The Integration of Aerial Sensing and Geophysical Techniques to Identify Buried Archaeological Properties in Sungai Batu, Bujang Valley

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Abstract. The paper investigates the different approaches in identifying the buried archaeological properties by using two different technology platforms which are aerial remote sensing and ground-based physical sensing; geophysical techniques. Aerial remote sensing has exhibited great potential for archaeological observation and detection, contrasting to geophysical measurement which it's synonymous with geological investigation in Malaysia. On the other hand, by integrating these two platforms, it shows a high potential response depending on the technique apply. Two different perspectives of technology are examined, namely SPOT multispectral remote sensing satellite imagery and geophysical prospection called electric resistivity. In order to determine co-relationships of two variables; several Vegetation Index (satellite datasets) has been correlated to the resistivity (ground-based values) through regression analysis to show the strong connection between variables. The overall outcomes demonstrated that the data fusion technique and regression analysis applied towards multiple sensing datasets is useful to improve the accuracy (estimation) and minimize the error probability in identifying the buried archaeological remains. This research then will be expanded further to explore the capabilities of geophysical technique with another potential platform in identifying the buried archaeological remain in the Malaysian context.

Keywords : Remote sensing; satellite imagery; Electrical Resistivity Tomography (ERT); archaeological; Vegetation Index; spectral correlation; Bujang Valley.

1. Introduction

Over the last years, the remote sensing and geophysical platform have benefited archaeologists and scholars in their archaeological investigations and research [1 - 3]. Satellite remote sensing datasets have been used to observe the changes of land cover and map the current land use of the areas with archeological interest, identify the location of buried archaeological remain based on vegetation characteristic analysis [4], to recognize the pathologies of the archaeological structure [5] or even to generate 3D Digital Terrain Model (DTM) generation and 3D city modeling with high-resolution imaging satellite sensor [6]. In the archaeological context, various remote sensing sensors have been used to identify or investigated archeological remains. In general, buried archaeological remains have a different response to the backscattering signal captured by the sensing sensors. For example, both satellite images and ground spectral signature have the capability to record the vegetation status over the archaeological landscape and therefore sense any vegetation-stressed conditions. This vegetation stress was called a crop marks phenomenon [7].

Significantly, remote sensing dataset such as multispectral SPOT-6 or SPOT-7 imageries were found to be effective to distinguish the crop marks [8], crop stress [9]; or vegetation detection in agriculture [10] through vegetation index (VI) maps application; particularly in Normalised Difference Vegetation Index (NDVI) technique. For example, studied by [11] demonstrated that the SPOT-5 image dataset has contributed to the early investigation of the Greater Angkor Project in Cambodia to identified and analyzed paleo-environmental trace and anthropogenic features in ancient Angkor sites before the reconnaissance in remote sensing satellite platforms in the 2000s. More studies by Giuliani et al., 2017 [12], have discussed the potential impact of these platforms within archaeological remote sensing, particularly in the context of heritage monitoring and management applications. It is because the SPOT-6 and SPOT-7 satellite dataset is able to collect information at a higher spatial resolution at 1.5m with its panchromatic instrument, 6m with its multispectral instruments and 1.5m with color merge (pan-sharpening process) [13].

On the contrary, the geophysical technique is about subsurface survey structures used to characterize subsurface ground conditions in 3D visualization [14] by using various methods measurement such as electrical resistivity, Ground Penetrating Radar [8], resistivity magnetic [15] and many [16 - 17]. Basically, ground resistivity is related to identify various geological parameters. For example, mineral and fluid content [18], degree of water [14] or even the soil erosion analysis [19].

However, the integration of various remote sensing datasets and ground geophysical prospection becoming useful in state-of-the-art surveys and fields of research beyond geophysics and geology including geotechnical engineering and archaeology. In the archaeological context, it contributes to the investigation or even mapping over the area of archaeological interest. [20] demonstrated the combine techniques of the geophysical technique; electrical resistivity tomography (ERT) and NDVI analysis derived from the Lidar images to measure the subsoil characteristic and factors which contributed to the soil erosion in the Middle Neosho Watershed, southeastern Kansas. In the authors' opinion, the methodology and analysis approach can equally be applied to identify the archaeological crop marks based on the area of soil erosion identification and analyses.

