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COMPUTER ANOMALY RECOGNITION AND CLASSIFICATION

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ABSTRACT

A study has been made of computer methods of anomaly recognition and classification, suitable for application in multichannel airborne electromagnetic methods. Synthetic and real data from the Barringer INPUT System have been used in all experiments. A variety of processing methods, including multichannel Fourier filtering, have been tried with varying success. The best procedure found so far involves the following steps. First, the profiles are scanned to find local maxima, which may indicate an anomaly. Then the width and area of these tentative anomalies are estimated and unimportant peaks discarded. This process can be done on each channel separately, or on a summation profile, where each point is a weighted sum of the corresponding points on the six channels. The decay rate of anomaly amplitude from channel 1 to 6 is next determined by fitting an exponential to the six values. The ratio, sum of the six traces divided by the decay rate, seems to be a good indication of the conductor quality and importance. Theoretically, the dependence of the INPUT data on flight altitude depends on anomaly decay rate, and therefore one can only introduce flight height correction to the anomaly amplitude at this point. However, it might be more convenient to introduce a constant third power correction as the first step of the described process. As a final step all parameters are employed in the correlation of several neighboring profiles.
1. **INTRODUCTION**

Airborne electromagnetic measurements are constantly becoming more complicated. Each newly developed system measures more and more quantities. Thus, looking to the future, one may forecast a situation where the interpreter is going to be overwhelmed with data, all of which contains potentially useful information. In seismic work, this situation arose quite a few years ago and has been met by computer processing. Perhaps we shall follow the same route. Thus it seems to us worthwhile to begin exploring the possibilities of computer analysis of EM data now, even though present day systems may not really require such an approach.

As a starting point to the investigation a present day multichannel air EM system, the Barringer INPUT (Ward, 1967), was chosen. The aim was to devise a computational algorithm which would replace much of the visual and manual interpretation done by medium qualified personnel. The discussion which follows indicates the progress made to date. We have certainly not yet arrived at a fully satisfactory algorithm, but we are encouraged enough by the present results to think that it is indeed possible. Initially, a promising way to tackle the problem seemed to be the Wiener optimum least squares filtering. It should enhance the particular features in which we are interested and suppress
the others. Unfortunately, after many tests the results did not fulfill the expectations. Also, the relatively high computer cost seemed prohibiting. For that reason, we began working from a different basis and tried to devise a procedure which would simulate what is done by an interpreter. A similar approach, non-linear filtering based on anomaly width, has been used by H. Naudy and H. Dreyer (1968) for the interpretation of aeromagnetic profiles.

In an airborne survey with INPUT system several instrument outputs are recorded: INPUT with gates centered at times 0.3, 0.5, 0.7, 1.1, 1.5, 1.9 msec. for channels 1 to 6, radio altimeter, magnetometer, gamma ray spectrometer with four channels (total, thorium, uranium and potassium counts). In our study only the six EM channels and altimeter were considered. Two examples of actual INPUT surveys from the Canadian Precambrian Shield are shown in Figures 1 and 2. The original records, where the peaks face downwards, were digitized with rate 33 points per mile and replotted by CALCOMP. In future, the analogue registration may be replaced or supplemented by a digital one and then computer processing will become a necessity. The examples show 3 mile long sections from two different areas. In visual interpretation, the interpreter is looking for peaks; he estimates how broad and intensive they are and how they change from channel to channel. In our approach, we proceed in similar steps.
Fig. 1 Barringer INPUT record replotted by CALCOMP. The amplitudes and distances are in arbitrary units. Anomalies recognized are indicated by arrows.

Fig. 2 Example of Barringer INPUT survey from the Canadian Precambrian Shield. Legend as in Fig. 1.
2. PEAK RECOGNITION

In the first step, a given profile is searched for local maxima which may be peaks of anomalies. We can look for peaks on all 6 channels and if they are present on several of them the anomaly will be further investigated. This is the case in traditional interpretation, where anomalies are distinguished according to the number of channels on which recognizable maxima are present. We found that the peak recognition can be done with advantage on a sum of 6 traces, possibly with different weights given to each channel. The weighted and unweighted summation profiles are compared in Figures 3 and 4 for the records shown in Figures 1 and 2. The resolution on the weighted sum is slightly better. By weighting the higher number channels more heavily, the slowly decaying anomalies which are important for exploration will be more emphasized than those due to overburden or man-made disturbances. The random noise will be substantially reduced.

The peak recognition is done by comparing the amplitudes at each point of the profile with that at its four neighbouring points. Also anomalies hidden in the slope can be recognized by using the relative amplitude above chords instead of the absolute amplitudes.
Fig. 3  Summation of six channels of the record shown in Fig. 1. Recognized anomalies are indicated by arrows.

Top: Weighting factors for each of the six channels are listed in the table.

