Reply to Review by Dr. Bertrand Gauthier

Reviewer Comment

General comments

This paper describes a new method to automatically interpret fracture traces from 2D images (e.g. drone acquisition) using a novel technique. After explaining why an automated approach is better than manual interpretations, the method is briefly described in the main text and in more details in an appendix. The method is then applied to three different areas from different quality and resolution of images. Results are compared to manual interpretations. Finally advantages, disadvantages and way forward are discussed.

The paper is globally well organized, well written and easy to read despite some technical terms which are not clearly explained for the reader not familiar with these techniques. The figures are also globally well-presented although some of them would require some clarification. The abstract clearly summarizes the paper. A random check of the references did show any errors. The appendix is beyond my competence for a thorough review.

Considering the importance of such automatic interpretation methods and, from my knowledge, the original technique used, I accept this paper pending minor revision which are given below.

My main concern is that if the (non-mathematician) reader can conclude that this shearlet transform allows convincing and fast automatic interpretation of fracture traces, he does not understand how physically it works.

Author's Response

The authors would like to thank the reviewer for his comments. We have added a new figure within the background section that highlights the changes in detection parameters on the extraction results.

Reviewer Comment #1

Page 2 – line 2-6

Geomechanically derived DFNs are based on the physics of fracture propagation (Olson et al., 2009; Thomas et al., 2018) and can reproduce realistic fracture patterns providing the complex paleostress field and paleo rock properties are known. ; *however, They are also computationally intensive and hence have limited applicability. A carefully chosen fractured outcrop that is relatively free of noise (fractures resulting from exhumation and weathering* and not too much hidden by vegetation) *may be used to interpret realistic fracture networks which are geometrical inputs used in simulating various subsurface* thermo-hydro-mechanical-chemical processes (THMC) *processes.*

Author's Response to Reviewer Comment #1

We have modified the text incorporating the suggested sentence corrections by the reviewer (See Page 2, Lines 4-7 in the marked down manuscript).

Reviewer Comment #2

2.2 The Complex Shearlet Transform

A shearlet definition for dummies (the simple geologists) and/or a simple analogy would be welcome in this chapter since it is the heart of the method. This chapter is reproduced from different references which are fundamentally mathematical hence difficult to understand for non-mathematician readers.

Author' s Response to Reviewer Comment #2

We will modify the text in this section in the revised manuscript for a more simpler explanation behind the theory of the complex shearlet transform.

Reviewer Comment #3

Page 5 – line 11

CoShREM with Canny, Sobel, phase congruency: ????

Author' s Response to Reviewer Comment #3

This sentence was quite unclear and is replaced with "..complex shearlet based feature detection compared with conventional edge detectors such as Canny (Canny, 1986), Sobel (Sobel and Feldman, 1973), phase congruency (Kovesi, 1999) …" in the revised manuscript. (See Page 5, Lines 19-21 in the marked down manuscript).

Reviewer Comment #4

3.2 Shearlet parameter selection

The parameters which finally control the quality of the final fracture trace extraction are briefly described in Table 1 but their role and their physical meaning is not clear to me. Could it be possible to represent them on a figure (e.g. as part of Fig. 1).

Author' s Response to Reviewer Comment #4

We have added a new figure (see Figure 2, Page 26 in the marked down manuscript) referenced within Section 3.1 (see Page 4, Lines 7-8 in the marked down manuscript) where the effect of parameters are highlighted. A simple example of fractured sandstone rock is chosen to depict to highlight the effects.

Reviewer Comment #5

Page 6 - line 25

We use the structural similarity measure (SSIM) : explain what it physically means or at least give a reference.

Author' s Response to Reviewer Comment #5

The reference to the original paper (Wang et al., 2004) that introduced the SSIM was already in the manuscript (Page 6, Line 27 in old manuscript). We have now moved this reference to the first instance where the SSIM is referred to in the manuscript (See Page 7, Lines 5-6 in the marked down manuscript)

Reviewer Comment #6

Page 8 - Line 30

there is a tendency to interpret and link together disconnected features from the original raster image.

