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Review of PhD thesis

Advanced migration and filtration techniques for microseismic data

by

Jacek Trojanowski

Reviewer: Dr. Andreas Wuestefeld, NORSAR, 2007 Keller, Norway

Microseismic monitoring has become over the past 10 years or more a widely applied technology that gives unique insight to the processes in the subsurface. Numerous commercial and academic entities provided a wide range processing approaches. The thesis presented analyses (amongst other things) the widely neglected aspect of how to compare (or unify) the triggering thresholds. Furthermore, this thesis treats approaches of correlated noise removal. These two aspects of microseismic data are very relevant and as such, this thesis is a welcome contribution to the community and will hopefully serve to better understand the sometimes varying results given by different groups that analyze the same data sets.

The thesis is organized in five chapters: Chapters 1 and 2 discuss the development and subsequent application of a probabilistic, imaging function agnostic trigger threshold. Chapters 3 and 4 present theory and application of correlated noise removal. Chapter 5 applies these developments to a data set.

In general, this thesis well written, and concepts are clearly presented. At several occasions a few more figures would be helpful to further clarify certain assumptions and decisions on parameter choice. I understand that this is a synthesis of published papers, where space for figures is limited. However such limitations do not apply in a thesis, and the author should consider adding more figures to increase the transfer of findings to subsequent work.

The thesis shows the enthusiasm and interest invested by Jacek Trojanowski in this work. He analyzed in detail several aspects of microseismic processing that are too often neglected. This thesis is thus a useful contribution to the scientific (and commercial) community. The research performed by Jacek is an original solution to the given research question/topic. He demonstrated his knowledge in the field, as well as that he can work independently. In conclusion, I recommend this thesis to be accepted for further proceeding by the PhD committee. The below remarks do not impact my assessment of the thesis as a whole. They can be considered by the author in further publications or when publishing the thesis as a monograph and discussed during the public defense

Dr Andreas Wüstefeld, 26 Feb 2019

General comments:

In the introduction of each chapter, add the original reference of the paper. Likewise, on some occasions, you refer to papers (e.g. Trojanowski and Eisner, 2017), where an additional reference to a chapter seems appropriate. Such double referencing allows better orientation. Furthermore, I suggest to make figure captions more descriptive to make the thesis more accessible to a broader audience. This in my experience helps to get the occasional reader (of papers) interested to read und try to understand the text. This is getting ever more necessary with the general increase of publications, which leads to readers first scanning through the figures and then deciding if it is worth reading the full publication.

Note that most comments below are meant as general indications for future work. Formulations such as "should" are not meant as requests for changes, but rather as indication of how to address such issues in future work in the upcoming career as a scientist.

Chapter 1:

The concept of probabilistic and time-varying detection thresholds is certainly interesting and useful for the community. In microseismic (and migration-based algorithms) it is to my best knowledge novel.

The presented probabilistic detection threshold is built on the maxima of the various imaging functions. It would be interesting to discuss in more detail how this probabilistic approach could minimize "False Positives", i.e. stacked noise above the threshold. If my understanding of the approach is correct, quiet periods should result in a lower detection threshold (the threshold is adaptive, i.e. changes over time).

Also, coherent noise, stacks up to false location. The synthetic examples in Chapter 1 only discuss random noise. How does this behave for coherent noise?

In Chapter 1.2 the noise is assumed as random across the sensors, but in reality neighbouring sensors will record noise that is not independent. How does this affect your approach?

You make use of the "generalize extreme value distribution" theory. It would be helpful to give more background here than just referring to the original paper by McFadden. Why is this better suited here than other distributions (Weibull, lognorm,...). A figure with different values for equations 1.7 and 1.8 would help to clarify the concept. Furthermore, please unify nomenclature, notably on page 13: You use function value, location parameter, and scale parameter first; then you refer to them as mean and variance. I assume they are the same?

The next sections discuss detection threshold and detectability. I am wondering if the presented approach could be used also as a modelling tool: The recorded amplitudes of events depend on distance from the sensors. How does the detectability vary in space and time? This would be a useful tool in both the planning phase (Is the area of interest covered well enough to meet the project targets?) and the interpretation phase of a project (what is my magnitude of completeness for meaningful interpretation?). Is it possible to generate real-time maps of detection thresholds? These aspects could be added at least as short discussion at the end of the chapter or in the summary/conclusion of the thesis to give starting points for future work.

In the synthetic example section, you give amplitudes of the signal, but never explicitly give the amplitude of the noise. I assume the (random) noise has an amplitude of 1? But is it maximum or standard deviation? Furthermore, the exact values for the synthetic events are not listed. A table would help to understand later reference to seventh and third event. Maybe add markers and text in Figure 1.4?

The calculation of threshold values of 220 and 920 is unclear. Please be more explicit.

Chapter 1.3 ("data processing") is in general lacking some reference to the "standard" techniques. Adding a few references would be good scientific practice and allow the reader to get a starting point learn more details.

A common de-spiking algorithm is also a median filter. This is typically used for electrical (single-sample) spikes. It is unclear if you want to achieve the same here, but I feel that a damping as described here is detrimental to an analysis beyond location (especially magnitude determination). Can you discuss this here?

Do you have a reference for the sqrt(N) rule?

Figure 1.6 is unclear to me after several reads.

Page 21: Fragment sentence: "...assigned threshold changes. and it would ..."