Bottom: Equal weighting of the channels.
Fig. 4 Summation traces for the record shown in Fig. 2.
3. **ANOMALY WIDTH ESTIMATION**

Besides the location of the anomaly, its intensity and shape are important for correlation between profiles. In our approach three parameters, the amplitude, width and excess area of an anomaly are determined in this step. The stages of the width estimation are shown in Figure 5. At each point of the profile where a peak has been found a chord five points long is taken. So as to take possible asymmetry into account, the amplitude difference between the left and right side is kept within a preset range. This can be achieved in an additional iteration process, where the length of the higher amplitude side is increased.

In the first stage, the excess area $A_2$ above the chord is computed. Then the chord length is increased by two or more points, depending on symmetry, and a similar area $A_3$ computed. Comparing the two areas $A_3$ and $A_2$, the ratio $R_3 = A_3/A_2$ is obtained. If this process is repeated successively for increasing chord length, then $R_k$ approaches 1 when the chord nears the background level. Thus the width and area of the anomaly can be determined by stopping the process at some critical value of $R_k$. In the case of larger anomalies $R_k$ will be closer to one for the same difference in areas. Therefore, an area dependent gate $P_k$ was used. In Figure 5, the criterion
R_k < P_k is satisfied for k=8 and the iteration process terminated at this level. Area parameters A_k can be used to discard the low amplitude anomalies by comparing them with a suitably chosen constant value.

An example of the analysis of a summation profile is in Fig. 6. The area A_k is hatched, and the position, estimated width and area A_k of found anomalies are marked.

4. DECAY RATE DETERMINATION

Another quantity useful for interpretation is the decay rate. The exponential fit seems to be the best, though the function \( x^{-a} \), a being a rational number in the range 0 to 5 gives better results in some instances. The decay rate is estimated at each point on the profile using the sampled amplitudes of the six channels. The exponential is fitted in the least squares sense on the linear scale. If we would attempt to fit a straight line on the logarithmic scale, which would seem to be advantageous, the small differences on higher channels, mostly due to noise, would be overemphasized. Also, the repeated taking of logarithms is costly in computer time. Sometimes, there are problems in estimating the decay rate immediately. In practice, the zero levels of the six channels are not always set properly and additional level shifting may
Fig. 5  Principle of anomaly width estimation. At point
j=24 a peak has been discovered. Area $A_k$ and width
$W$ are computed for a chord 5 points long (first stage).
Then the chord length is increased by two points in
an iteration process until $(A_k/A_{k+1}) < P_k$. This was
achieved for $k=8$, in the seventh stage.
Fig. 6 Example of peak recognition and width estimation. Area $A_K$ is hatched.

Position, width $W$, and area $A_K$ are indicated.
be desirable. The optimum shift can be found by an iteration process, in which the mean square error in fits for the exponentials is calculated and minimized by trial and error adjustment of the base lines. In Figure 7, we show some examples of exponentials fitted to the sampled amplitudes. The original record was shown in Figure 2 (profile 41). Only anomaly peaks are shown in the figure, although the process is applied to all data points.

The decay constant $D$ is shown in Figure 8 for all points of the profile. Significant background noise, which is uncorrelated on six channels, caused wide scatter in $D$, nevertheless much higher decay rates at the right edge indicate an overburden anomaly. Also the unweighted sum of six channels is shown for comparison.

Another interesting result was obtained by dividing the sum of six channels by the decay rate (Fig. 9). The important anomalies with low decay rates are most enhanced and those due to overburden are suppressed. A fast decaying anomaly at point 69 seems to be unimportant now, while another at 46, barely visible on the original record, becomes more evident.

The same procedure was applied to the first set of data which has a lower noise level. The original record is plotted in Figure 1. Six anomalies were found and their decay rates
Fig. 7  Decay curves for anomaly peaks indicated by arrows in Fig. 4. Crosses indicate the sampled amplitudes on the six channels, solid line the fitted exponential, $D$ is its exponent. Time scale is real, in msec. Amplitudes are in arbitrary units, the same for all channels.
Fig. 8  Summed trace with equal weights for 6 channels marked by a solid line, the estimated decay rate by dots.

Fig. 9  Ratio obtained by dividing the unweighted sum of 6 channels by the decay rate. Note the better anomaly resolution than on the original record in Fig. 2.
estimated (Figure 10). Easily recognizable differences in D are seen for those anomalies. Therefore, we tried to use this information for correlation with the neighboring profiles 16 and 17. Three anomalies that could be matched are on Figure 11. Besides D the area parameter $\text{A}_k$ is shown and it seems to be consistent on all three profiles. The only exception is anomaly C which is rather weak and therefore we must expect higher variation.

The decay rates for all points of the three profiles and the equally weighted sums of six traces are plotted in Figure 12. In this example, the decay rate seems to contain less noise than in the previous one, and it shows a certain consistency on all three profiles. Lower decay rates are found in the central part and higher values on both sides. Thus the central anomaly on the profiles seems to be due to a very good conductor, while that at the left side due to only a fair one. As in the previous example, the information on both traces of the profiles can be combined by dividing the sum of the six channels by the decay constant D (Figure 13). Anomalies A, B, C are indicated by arrows. They can be easily correlated on all profiles. Knowing the length of profiles, their distance and orientation, we may compute the strike of geological bodies or position of other disturbances. Also this
Fig. 10  Decay curves for anomaly peaks indicated by arrows in Fig. 3. Explanation as in Fig. 7.
Fig. 11 Decay curves for anomalies A, B, C on neighboring profiles 15, 16, 17. Explanation as in Fig. 7.