Others have applied multi-disciplinary study in the area of South Andaman Island, India. Garzelli, 2015 [21] has exploited the satellite remote sensing and two types of geophysical techniques; ground-penetrating radar and resistivity to identify the ground water-bearing zone in the Ophiolitic complex. The satellite remote sensing dataset had a functional in aerial image analysis, while, the geophysical outcome provided the horizontal and elevation profile images which show the hydrological setting and fractured zone of the groundwater system overall.

Moreover, both geophysical methods are a non-invasive technique and becoming one of the best practices to identify the underground anomalies or hidden structures not only in geological discipline also suitable in archaeological investigation. Therefore, the same integration of the techniques approaches has been adopted in this study and brings a new perspective of archaeological identification, especially in Malaysia context by experimenting with the integration of multispectral remote sensing dataset and geophysical prospection; electrical resistivity over Sungai Batu. Then, the result will be evaluated base on the correlation result between electrical resistivity spectral data and the several Vegetation Indices algorithms.

2. The Study Area

The Bujang Valley is located in Sungai Petani, South Kedah and drained by the main rivers which are Sungai Merbok and Sungai Muda. Their tributaries, notably Sungai Batu and Sungai Bujang [23]. Bujang Valley civilization has begun as earlier as 4th century CE (Common Era) and established as an international maritime and trading in the iron industry from the 1st century between China, India and Arab [23]. In this study, the data covering an area of SB2 at latitude 5°41'52.76"N and longitude 100°27'8.73"E within Sungai Batu. Figure 1 shows the location of the interest respectively. Geomorphologically, this area surrounded by oil palm plantation and rubber trees with almost flat earth surfaces. Sungai Batu area is mostly composed of sandy clay covered by the fine sand [22].

(a) (b)

Figure 1. (a) The archaeological area of Sungai Batu obtained from the Multispectral SPOT-7 data satellite image in 2017 (MalaysiaAgencyRemoteSensing., 2019). (b) Elevation profile in the specific study area of Sungai Batu (GoogleEarthPro., Feb2020)

3. Material and Methods

3.1 Materials

In this study, the SPOT-7 satellite image acquired in May 2017 is used. SPOT-7 satellite has one panchromatic (Pan) band with 1.5m spatial resolution and four multispectral (MS) bands; Red (0.625 µm – 0.695 µm), Green (0.530 µm – 0.590 µm), Blue (0.455 µm – 0.525 µm) and Near-Infrared (0.760 µm – 0.890 µm) with 6.0m spatial resolution [24]. Some pre-processing steps are employed to the multispectral and panchromatic images such as a pan-sharpening method using ArcGIS software to enhance the spectral resolution of the image in terms of their sharpness and spectral quality dataset for further image processing and analysis. Additionally, the electrical resistivity data obtained in 2017 from the Department of Geology, the University of Science Malaysia to support the experimental for the preliminary study. Table 1 summarizes some of the characteristics of the two platforms; aerial and ground, used in this study; (i) SPOT multispectral dataset and (ii) electrical resistivity. The table provides the advantages, limitations and basic attributes of both methods.

Table 1. The characteristic of satellite remote sensing and geophysical methods in identifying the buried archaeological remains in Sungai Batu, Bujang Valley.

