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Contrast Enhancement for Automatic Breakout Segmentation in Clipped Borehole Acoustic Image Logs

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Abstract

Borehole image logs are often subject to data processing techniques that can substantially interfere with the automatic segmentation of structures, mainly due to the lack of standardized procedures in the industry. To enhance the robustness of automatic breakout detection in log images, this work proposes a pre-processing technique designed to recover information about the data distribution from inputs with clipped histograms.

Introduction

Borehole image logs are essential in collecting high-resolution and accurate subsurface data. However, the process of manual segmentation is laborious and time-consuming, demanding significant expertise. Recent advances in computer vision, particularly convolutional neural networks (CNNs), offer the potential to automate this segmentation process, significantly reducing the required time and effort (Anjos et al., 2023) (Cunha et al., 2024).

Borehole image logs often undergo transformations to enhance their quality, which, unfortunately, can be detrimental to CNN models if not adequately represented in the training set or if there is no standardized process to ensure consistency across data samples. A key challenge arises with the application of histogram clipping, a technique that limits values to within a specified range, as illustrated in Figure 1.

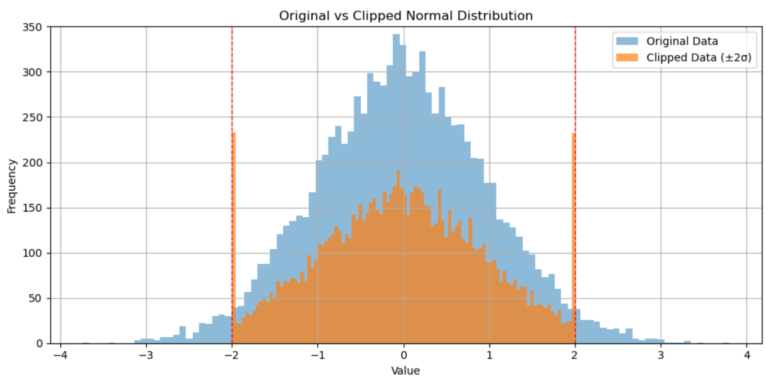

Figure 1: Histograms of normally distributed data clipped at 2σ.

The model presented by Cunha et al. (2024) provided satisfactory results in our production environment, but could not guarantee support for data with clipped histograms, leading to failures as in Figure 3. This motivated the development of the present method.

Method and Theory

The method we developed consists of applying the Bilateral filter (Tomasi and Manduchi, 1998) to reduce the noise created during clipping, followed by the function $f(x) = -x^{-1/2} + 1$ to increase contrast in low amplitude regions.

Several functions can be used to increase contrast at low amplitude regions, notable examples being the power function (gamma adjustment), the Sigmoid (Braun and Fairchild, 1999) and the Log. Comparative studies of these techniques revealed that gamma adjustment offered no improvement, whereas sigmoid and logarithmic methods yielded modest enhancements in segmentation performance. This motivated the choice of the novel function:

$$f(x) = -\frac{1}{\sqrt{x}} + 1$$

that when applied to data in the range $[0, 1]$, has the property of preserving contrast at high amplitude regions (close to 1), while increasing contrast at low amplitude regions (close to 0).

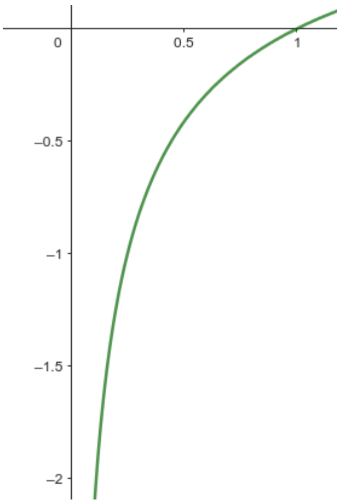

Figure 2: The function $f(x) = -x^{-1/2} + 1$ in the interval $[0, 1]$.

The Bilateral filter is an image filter similar to the Gaussian blur, but with the key advantage of preserving edges. This enables effective noise reduction while preserving important structures, such as breakouts.

Like the Gaussian filter, the Bilateral filter replaces the value of each pixel p_c with a weighted average of its neighboring pixels p_n. However, unlike the Gaussian filter, each neighbor p_n is assigned two weights: one based on its Euclidean distance from p_c, and the other based on the difference in value magnitude. The weight of p_n is then given by:

$$W(p_n, p_c) = exp(-\frac{|p_n - p_c|^2}{2\sigma_d^2})exp(-\frac{|I(p_n) - I(p_c)|^2}{2\sigma_r^2})$$

where $|p_n - p_c|$ is the Euclidean distance and $|I(p_n) - I(p_c)|$ is the difference in value magnitude between pixels p_n and p_c.

Results

To test our method, we clipped the data of 11 wells, from different companies. On 7 wells, representing 63% of the dataset, the method achieved high accuracy breakout detection, while results for the remaining data were either poor or inconclusive. The main issue with the enhanced data was that of false positives; dark features such as fractures or data artifacts were segmented as breakouts, see Figure 5. On Figures 3, 4 and 5 we present sections of different wells; prior to enhancement the segmentation was poor or failed completely.

