Testing and Analysis of Geostatistical Characterization Techniques using Full-Coverage Magnetometer Data Sets

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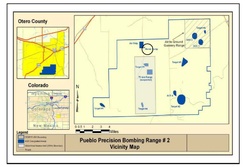
Introduction

The identification of probable target areas at former artillery and bombing ranges is difficult due to lack of historical documentation. Range characterization using 100% geophysical surveys are too costly and inefficient considering the large size of these ranges. To address this problem, geostatistical based techniques were developed to identify likely target area locations based on limited geophysical transect data. Presented here are results of testing of the geostatistical estimates against comprehensive field data.

Pueblo Bombing Range

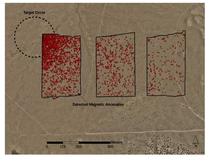


The study area for these analyses covers a portion of the Pueblo Precision Bombing Range (PPBR) located in south-eastern Colorado. The PPBR was used for aerial bombing practice from 1942 to 1946. The study area (circled location) for the work presented here is a subset of a larger Wide Area Assessment study site. The study area considered here is directly adjacent to a circular target feature identified in imagery of the site.

Data Sets

Two separate data sets were used in the analysis. The first consists of 2 meter wide magnetometer surveys collected along pre-planed transects spaced at approximately 155 meter intervals. These were the data used in the geostatistical estimation. The second set of data were comprehensive (full coverage) magnetometer surveys of specific plot locations. These were typically 300x500 meter rectangular plots which were fully surveyed using the same magnetometer system as used for the transect surveys. Three of these full coverage plots were available for the study areas considered here. These data represented the known information used in testing the geostatistical estimates.

The magnetic anomalies identified within the survey transects (red dots) were spatially averaged to provide representative information, and then used to produce Ordinary Kriging estimates of per-area anomaly densities for a grid of points covering the area of interest.



The magnetic anomalies identified within the full coverage survey were spatially averaged using a quadratic kernel function to provide per-area anomaly densities for a grid of points covering each survey plot. This provided the known data used in testing the kriging estimates.

Geostatistical Analysis

Kriging Estimator

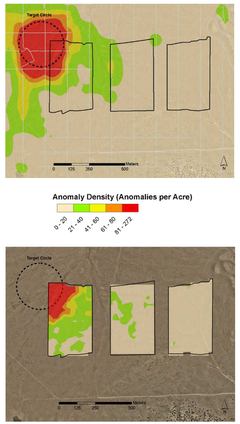
The kriging equation estimates the value at an unsampled location by using a weighted average of the sample values around the unsampled location. The weighting of each sample point depends on the distance from the estimate location, and on the shape of the autocorrelation model (semivariogram) adopted for that data set

$$z^*(\mathbf{u}) = \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u}) z(\mathbf{u}_\alpha)$$

Where $\lambda_\alpha(\mathbf{u})$ is the computed weight assigned to sampled point $z(\mathbf{u}_\alpha)$ based on the spatial correlation model developed in the variogram analysis.

Kriging Results

Ordinary kriging is used to estimate the spatially varying anomaly density within a lattice of 25x25 meter grid cells covering the site. These were developed using the sample transect data collected at the site as conditioning data. The transects were 2 meters in width with a spacing of 155 meters. The sampled area (transects) represented less than 2% of the total study site.



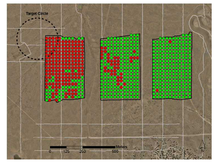
This plot shows the kriging estimates of anomaly density developed from the magnetometer transect data. The transect locations are shown as light-gray lines and represent < 2% of the total study area. The sampling plots for the full coverage magnetometer surveys are shown as the solid black outlines. The target circle identified via imagery is shown by the dashed outline.

This plot shows the known anomaly density values from the full coverage magnetometer data. The sampling plots for the full coverage surveys are shown as the solid black outlines. The target circle identified via imagery is shown by the dashed outline.

Evaluation of Kriging Estimates

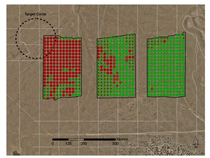
Single Threshold Results

To evaluate the target area delineation performance of the kriging anomaly density estimate, an evaluation target threshold was established for the known anomaly density values. Locations with density values above the threshold were considered within the target boundary; locations with values at or below the threshold were considered outside of the boundary

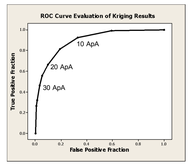


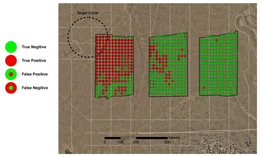
This plot shows a binary color display of the known anomaly density values measured in 3 separate sampling plots. A threshold of 20 Anomalies per Acre (ApA) was then applied to the measured density data. Locations with anomaly density above the threshold (target) are shown in red. Locations with anomaly density at or below the threshold (non-target) are shown in green. This establishes a baseline to use in testing the kriging estimates.

The ROC curve shows how well the kriging model identified the target locations specified by applying the threshold to the known field data. The ROC curve was developed by applying multiple threshold values to the kriging estimate and then comparing the identified target cells against those determined from the field data. It shows the fraction of true positive identifications and false positive identifications when different threshold levels are applied to the kriging anomaly density estimate. The plots below show the spatial distribution of 3 of the testing levels displayed on the ROC curve.

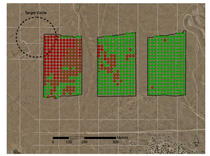


10 ApA Test Level – Accuracy = 75%
Near background density levels





20 ApA Test Level – Accuracy = 83%
At target definition density level



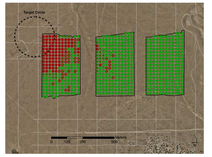
30 ApA Test Level – Accuracy = 81%
10 ApA above definition density level

Evaluation of Kriging Estimates

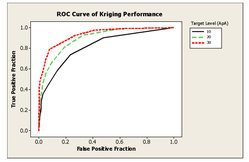
Results with Differing Thresholds

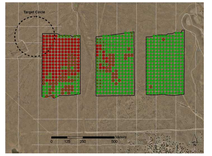
The figure below shows ROC curves developed using 3 different target definition thresholds (10, 20, and 30 ApA). The ROC curves show that the kriging anomaly density estimates provide a strong target identification tool across a range of target threshold values.

The ROC curves shown below represent the kriging model's ability to identify targets at different anomaly density levels. The red, green, and black curves represent target *definition* thresholds of 30, 20, and 10 anomalies per acre. The accompanying maps show the spatial distribution of the target cells identified in the known data and those identified in the kriging estimate for each of the 3 different target definition threshold values. Background values of anomaly density for this area range between 10 and 20 ApA.

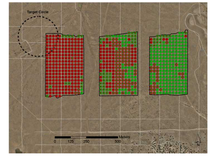


30 ApA Definition/Test Level – Accuracy = 90%





20 ApA Definition/Test Level – Accuracy = 83%



10 ApA Definition/Test Level – Accuracy = 75%

Summary

Comparison between estimated and known anomaly densities for a former bombing range has confirmed that reliable anomaly density estimates can be developed from sparse magnetometer transects using the geostatistical techniques presented here. ROC curve analysis shows these techniques to be an effective and robust tool for identifying target area locations based on anomaly density thresholds. The application of these techniques using limited transect survey data, can provide significant cost savings in the characterization and identification of target areas at former bombing and artillery ranges.

http://www.sandia.gov/geostats