Characteristic	**Satellite Remote Sensing**	**Geophysical**
Medium	SPOT-7	Electrical Resistivity
Year	2017	2017
Spatial Resolution	High Visual Resolution 1.5km	High-Very High
Spectral range	Multispectral (Visible – Near Infrared)	Electric wave

Spatial Extend	Several km^2 (Elevation)	Several Hectares (vertical)
3D visualization	Not Available	Available
Soil Penetration	Not Available	Available
Type information	Raster	Point

3.2 Methods

The primary objective of this preliminary study is to establish a co-relationship between aerial remote sensing; SPOT-7 with high visual resolution and geophysical technique in identifying the archaeological properties in Sungai Batu, Bujang Valley. In detail, two processing steps have been employed consist of; (i) image classification (satellite image dataset) and (ii) correlation analysis. Using multispectral sensors, the accuracy of detecting classes area such as invasive plants, the result using image classification methods thus improve. In this study, the image divided into three classes; (a) high dense vegetation (b) medium dense vegetation (c) low dense vegetation area. Further, the result will be interpreted and analyzed. Secondly, the collected data from electrical resistivity and multispectral were analyzed using the Pearson correlation coefficient ***-r*** method to determine the association of two variables. Two variables applied; resistivity values as the independent X variable and Vegetation Indices (algorithm) values as the independent Y variable. The Linear regression model has been selected and evaluated because of its ability to perform superior results compared to the other types of regression models (mathematical models) such as Exponential, Fourier, Gaussian, Polynomial, Power, Rational or Sum of Sin [8]. The methodology applied described in Figure 2.

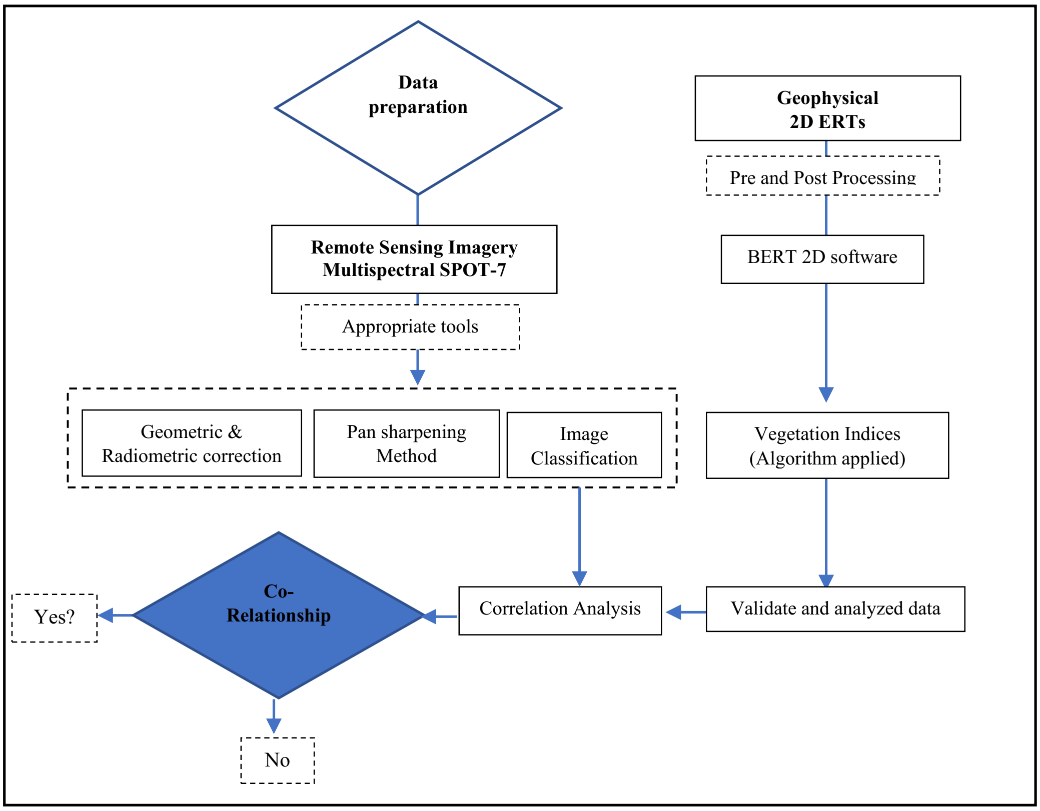


Figure 2. The overall proposed methodology for the integration of multispectral SPOT satellite images and Two Dimensional (2D) ERTs data in identifying buried archaeological properties in Sungai Batu, Bujang Valley.