Decay rate D and anomaly area A_k are indicated.
Fig. 12 Summation traces with equal weights for the six channels marked by solid lines, the estimated decay rates by dashed lines.

Fig. 13 Summation trace divided by the decay rate for profiles 15, 16, 17. Explanation as in Fig. 9.
part is made with advantage by a computer looking for similar parameters in all directions and assuming a not too rapid change in strike.
5) FLIGHT ALTITUDE CORRECTION

The aircraft elevation changes sometimes substantially, within more than 100 ft. Therefore we tried to estimate its effect on the measured INPUT data and possibly devise optimum correction. In Figures 14-16, the altimeter record is plotted at the top. Six recorded INPUT channels are marked by solid lines. For the computation of corrected values we were using formula

\[ H_{\text{corr}}^j = H_{\text{orig}}^j \left[ \frac{V_j}{V_{av}} \right]^a, \]

where

- \( H_{\text{corr}}^j \) – corrected INPUT value at point \( j \)
- \( H_{\text{orig}}^j \) – measured INPUT value at point \( j \)
- \( V_j \) – elevation recorded by altimeter at point \( j \)
- \( V_{av} \) – average flight altitude on the profile
- \( a \) – exponent, varying in different examples

In Figure 14, the value of exponent \( a \) was a constant equal 2 for all points. Between points 130 and 140 (anomaly \( p \)) two maxima were recorded. Apparently they are caused by one body only and the anomaly was split because of a sudden increase in the aircraft-ground distance, since after introduction of the flight altitude correction only one peak appears.
A. Becker (1969) suggested that the exponent in the given formula varies between 2 and 3 according to the decay rate. It equals 2 for the fast decaying anomalies and 3 for the slower decaying ones. We let the exponent change as a function of the estimated decay rate as \( a = 3 - D_j / D_{\text{max}} \), where \( D_j \) - decay rate at point \( j \), \( D_{\text{max}} \) - maximum decay rate on the profile (Figure 15). The slower decaying anomalies are therefore more affected by the correction.

The third example (Figure 16) shows the flight altitude correction for an exponent varying between 2 and 4, \( a = 4 - 2D_j / D_{\text{max}} \). Anomaly D between 130 and 140 now seems to be more important than A at 24. The opposite was true before the correction.

We computed the correlation between the altimeter record and the six channels for three exponents shown and some others. On most profiles analyzed the correlation was minimum for a decay dependent exponent varying between 2 and 4. However, the minima of correlation are very broad and it is difficult to suggest any exponent combination as the best for all cases. It might be more suitable to introduce the flight altitude corrections before the peak recognition step. The exponent would be constant for all decays (3 was best in our experience).
Fig. 14 Record of a Barringer INPUT survey. The altimeter trace is at the top. Measured values marked by solid lines, corrected values by dashed lines. Formula used for the correction computation given at the top.
Fig. 15  As in Figure 14, but exponent $a = 3 - D_j/D_{\text{max}}$. 

$$H_j^{\text{cor}} = H_j \left( \frac{V_j}{V} \right)^{3 - \frac{D_j}{D_{\text{max}}}}$$
Fig. 16  As in Figure 14, but exponent $a = 4 - 2D_j / D_{\text{max}}$. 
6) SUMMARY

The first step of our program is peak recognition, which might be done either on a sum of the six traces, or on each channel separately. The latter is the case in visual interpretation where presence of peaks on several channels is the acceptance criterion. We have found that it is advantageous to use the summation profile with weights increasing from channel 1 to 6. Then the anomaly is passed to the width and area estimation. From this step on only important anomalies are retained. Next the decay rate is determined. The least squares fitting of an exponential seems to be the most suitable approximation. The knowledge of the decay rate is useful for flight altitude correction, which at least theoretically seems to be decay dependent. In this step, we might have changed the total amplitude and area by as much as 30 percent. Therefore, a repetition of width and area estimation would be necessary. Generally, it would likely be better to introduce the flight altitude correction with a constant exponent before the peak recognition step, or omit it. The final step is the correlation of anomalies across profiles, where a knowledge of all parameters previously determined will be employed.

How expensive this process is? Take as an example a 3 mile long profile, represented by 100 points. The execution
time of the whole program described is about 12 seconds on IBM 360/65 computer, which costs 40¢.

This paper should not be understood as a definitive procedure for the computer analysis of Barringer INPUT System data, but rather as a first proposal on how one might handle large quantities of multichannel data economically. In continuing the work, we would like to establish the decay rate estimate for compound anomalies showing two different decay rates. Possibly we might then be able to divide the response into separate poor and good conductor components.
REFERENCES


