-Canaanite, paleo-Hebrew.

1 Introduction

Modern imaging technologies brought significant changes on archeology and cultural heritage sector. Multispectral imaging has emerged as a promising technology in recent times for documentation and analysis. [1][2][3]. Spectral imaging acquires both spatial and spectral information simultaneously from an object, covering a portion of the electromagnetic spectrum. Initially the technique has developed and matured in remote sensing. The potential application of spectral imaging in cultural heritage sector has several advantages. This noninvasive techniques has primarily been used to find underdrawings and for precise documentation. The combined advantages of spectroscopy and imaging also provide the opportunity for scientific investigation of the material characteristics which directly support the conservators and restorers. Spectral imaging has been researched substantially in archaeology and some of the notable investigations include imaging of Petra Scrolls [4], the Archimedes Palimpsest [5] and Dead Sea Scrolls [6].

Khirbet Qeiyafa is a small border fortress on the border between Judah and the Philistines [6]. The excavation is presented as a one period site with a short

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iron age window of about 40-50 years around 1000 BCE. The dating of the iron age village is based on analysis of the ceramics at the time of the transition between Iron I and Iron IIa [7] and on C14 dating of oil pits: 1051-969 BCE (77% probability) or 963-931 BCE (17,6% probability) [8]. The location gives three possible cultural associations for Khirbet Qeiyafa: 1) Philistine, 2) Judah and 3) Israel. In the early phase, some argued for a Philistine city; however, this position has little support at present. This is due to the particular building technique used with a case mate wall, a double ring wall with houses located between the two ring walls, and doors open to the inside. Secondly, there are one or possibly two six chamber gates. This is a particular building technique used by Israelites and Judeans in Iron IIa onwards [8]. In addition to urban planning, the site is identified by the absence of pig bone, the presence of typical Judean baking trays, the presence of typical Judean administrative system that marks the pottery, the presence of early Semitic and probably early Hebrew writing, Judean cult stands, a cultic standing stone, and the location on the border between Judah and the Phillistines overlooking the Elah valley, the traditional site of the battle between David and Goliath [8]. Finkenstein [9], places Khirbet Qeiyafa in the Gibeah polity often related to the dynasty of Saul, in between the Shiloh entity of the judges, which was destroyed about 1050 BCE and the later Israel polity with its capital in Samaria towards the end of the tenth century. Whether or not the site belonged to the polity of Saul, David or Salomon may probably not be decided on the basis of the archaeology, but would be depend on identification of written material.

The only inscription found at Khirbet Qeiyafa is an ostracon, a piece of pottery inscribed with ink in five lines, which has been identified as belonging to the Iron IIa period [6]. The ostracon was found during the 2008 season of the dig and secure decipherment of the text is still wanting. It is inscribed in an alphabet which may be described as somewhere between the proto-Canaanite alphabet and the paleo-Hebrew alphabet.

The following sections present the details of multispectral image acquisition of the Khirbet Qeiyafa ostracon and results of the analysis.

2 Spectral Image Acquisition of the Ostracon

Spectral imaging refers to the capture of images of specific wavebands of the spectral region, with each image recorded at a different wavelength form a complete spectrum for every pixel of the image. Multispectral images of the ostracon was captured using imaging technology from CRI Inc., [10]. The image set consist of 31 spectral bands from 400 to 950 nm with a nominal bandwidth of 20nm. Due to the slightly oval shape of the pottery piece, the imaging process was divided into six areas of the ostracon. Reference image data set using a standard reference target was also acquired along with the ostracon. All the six spectral images having spatial resolution of 1400 x 1000 pixels were calibrated using the reference data. Figure 1 shows the spectral cube formed from the ostracon multispectral image.

