Automated fracture detection with well logs using global optimization

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Abstract

A method for automation of fracture detection with well logs was developed using global optimization. Sinusoids generated with the parameters found with the application of our method match the fractures, confirming the viability of the model.

Introduction

Geophysical well logging allows detailed recording of geological formation, based on the geophysical properties of the rock formations in the subsurface (Serra, 1984). The detection of fractures in well-log images is an important issue in geophysics for determining reservoir characteristics and economic viability. In this sense we have developed a method based on global optimization for automated fracture detection aiming the decision-making support in order to save time and effort in data analysis.

The problem consists in determining automatically the parameters amplitude, phase angle, and linear coefficient related to a sinusoid that represents the fracture in borehole images. For a global optimization approach, we associated pixel intensity information in such images with a 3D-plot in order to define a fitness function for the global optimization method applied, which was the Particle Swarm Optimization algorithm. We have associated each image to a 3D-plot for determining the fitness function to be used by global optimization methods. The Particle Swarm Optimization (PSO; Kennedy and Eberhart, 1995) was used for global optimization since it has been successful in many theoretical and real-world applications.

A synthetic model (with 250x337 pixels^2) and a real well-log image segment (357x1083 pixels^2; database at http://iodp.ldeo.columbia.edu/LOG_SUM/exp304_305/304_305.index.html), were used in order to demonstrate the method (Figs. 1 and 2).

Sinusoids generated with the parameters found with our method match the fractures depicted in the borehole images, corroborating the viability of the method.

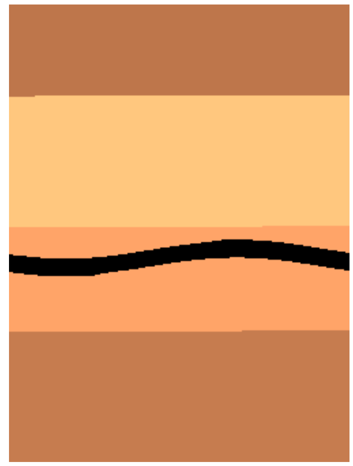

Figure 1: Synthetic well-log model *5b* used in order to demonstrate the method.

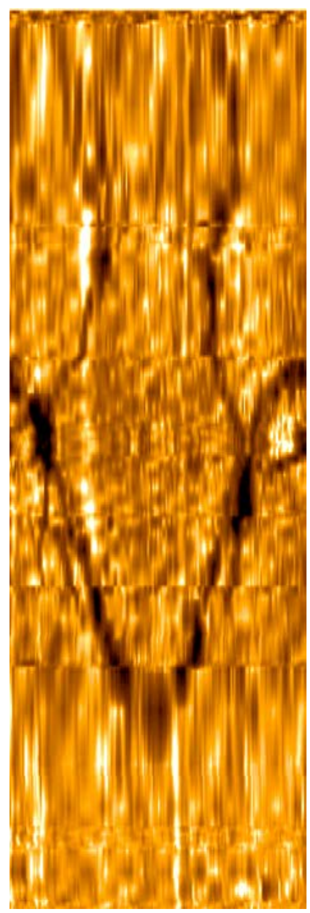

Figure 2: Real well-log segment used in order to demonstrate the method.

Associating images with a 3D-plot for fitness evaluation of candidate solutions

Firstly, the original images were converted into grayscale 8-bit images. Afterwards, binary images were created, with a pixel intensity threshold 65 (Figs. 3 and 4).

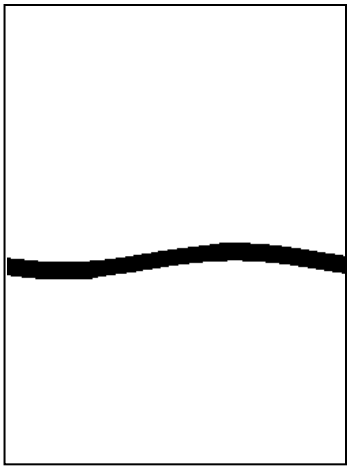

Figure 3: Binary image obtained from the synthetic well-log model *5b*.

Figure 4: Binary image obtained from the synthetic well-log model *5b*.

Then a 3D-plot was associated with each image, generated in the following way. The binary images were considered as a xy plan and for each black pixel (x_i,y_i) in the images, a paraboloid P_i given by $z = (x - x_i)^2 + (y - y_i)^2$ was generated. For each image, the resultant 3D-plot depicted in the Figs. 5 and 6 is the minimum among all P_i.