Could it be possible to show differences in fracture length distribution between automatic and manual interpretation? (also valid for the other examples)

Author' s Response to Reviewer Comment #6

Length weighted rose diagrams and cumulative trace length distributions are added to the figures where automatic and manual interpretations are depicted for Parmelan and Brejoes examples. In the case of Bingie Bingie examples rose plots and cumulative trace length distributions are added for the automatic and assisted interpretations (see Figures 8, 11, 12, and 13 in the marked down manuscript).

Reviewer Comment #7

Page 9 – line 4

(see Fig. 10a, 10b)

Author' s Response to Reviewer Comment #7

Modified within revised manuscript (see Page 9, Line 15 in the marked down manuscript. The figure number has changed to Fig.9).

Reviewer Comment #8

Page 9 – line 11

is shown in Fig. 10~~b~~c

Author' s Response to Reviewer Comment #8

Modified within revised manuscript (see Page 9, Line 22 in the marked down manuscript. The figure number has changed to Fig.9c).

Reviewer Comment #9

Page 9 – line 16

Fig. 10d depicts the P_{21}

Author' s Response to Reviewer Comment #9

Modified within revised manuscript (see Page 9, Line 27 in the marked down manuscript. The figure number has changed to Fig.9).

Reviewer Comment #10

Page 9 – line 22

comparison between both ~~the~~ vectorizations

Author' s Response to Reviewer Comment #10

Modified within revised manuscript (see Page 10, Line 4 in the marked down manuscript).

Reviewer Comment #11

Page 9 – line 22

no real evidence of rock ~~displacement~~ failure

Author' s Response to Reviewer Comment #11

Modified within revised manuscript (see Page 10, Line 7 in the marked down manuscript).

Reviewer Comment #12

Page 10 – line 16

which are comparable in quality to the manual interpretation of Thiele et al. (2017) : these manual interpretations are no shown so it is difficult for the reader to make his judgement.

Author's Response to Reviewer Comment #12

Thiele et al, 2017 have not released vectorised versions of their assisted interpretations. Hence, we have interpreted a trace map derived from the assisted interpretations in that paper and added to the relevant figures of Bingie Bingie #1 and #2 (see Fig.12(k) and Fig.13(k) in the marked down manuscript).

Reviewer Comment #13

Page 11 – line 10

King (2019), blob detection measures : not clear what it is

Author's Response to Reviewer Comment #13

The pre-print of Reisenhofer and King (2019) has now been published in SIAM Journal on Imaging Sciences and we have updated the reference. A blob within an image, is simply a group of connected pixels that differ in properties as compared to the surrounding. Compared to thin features such as edges and ridges which are akin to lower dimensional structures within a 2D image, blobs are 2D regions within the same 2D image. In our carbonate examples, weathering has caused such cavities which are better extracted using blob detection algorithms rather than ridge detection measures hence we referred to these techniques.

Reviewer Comment #14

Page 12 – line 2-4

K. Bisdom (2016) gives some relations between distance, resolution and camera length size which could be useful here (Burial related fracturing in sub-horizontal and fold reservoir – TU-Delft PhD thesis – ISBN 978-94-6186-740-7).

Since we are here in the suggestion part, you could also advise to make, if possible, 2 or 3 flight acquisitions at different altitudes to define resolution further.

Author's Response to Reviewer Comment #14

The relation provided by Bisdom, 2016 connecting resolution to flight altitude is specific to the type of camera that was used i.e., OPTIO S1. Multiple flights at same location to define the ideal resolution is a good suggestion and we have added the following sentence to the second last paragraph of the discussion. "The ideal flying resolution to identify features of interest may be ascertained by carrying out a series of acquisitions at a location where ground truth is known." (see Page 12, Lines 20-21 in the marked down manuscript)

Reviewer Comment #15

Page 12 – line 5-17

The use of MPS is to mean important complement of the interpretation results. MPS could also be used to fill regions with false positives related to e.g. shrubbery.

