MRS2015 / 6th International Workshop on Magnetic Resonance

Study of error propagation in NMR well logging data processing

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SUMMARY

The T2 distribution derived from NMR measurements is very important input data for some petrophysical parameter. Therefore the uncertainties of T2 data are appear in the further calculation. Analyzing the NMR data processing permits to study the error propagation through the inversion at different signal to noise ratios. The error analysis consists of two parts. At first the study were carried out on artificially created datasets with simulated noise, which also gives the opportunity to investigate the effect of measurement parameters such as sample rate. Then the real datasets were used in the analysis with varying signal to noise ratios.

Key words: inversion error propagation nmr

INTRODUCTION

The ill-posed problems of NMR data inversions are widely discussed, therefore in the cases of low signal to noise ratio, the solutions can be unstable causing equivalences between the fitted parameters. Even if the solution seems to be correct, the variance and the bias of the T2 values might be high.

In this work the reliability and uncertainty of T2 distribution are examined estimating the covariance matrix and studying the sensitivity to signal-to-noise ratio. This covariance matrix is also needed in further calculation, where the T2 values are used as a basis of error propagation estimation.

METHOD AND RESULTS

The analysis was divided to two parts, (i) the analysis of artificially created, simulated dataset and its dependency in signal-to-noise ratio and (ii) a real measurement's inversion.

In the first part, assumed T2 distribution was transformed into an exponentially decaying curve and also the proper noise was added to simulate the measurement. This exponential data was inverted and analysed. During the inversion two constraints were used avoiding the instability. At first (i) a diagonal matrix, comes from the least squares method, and (ii) a tridiagonal matrix, which ensures the smoothness of the first derivative of the normalized term. This equation takes shape in the following form:

$$\left\| \mathbf{J}^{T} \mathbf{J} \right\| + \lambda \left\| \mathbf{W}_{1}^{T} \mathbf{W}_{1} \right\| + \mu \left\| \mathbf{W}_{2}^{T} \mathbf{W}_{2} \right\| \rightarrow \min \qquad (1)$$

where **J** is the Jacobian matrix, λ, μ are the regularisation parameters, $\mathbf{W}_1$, $\mathbf{W}_2$ are the constraint matrices. This problem was solved with an iterative non-linear Gauss-Newton method.

In the study different zero mean Gaussian noise was added (with different variances). The SNR=1, 10, 50, 100 cases were investigated. The model space - T2 distribution, - was logarithmically spaced into 64 parts, between 3 and 3000 ms.

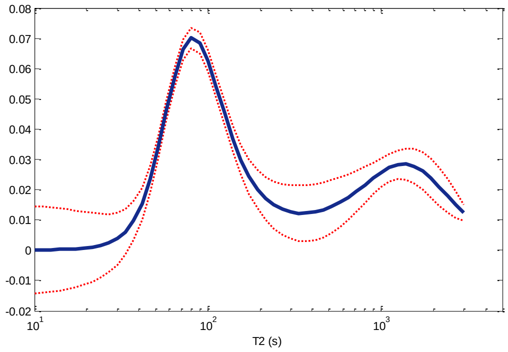

Figure 1. The T2 distribution when no noise is present. The blue line is the T2 values, red dotted line is the standard deviance.

As it can be seen in figure (1), at small T2 values are quite unstable, due to the small regularisation factors, but at the hidden peaks, the inversion is reliable enough.

Also the covariance matrix of the inversions were calculated.

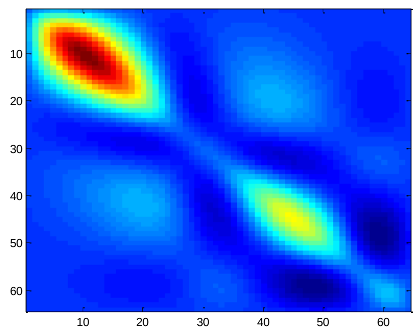

Figure 2. Covariance matrix of the parameters.

It is not only shows the strong close neighbour correlation, but the correlation between nearby elements.

The paper investigates the properties of the effect of different SNR levels on the synthetic dataset.

The second part of study was the real measurement's analysis. This examined dataset was probably loaded with high noise, therefore stronger regularisation parameters were used. The proper selection of regularisation parameter also was the part of the investigation.

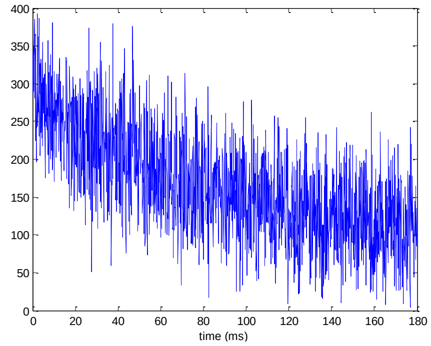

Figure 3. The noisy input data.

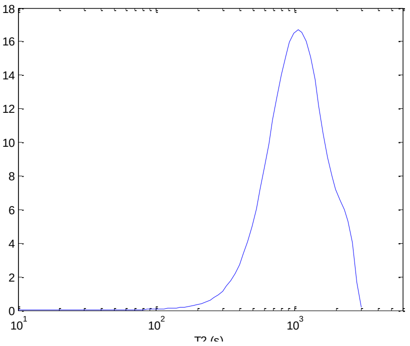

Figure 4. The T2 distribution of the data.

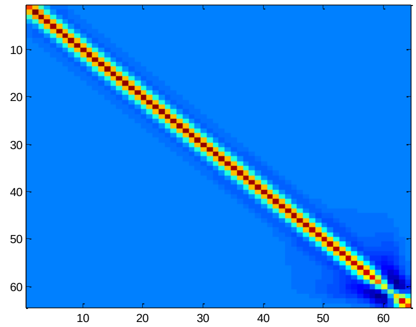

Figure 5. The covariance matrix.

In this case the covariance matrix was dominantly diagonal, and at the high T2 values there is a broadening indicated the measurement's length was not proper, therefore the slowly decaying exponential term cannot be clearly distinguished.

CONCLUSIONS

The analysis gives a possible estimation of T2 confidence based on the signal to noise ratio.

The study demonstrates the effect of noise on the deviance of the T2 values after the inversion. Also the increasing deviance in the function of noise is described.

The variation of the sampling and noise conditions of the synthetic data were investigated and their propagation to derived parameters.

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