3.2.1 NDVI classification

Buried archaeology remains to affect vegetation growth and it can be best understood by applied Vegetation Indices such as NDVI [25 - 26]. This method is one of the practices to detect subsurface features by using color classes and images enhancement and was found to be effective for distinguishing crop marks [27]. NDVI compares the reflectivity of near infra-red and red wavelength bands and was calculated from the following equation (1). Measuring green vegetation through normalized ratio is ranging from -1 to +1 [8]. On the other hand, healthy green vegetation has a stronger near-infrared reflectance thereby close to +1 in NDVI values [28]. Particularly, vegetation has the property to reflect more in the near-infrared (NIR) band, however, it absorbs more in the red (R) band. Thus, it provides useful information regarding the vegetation's health (growth), detecting changes in the soil and the data can then be used to identify hidden archaeological features in the soil. This method has the advantages of emphasis on the differences of features and reduces the impact of topography effects and illumination through spectral responses [29].

$$\mathbf{NDVI = \{(NIR - RED) / (NIR + RED)\}} \quad (1)$$

3.2.2 Electrical resistivity

Two Dimensional electrical resistivity tomography (2D-ERT) surveys were conducted in the apart of the study area in Sungai Batu by using the ABEM SAS4000 system and the survey applied Pole-dipole array method. The raw data was processed and analyzed using BERT 2D software.

3.2.3 Correlation analysis

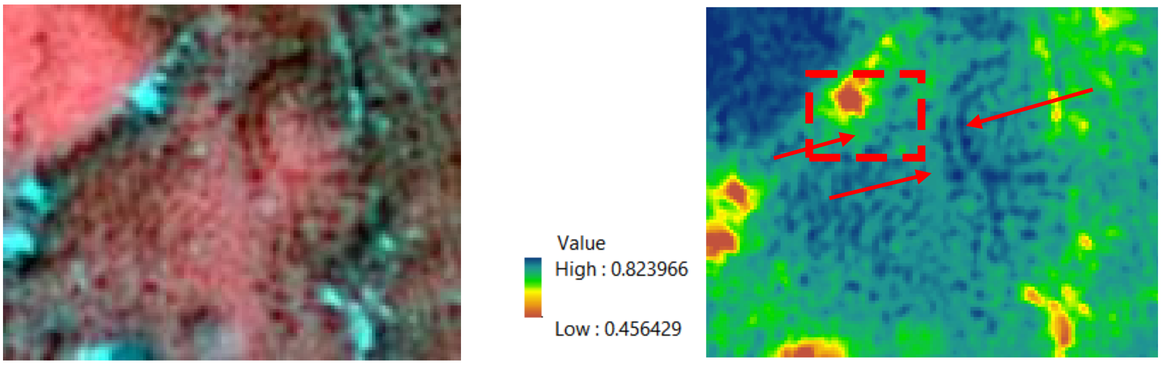
Besides, in order to determine the co-relationships of this technique, all data from existing ground resistivity [30 - 33, 22] is correlated with several Vegetation Indices and specific wavelengths (spectral signature). The Pearson correlation coefficient known as ***r*** is used to measure the strength of the linear relationship between two variables [8]. The calculation was performed with the correlation parameter as shown in equation 1.

$$\boldsymbol{r} = \frac{\boldsymbol{\Sigma(x-\bar{x})-(y-\bar{y})}}{\sqrt{\boldsymbol{\Sigma(x-\bar{x})^2\Sigma(y-\bar{y})^2}}} \quad (2)$$

4. Results and Discussion

4.1 NDVI image analysis

The NDVI images were derived and classified to produce vegetation maps using ERDAS Image 2020 software. In Figure 3b, the classification image (based on the NDVI image) represented the areas with high dense vegetation that are blue color meanwhile the areas covered with the green and yellow color defined a medium dense vegetation area. Finally, the areas covered with red color shows the area is low dense vegetation areas. Meanwhile, the values of NDVI in the study area is between 0.456 to 0.824. Red dotted shows the location of resistivity measurement has been done by the Department of Geology, USM, and Centre of Global Archaeology Research, USM in 2017. Meanwhile, it is assumed that the study area is near to the small stream based on the elevation profile in Figure 1 (see also arrows in Figure 3b). From this image interpretation, next, it will be compared to the result of the 2D ERTs inversion model images in Figure 4.