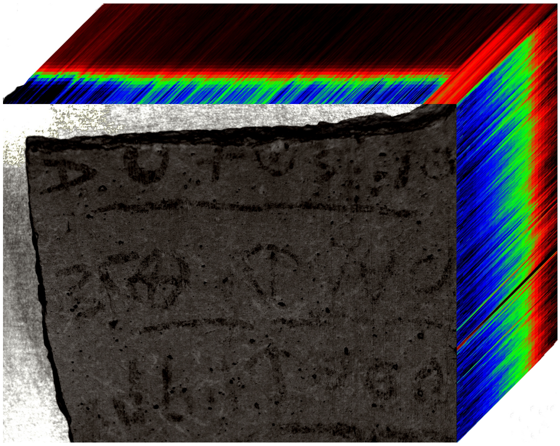

Fig. 1. Visualisation of the ostracon spectral image cube (Images courtesy of Dr. Greg Bearman and the Hebrew University Khirbet Qeiyafa expedition)

3 Analysis of the Ostracon Spectral Images

The inscription on the pottery is not well readable due to aging and enviornmental effects over the years. To make the inscription more readable a better contrast has to be obtained between the ink and background. In order to extract maximum information, various processing algorithms are applied over the multispectral images. Before performing any spectral analysis, each of the individual band images were used to identify the characters in the pottery. Since the ink has undergone different degree of degradation, there were many characters missing in this case and it was not easy to choose a band which carries most of the information. One of the advantage of infrared (IR) bands is that it enable the detection and sharper visualisation of the original material signature, in this case the ink, since it undergoes less scattering. We, therefore, employed different widely used methods for multispectral data analysis in order to improve the contrast and have a well defined image as a result. There are a variety of methods that are used in spectral image analysis to combine the information in different bands. Multivariate approches like principal component analysis and independent component analysis has proven to be efficient methods for feature extraction and visualisation in cultural heritage imaging [11].

Principal Component Analysis (PCA). is a well known mathematical transformation which is widely used for dimensionality reduction of spectral data [12]. In spectral imaging different band images obtained at distict wavelengths may be highly correlated and could be combined using PCA. This technique has been adopted in many signal processing algorithms for feature extraction. Using this tool, features in different bands can be combined and visualised.

Independent Component Analysis (ICA). is another transformation used for spectral classification in spectral image analysis. The ICA extracts the original signals from mixed spectral data without a priori information of the sources and the process of the mixture. In ICA, the data variables are assumed to be linear mixtures of some unknown latent variables, and the mixing also unknown. The latent variables are assumed nongaussian and mutually independent, and they are called the independent components of the observed data [13].

4 Results and Discussions

This paper discusses the multispectral analysis carried out on the first image out of six parts of the ostracon. One of the significant result from the proposed method is the improvement in clarity of the characters in the ostracon. In order to validate the accuracy of the detection, an archeologist who has background knowledge about this object and sites association with the different political entities in the area has performed the verification.

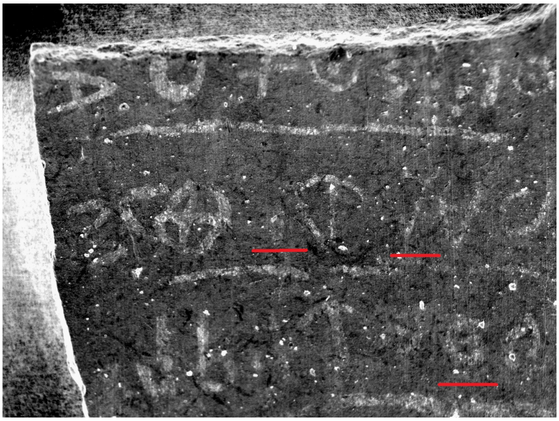

Fig. 2. First principal component of part 1 of the ostracon. Red lines shows the areas where characters identified after PCA (Images courtesy of Dr. Greg Bearman and the Hebrew University Khirbet Qeiyafa expedition).

Figure 2 shows the results of principal component analysis performed on the image cube. For better visualisation, first three PCA bands are combined and is shown in Figure 3. These images are used by the expert to detect the characters and its meaning. In a similar way first three ICA bands are combined and is shown in Figure 4.