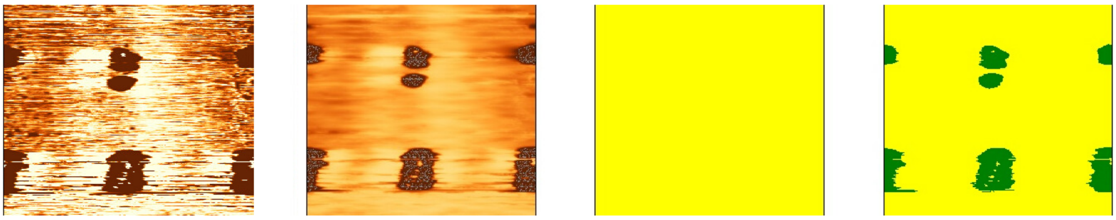

Figure 3: From left to right: Original clipped amplitude image log data; Data after the proposed contrast enhancement technique (feature edges are preserved even with strong noise reduction); Breakout segmentation proposed by Cunha et al. (2024) (it fails completely); Breakout segmentation after the proposed contrast enhancement.

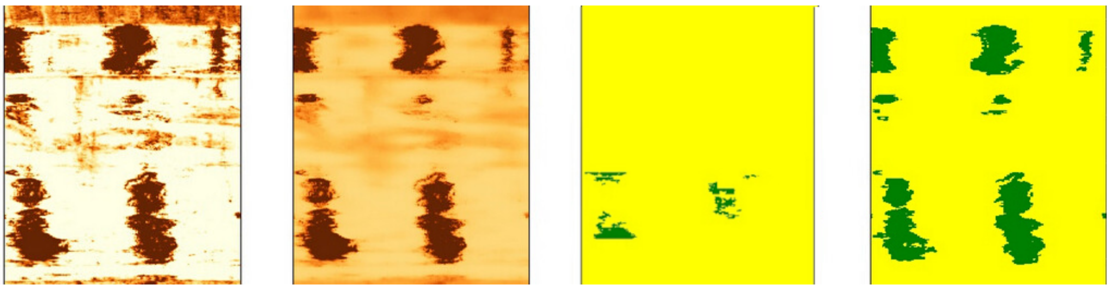

Figure 4: From left to right: Original clipped amplitude image log data; Data after the proposed contrast enhancement technique; Breakout segmentation proposed by Cunha et al. (2024) (the model segmented a very small area); Breakout segmentation after the proposed contrast enhancement.

Conclusions

Training the model on clipped data was not possible due to the limited number of borehole image logs and the absence of labeled data; yet we demonstrated that it is possible to achieve good segmentation results with pre-processing techniques alone. The contrast adjustment function and the Bilateral filter are both computationally inexpensive, requiring significantly less processing time than the segmentation process itself.

Future work will focus on: (1) investigating adaptive parameter selection for the Bilateral filter to optimize results for data from different vendors and with varying levels of noise and (2) exploring methods to further reduce false positives.

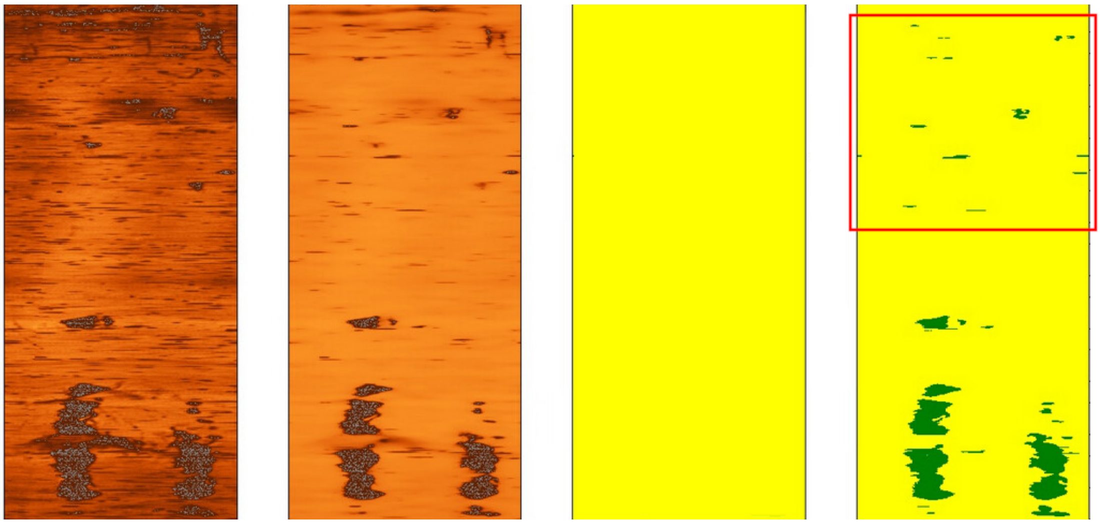

Figure 5: From left to right: Original clipped amplitude image log data; Data after the proposed contrast enhancement technique; Breakout segmentation proposed by Cunha et al. (2024) (segmentation failed completely); Breakout segmentation after the proposed contrast enhancement with false positives marked in red.

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