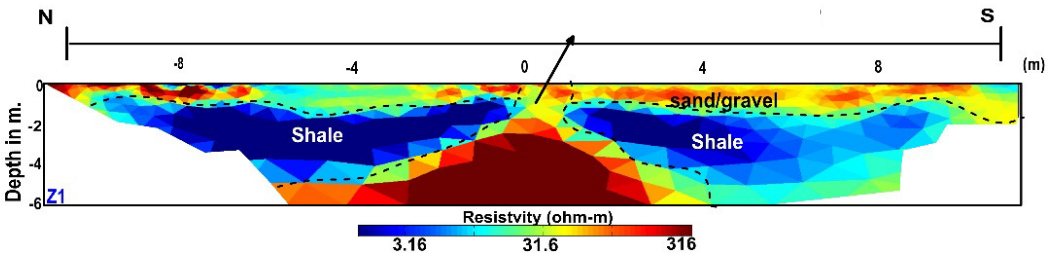


(a) (b)

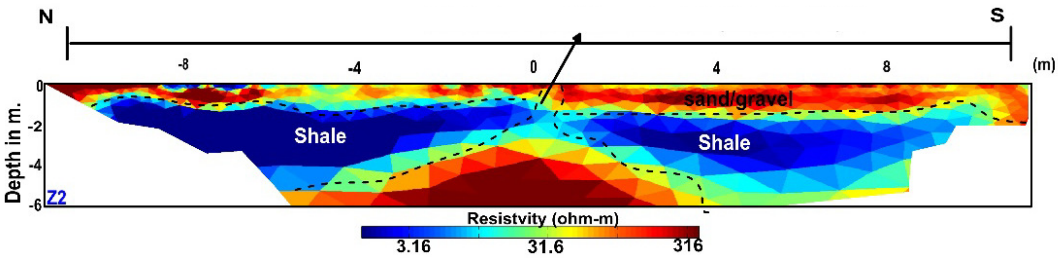
Figure 3. (a) The image (subset) of the study area after through image filtering using the Erdas Image 2020 software. (b) The classification image in each color defined the classes' areas. A red dotted square shows where the location of resistivity measurement has been done (Department of Geology, USM, 2017). It is predicted that the shape of the curve (see arrows) is a small stream or river based on the elevation profile in Figure 1.

4.2 2D Resistivity analysis

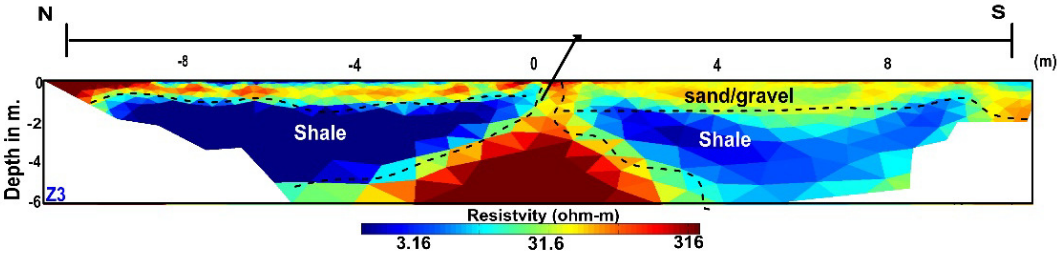
Eight lines of electrical resistivity have been analyzed using BERT 2D software. Figure 4 shows the selected resistivity inversion model images of Line 1 to Line 3 with a maximum penetration depth of 6m and resistivity value range from 3.16 – 316 Ω.m. In general, the subsurface resistivity distributions can be classified into two parts which values range between 3.16 - 31.6 ohm.m represented as the original ground while values range between 31.6 – 316 Ω.m interpreted as dry or low conductance. In the middle section, between range 3.16 to 316 Ω.m represented as saturated soil; including clay and sandy clay.