Figure 5 is a version of the three letters in line one. We have drawn a 'qof', a line with a circular head which is in line with earlier drawings by Yardani. The following letter seems to be a 'Shin', a 'w' shaped letter tilted to the right 90 degrees. The end of each of the five lines are more profoundly visible than

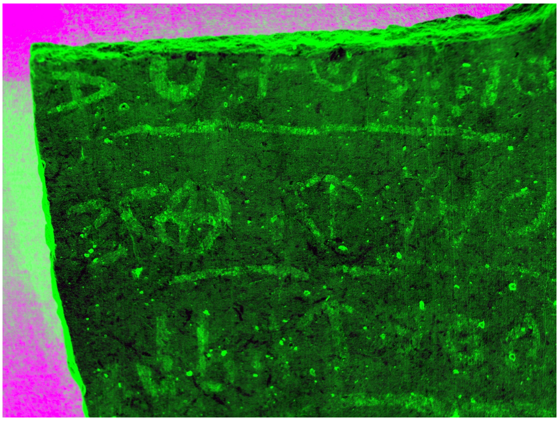

Fig. 3. False colour visualisation of first 3 principal components (Images courtesy of Dr. Greg Bearman and the Hebrew University Khirbet Qeiyafa expedition)

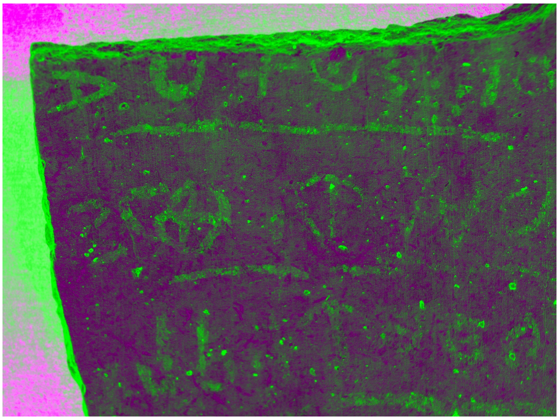

Fig. 4. False colour visualisation of first 3 ICA components (Images courtesy of Dr. Greg Bearman and the Hebrew University Khirbet Qeiyafa expedition)

Fig. 5. Drawings made based on mathematical transformations

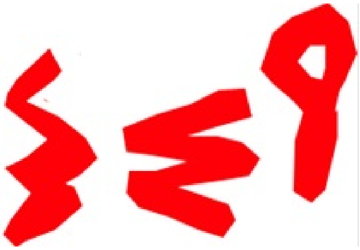

Fig. 6. Characters interpreted based on PCA & ICA

the line in between. The third letter was earlier drawn like a 'nun', but there is residue of ink above and below this letter suggesting that it might be a 'mem'.

The drawing in Figure 6 was made based on the processed images shown in Figure 3, and 4. Most of the drawing corresponds to earlier drawings and interpretations done by Yardeni [14] and Misgav [6]. One new character has been found at the end of line three looking like an 'X', probably representing the Hebrew letter tav τ. This letter lines well up with the left end of the previous lines. The most problematic part of this picture is the second, third and fourth letter from the right in line one, the two empty spaces in line two, and the first and fifth letter from the right in line three.

With this reading we get the name 'Iqesh', which is possible at the suggested time. A name would be a probable reading in the first line. In line two the two empty spaces is very difficult to identify even with improved processing of the picture. The first empty space in from the left might be a resh or a shin, but it might also be a void.

In line three we have identified one more letter compared to earlier drawings, a tav that looks like an 'x', at the left end of the line. The fifth letter from the right seems to be a samek (a vertical line, with three horizontal lines drawn across or at tav looking like a + sign). It is difficult to tell whether the upper part of the character is present or not. This allows the following reading of the upper left part of the ostracon:

Table 1. Interpreted meaning from the characters identified based on PCA & ICA results

Line 1	עקש מעת לא	... Ikesh for a time. Do not
Line 2	שג טבו אל	stray, do well, do not ...
Line 3	סלע בת קל ת	... Take the cliff house

The above interpretation in Table 1, is the first part of a full reconstruction of the ostracon reading. Line-1 from right to left, Line-2 from left to right and Line-3 from right to left.

5 Conclusion

Multispectral acquisition and analysis have found to be a one of the very useful tools to detect and visualise the osctracon writings beyond the possibilities of the conventional imaging. Some of the widely accepted data reduction mathematical transformations are applied on the image cube and visualised their usefulness. This methods gave better visibility and enabled the interpretations in a meaningful way than earlier used techniques. These techniques are limited to some extend by the lack of prior knowledge about the writings and physical damages in the ostracon.

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