The end of the chapter is a bit strange. Maybe a link to the following chapters and an outlook for future work (see above) might be helpful

Chapter 2:

Chapter 2 presents a comparison of migration-based methods with special focus on moment tensor resolvability, i.e. polarization. A modified version of the approach by Grandi and Oates is presented. One of the main advantages it seems is the shorter time window required. The author should discuss in more detail why such a short time window is beneficial and where the disadvantages are.

For the synthetic test a velocity model was chosen. An additional figure with a velocity profile (or an inset into Fig2.3) would be very illustrative.

The author choses Gaussian noise on top of the synthetic seismograms. What effect would non-Gaussian noise have? What difficulties do you avoid thus?

Some methods of Group 2 of the stacking test yield "virtually the same results". Do you have any explanation of why (is it a result of band-limited synthetic data, and thus an artefact; or are the methods mathematically identical?)

Figure 2.5 shows stacks. I would have expected this figure (or reference to it) a bit earlier, buth that is the author's choice. In any case, some interpretative message should be added to that figure, or the caption to indicate what the result of this effort is.

In the last paragraph of "Group 2" (Page 35) the author claims "In the previous section I showed". Please be more explicit and refer to the exact paragraph in the thesis (that's what paragraphs are for: to be citable...)

Section 2.6 would benefit from additional figures, notably the last paragraph on page 36

Section 2.7 refers to "common knowledge", twice. It would be cleaner, scientifically, to provide a reference. In the age of "Fake News" referencing is becoming ever more important.

Page 40: "absolute value stacking is less *efficient*". Please define "efficient"

I must admit Figure 2.8 remains a bit mysterious to me. Admittedly it is all in the equations, but what is the take-away message that can be given to a non-specialist?

Chapter 3:

Figures 3.1 to 3.3 needs more explanation and referencing to the text (for a start, use labels 3.1a-h instead of "upper left panel", and explain each panel in sequence. Why do you show each panel? What is the take-away message of each panel? Once you have done that for Fig3.1, you can simply point out the differences in 3.2 and 3.3. Maybe it turns out that it is better for understanding to re-sort the panels, i.e. all a) in a figure, all b),... and so forth. But maybe the current organization is best.

Page 47 "...model of the signal to define a filter": How do you do that? Maybe add a reference to the relevant section.

Page 52: before you start the theory section, maybe add a sentence or two, repeating what you want to achieve

Figure 3.5: How do the distributions vary over time? If it is sensor coupling, it should remain relatively constant. Other causes could result in changes. Maybe add a plot with x-axis is time, and y-axis is standard deviation. Then make line-plots for each sensor

Page 56: grammar: event's

After multiple reads, the Figure 3.6 is still elusive to me.

Also, on bottom of page 57 "differently dipping... are represented by curvelets". How and where do I see that?

Page 61: Can you apply both filters to both surface and downhole data? State that more explicity! Is there a way to compare the performance of both methods? In Chapter 4 you apply the methods in sequence. It might be interesting to do that with your synthetic dataset. Also discuss here the strength and weaknesses of either method. When should it be applied, and under which conditions its use should be avoided.

Chapter 4:

Page 64: "I successfully applied...". Such statement doesn't belong into an introduction.

Page 64: how did you scale the events? By what factor?

Figure 4.7, 4.10: are the picks manual, automatic or theoretical?

Page 83: When discussing the performance of the MCCF, it would be good to have some sort of list or table that summarizes positive and negative effects. Completing that with references to your extensive selection of figures would improve navigation through this chapter. Is it possible to extract some "performance parameter" (xcorr, pick accuracy,...) and plot that against SNR?

You conclude that tube-wave are successfully removed. However, this aim was not stated in the previous discussion. Neither were tube-waves highlighted in any of the figures.

You perform a complex evaluation of different combinations of your processing steps. While this attention to detail is recommendable, it is also a bit confusing. Figure 4.34 is very interesting, but unfortunately only discussed in passing.

Chapter 5:

Page 107: "correctly detected events": How do you know if they are correct?

How does an 8% increase in velocity account for anisotropy? That certainly requires a more detailed description

Page 109: Do I understand it correctly that you use the catalogue of Anikiev as reference catalogue? You claim that the reference catalogue should be better than the tested method. So what is the point of your work if Anikiev already presented results that even you consider superior?

Can you somehow detect false positives, i.e. triggers that are not earthquakes?

Page 111: "slightly smaller number". Please give exact values. This is the result section. The interpretation section is for your assessment, but here you should give absolute numbers and leave it to the reader to assess if the difference is small

Figures 5.3 and 5.4 are good to show overall event cloud but it is impossible to correlate individual events. To make statements about "reliable" detections and locations (Page 111), it would be better to show how events moved, e.g. a histogram of event distance between your and the reference catalogue.

In general, a table of the reference catalogue and your catalogue similar to T5.1 would be good to have earlier

T5.1: what "restriction" did you apply?

Page 114: "processing of a few datasets": what dataset do you mean here?

Page 114: "coherent locations" what do you mean? Define coherent

Page 114: "high threshold" give value! Where is the link to chapter 1?

How do the events move for the different techniques? Is it statistically significant?

Overall, this chapter would benefit from a deeper statistical comparison of the event location and detections. A link to Chapter 1 would round up the whole thesis

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Conclusion

Here, an outlook would be interesting. What ideas came up during your work that could not be addressed in the time frame of the thesis? Where do you suggest future research to start? What avenues you consider dead-ends and should not pursued?