(a)



(b)



(c)

Figure 4. 2D inversion model using BERT analysis software; (a) Line 1 (b) Line 2 and (c) Line 3.

According to the result of the inversion model L1-L3, it is obviously seeming there is a potential buried archaeological feature with a shallow linear anomaly appear. It's consists of two parallel features about 10 m apart within the middle part of the inverted profiles. The potential of archaeological anomaly starting at depth up to 1 meter to 6 meter and resistivity value range of <17.38 Ω.m. In general, the low resistivity values can be related to clay sediments, but the high resistivity values can be related to a shallow feature depends on the local geological or archaeological conditions. However, in this case, the linear features can be described as a shale with a resistivity value of <17.38 Ω.m which can be potentially become an ancient river due to the geographical location which near to the small abandon stream and the location of archeological sites of Sungai Batu (SB2 site). Please refer to Figure 1 and Figure 3.

Finally, statistical analysis has been applied based on the previous result. The correlation coefficient (R^2) was performed in order to evaluate the different correlations between resistivity data and several indices (Vegetation Index) with a specific spectral wavelength of NIR ~ 0.800µm and Red ~0.700 µm and as shown in Table 2. Two separate types of resistivity data were selected; consist of the resistivity result of an ancient river and buried remain. The overall outcome demonstrated that the Simple Ratio and Modified Simple Ratio is more sensitive (positive and negative result) compared to other low correlations such as Reverse Simple Ratio.

Table 2. The result of the correlation coefficient (R) with a range of -1 for each vegetation index and for each type of resistivity data for the ancient river and buried properties. A higher correlation (either negative or positive) is highlighted with grey and blue in the table.

Vegetation Index	RAR	RBP
NDVI	0.47	0.56
SR	0.48	0.67
MSR	-0.54	-0.53
DVI	0.45	0.55
rSR	-0.4	-0.5

Abbreviation; NDVI=Normalised Difference Vegetation Indices, SR=Simple Ratio, MSR=Modified Simple Ratio, DVI=Difference Vegetation Index, rSR=Reverse Simple Ratio, RAR=Existing result of Resistivity; Ancient River, RBR= Existing result of Resistivity; Buried Properties

Relative strong +ve correlation

Relative strong -ve correlation

This preliminary study tested the application of remote sensing technique and 2D-ERTs data measurement (Department of Geology, Universiti Sains Malaysia in 2017) in order to determine the integration of both platforms to identify buried archaeological properties in the specific area of Sungai Batu. Therefore, the SPOT-7 satellite data image obtain in 2017 was analyzed to identify the vegetation status on the top of the surface, while on the other hand resistivity results in 2017 indicate the underground profile and the surrounding soil. The result demonstrates the difficulties in achieving high correlation especially between all vegetation indices algorithm and resistivity for the ancient river (see Table 2). In contrast, Simple Ratio and Modified Simple Ratio show a high negative and positive correlation (r=0.67, r=-0.54) in identifying buried archaeological properties. The challenges are each method in this study applied a different technology platform and there is challenging in terms of the fusion and integration of data due to the different sensors. In order to improve the accuracy of the result, further study will be conducted on the same date and time. This is to minimize the resulting error due to different or changing climatic or other environmental factors such as soil moisture and temperature.

5. Conclusion
This paper discussed an approach of integration technique between aerial remote sensing and geophysical technique to improve in identifying the buried archaeological properties in Sungai Batu, Kedah, Malaysia. The overall methodologies, SPOT-7 satellite dataset, and 2D-ERTs data measurement have been used to determine the co-relationship by using Pearson correlation coefficient analysis. The accuracy of the result can be further improved with the second fieldwork in the same data to minimize the error due to the environmental factors.

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