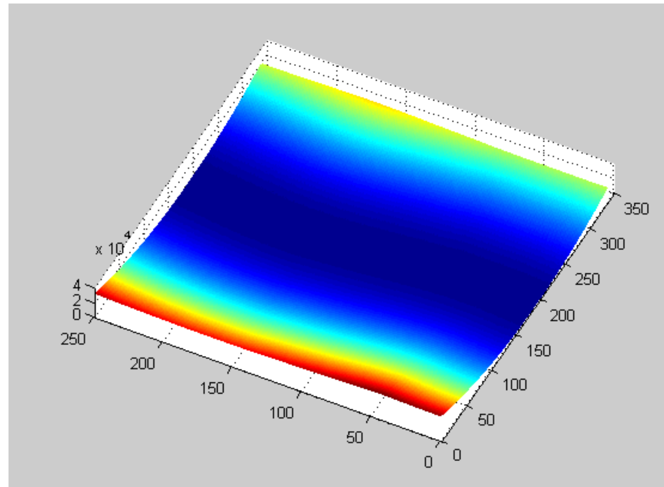

Figure 5: 3D-plot associated with the synthetic well-log model *5b* (notice the sinusoidal “valley” in dark blue at the center of the image corresponding to black pixels in Fig. 3).

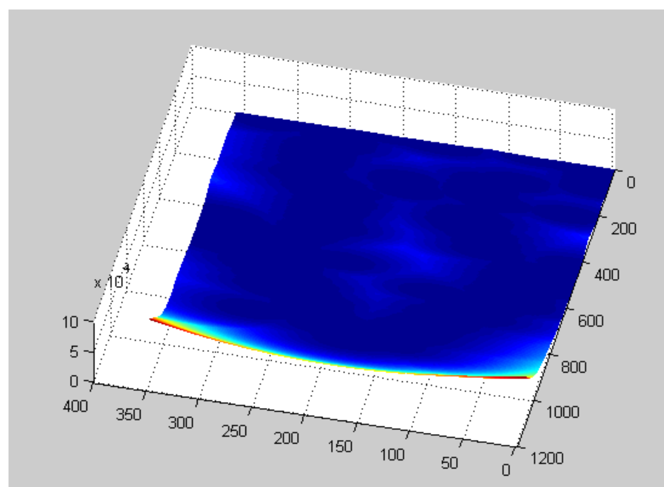

Figure 6: 3D-plot associated with the real well-log image (notice the sinusoidal “valleys” in dark blue corresponding to black pixels in Fig. 4).

Thus global optimization methods which work with fitness functions can use the 3D-plot in order to evaluate candidate solutions. Each point of the sinusoid generated by any method is evaluated according to the corresponding 3D-plot of the image. For example, a sinusoid that perfectly matches the valley in Fig. 5 has a fitness zero. On the other hand, a sinusoid that perfectly matches the fracture in Fig. 6 has a very low fitness, close to zero, although not zero since the record of fracture is imperfect.

Global optimization for fracture detection through the Particle Swarm Optimization (PSO) algorithm

The Particle Swarm Optimization (PSO) algorithm (Kennedy and Eberhart, 2001) models a collaborative search, taking into account the social aspects of intelligence. The PSO is a bio-inspired collaborative system whose computational optimization implementation has achieved successful results in various real-world and theoretical applications.

At each iteration, the PSO algorithm generates a population of candidate solutions distributed at a search space. In our method, each one of the candidate solutions is a particle with three coordinates (amplitude, phase angle and linear coefficient, that is, the parameters that completely describe a sinusoid in a plan). Each candidate solution is evaluated according to a fitness function based on the 3D-plot explained in the previous section. When a stopping criterion is met, an optimal or near-optimal solution is found. In our case, the parameters of the sinusoid that best matches the corresponding fractures in the original figures is found.

Results

For the image depicted in Fig. 1, the algorithm converged to an optimal solution in approximately 30 iterations. Due to the complexity of the image depicted in Fig. 2, the algorithm converged to an optimal solution in approximately 100 iterations.

Figs. 7 and 8 exhibit the evolution of the algorithm in the automated fracture detection.

Fig. 9 depicts the sinusoids generated with the best parameters found for the image in Fig. 1 (synthetic model *5b*). In Fig. 10, the overlap between the sinusoid of Fig. 9 (in gray) and the image in Fig. 3.