Author's Response to Reviewer Comment #15

Our suggestion was to use the method to generate realistic training image libraries for MPS based DFN generation. A similar exercise was performed by Pyrcz et al, 2008 for fluvial and deepwater systems. Such a library of training images needs to be carefully constructed after ensuring removal of any false positives. Failure to do so will replicate these false features in the output of the MPS algorithm. We have modified sentence in Page 12, Lines 10-11 "Our automated method can quickly produce accurate, geologically realistic, and unbiased training images that can feed into the MPS workflow" into "Corrected for false positives and noise, the automated method can produce accurate, geologically realistic, and unbiased training images that can feed into the MPS workflow." (see Page 12, Lines 27-29 in the marked down manuscript)

Reviewer Comment #16

Figure 1

Could be complemented by a drafted explanation of the shearlet transform parameters

Author's Response to Reviewer Comment #16)

We have added a new figure within Section 3.1 depicting the variation in each parameter on a simple example from a siliciclastic fractured rock sample (see Figure 2 in the marked down manuscript).

Reviewer Comment #18

Figure 4

In this present format, this figure does not mean anything for the basic reader. I suggest to shift it to the appendix and to replace it by the concrete effect of these parameters on the fracture trace extraction of a simple fracture network.

Author's Response to Reviewer Comment #18

Figure 4 is moved to the Appendix. The new figure depicting effect of parameters is placed within Section 3.1 (see Figure 2 in the marked down manuscript).

Reviewer Comment #19

Figure 5

Could it be possible to add an image showing lineaments color coded as function of the relative number of time that they have been detected by each realization?

Author's Response to Reviewer Comment #19

This is complicated to do, as when the vectorization is performed for each realization, there could be a slight shift in the position of the lineaments. The lineament lengths may also change in every realization making a one-to-one comparison quite difficult. However, in the revised manuscript we could make an image that displays the final trace map overlaid on a pixelated image that is colour coded with the number of times the particular pixel attained a non-zero intensity.

Reviewer Comment #20

Figure 8

Figure 8b is not readable. I suggest 1) remove the photo underneath and 2) improve the contrast of the color scale (e.g. a three color legend bar scaled between 0 and >5 since it seems that there are very few zones above this threshold).

Author's Response to Reviewer Comment #20

We have removed the underlying photograph and modified the colour bar scaling to better emphasize the variation in P_{21} (see Figure 7 in the marked down manuscript).

Reviewer Comment #21

Figure 9

Again, try to improve the P21 color scale contrast

Author's Response to Reviewer Comment #21

As per reviewers suggestion, we have modified this figure with better scaling of colour bar (see Figure 8 in the marked down manuscript).

Reviewer Comment #22

Figure 10

Same comment for 10d as for 8b

Author's Response to Reviewer Comment #22

As per reviewers suggestion, we have modified figure with better scaling of colour bar (see Figure 9 in the marked down manuscript).

Reviewer Comment #23

Figure 11

What is manual and what is automatic is not indicated. Put the fracture traces in white for better distinguishing them from the photo lineaments

Author's Response to Reviewer Comment #23

We have modified the figure 11 with the fracture traces in white colour. Caption is modified to identify the manual and automatic interpretations (see Figure 10 in the marked down manuscript).

Reviewer Comment #24

Figure 12

(a) Bingie Bingie Area ~~2~~ 1

Author's Response to Reviewer Comment #24

We have applied the above corrections to the revised manuscript (see Figure 12 in the marked down manuscript).

References

Pyrcz MJ, Boisvert JB, Deutsch C (2008), A library of training images for fluvial and deepwater reservoirs and associated code, Computers and Geosciences, 34(5):542-560, 10.1016/j.cageo.2007.05.015

Thiele, S. T., Grose, L., Samsu, A., Micklethwaite, S., Vollgger, S. A., and Cruden, A. R.: Rapid, semi-automatic fracture and contact mapping for point clouds, images and geophysical data, Solid Earth, 8 (6), 1241–1253, https://doi.org/10.5194/se-8-1241-2017

Reisenhofer R and King EJ (2019), Edge, Ridge and Blob Detection with Symmetric Molecules, SIAM Journal of Imaging Sciences, 12(4), 1585-1626, , https://doi.org/10.1137/19M1240861