Fig. 11 depicts the sinusoids generated with the best parameters found for the image in Fig. 2 (real well-log image). In Fig. 12, the overlap between the sinusoid of Fig. 11 (in gray) and the image in Fig. 4.

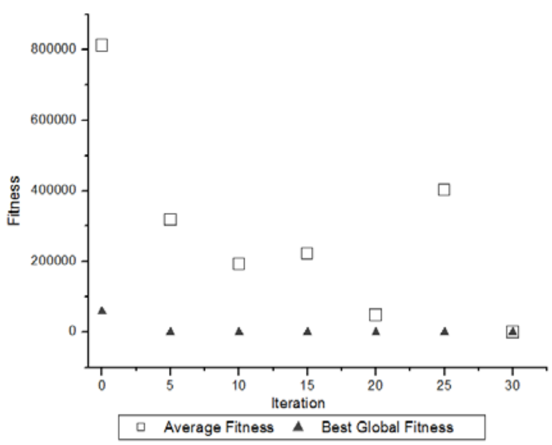

Figure 7: Convergence of the PSO algorithm for the automated fracture detection of the image in Fig. 1.

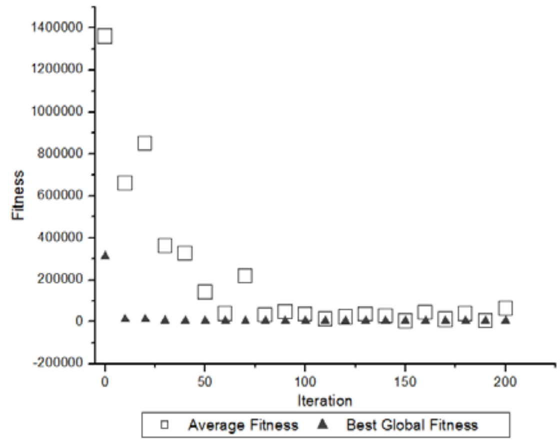

Figure 8: Convergence of the PSO algorithm for the automated fracture detection of the image in Fig. 2.

Figure 9: Sinusoid generated with the best parameters found for the synthetic model *5b*.

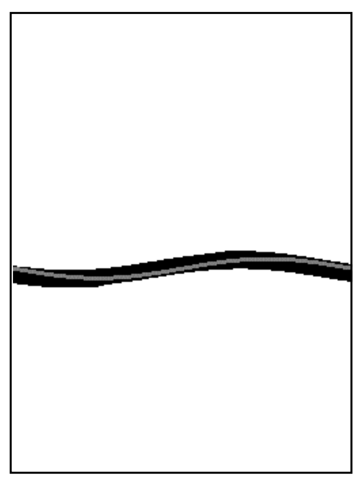

Figure 10: Overlap between the image in Fig. 3 and the sinusoid generated with the best parameters found for the model *5b* (in gray).

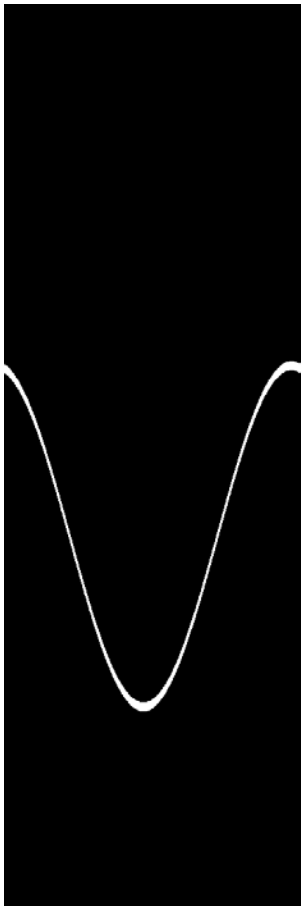

Figure 11: Sinusoid generated with the best parameters found for the synthetic model *5b*.

Figure 12: Overlap between the image in Fig. 4 and the sinusoid generated with the best parameters found for the real well-log image (in gray).

Conclusions

In the present work we demonstrated the automation of fracture detection in well-log images via Global Optimization. The method consisted in associating a fracture image with a 3D-plot, making possible a fitness evaluation, and therefore the usage of a global optimization technique, in our case, the PSO algorithm. The results corroborate the viability of the method. The overlap between the curves automatically found and the original images demonstrate the success in the use of the technique.

Acknowledgments

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References

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