Review Report of PhD Thesis

Integration of GNSS and InSAR observations for deformation monitoring in mining areas

Submitted by Mr. Damian Tondás

Reviewer:

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Contribution and originality of the thesis

The doctoral dissertation of Mr. Tondás addresses the topic of continuous ground movement monitoring in mining areas. In particular, his focus is on the integration of GNSS and InSAR methods. The originality of the thesis can be formulated by two major results. First, within his work he developed a new ultra-fast near-real-time (NRT) processing algorithm of GNSS data to obtain coordinates and troposphere parameters within a 15 min. interval with less than 14 minutes latency. Second, his work presents a new methodology of integrating GNSS and InSAR techniques for monitoring non-linear movements in mining areas. The fusion process is developed utilizing the Kalman-Filter. As a result, consistent 3D deformation information can be retrieved. With these solutions, the candidate demonstrated both, his ability to create an original solution in the scientific field of geomonitoring and general knowledge on the topic of his thesis.

Formal aspects

The submitted dissertation is a cumulated work consisting of an 80 page long introductory description of state-of-the art, methodology and results, followed by three scientific publications. Two of these have been peer reviewed and published in internationally recognized journals, one is available as a draft version. The main text is embedded in a thorough literature review consisting of 94 references. The text is supported by an adequate number of figures, which are in general of high quality. A minor aspect is the readability of some figures, e.g., figure 3.4.

Thesis structure and content

The first part of the thesis is characterized through an introductory and summarizing content. It is well written to embed the three scientific articles, which follow as attachment as main, detailed content. After a short introduction in Chapter 1, geodetic monitoring techniques are described followed by a cross comparison. While general aspects are well captured, a more focused and differentiated discussion on horizontal vs. vertical movements, direct and indirect measurements and limitation would have been useful to justify the decision oh the thesis focus - integration of InSAR with GNSS. In particular limitations of InSAR would have been of interesting comparing the precision of the location of the back scatterer. The subsequent section on ground movement deformations has a very general character. The requirement analysis in terms of movement rates is based on one particular underground mining case presented by Cui et al.2020. Here a more differentiated discussion would have been useful, in particular on different movement zones in a subsidence through and one ranges of movement

rates across a wider variety of underground mining projects, e.g., in Poland. In this regard, it is remarkable that these requirements analysis has been based on a paper from Chinese authors instead of Polish experiences in case studies. It follows a detailed and well-structured discussion on methods for integrating different monitoring techniques followed by a justified motivation of thesis. Chapter 2 presents the foundations of the InSAR and GNSS technique in adequate technical depth. Chapter 3 discussed the methodology in a structured way that links to the three publications. It appears that paper 1 (Development of NRT-GNSS service) and paper 2 (demonstration of capability of GNSS subsidence modelling) build well up on each other and focus on improved GNSS- monitoring. Paper 3 opens a quite distinct methodological topics, the integration of GNSS with InSAR, which in itself is an ambitious topic. Chapter 4 describes shortly the content of the publication and Chapter 5 provides conclusions, which provide a summary and potential future work. Here, the scope of the suggested future work is quite narrow and rather incremental. A broader vision on the topic would be appreciated.

Critical evaluation of content

The doctoral dissertation of Mr. Tondás addresses with real-time monitoring of ground movements above mining activities combined with fusion of different monitoring methods scientifically appealing topics. His results significantly contribute to the future development of these techniques. The impact of his results is within an improved environmental management of mining impacts, which will affect the acceptance level for these kinds of projects. The methods used and developed within his thesis go clearly beyond the state of the art. The analysis of results has been performed thoroughly leading the correct conclusions.

For the reviewer there remain few questions open and some questions are inspired through the thesis:

- What is the current status of the new NRT service in terms of technology readiness?
- Why the fusion concept has not been performed for InSAR and geodetic levelling data? These types of measurements seem to be more similar in many aspects.
- The fusion of InSAR and GNSS is based on only few GNSS observation points:

  The first remark is the question about the co-location of both sensor signals. How can be assured, that the signal of the GNSS location coincides with the location of the largest radar signal within the radar pixel?

  If this cannot be assured, might this incorporate systematic effects, e.g., through different movement behavior within the local neighborhood?

  Could there be a technical solution, e.g., by implementing the concept of multi-sensor reference stations combining a corner-reflector with a GNSS station?

- The fusion algorithm is based on a simple cumulative stacking of differential InSAR results, not, e.g., on PSI time series. In the latter case, the result would be rather movement rates in mm/a instead of absolute movements in mm. Would the algorithm perform similar well?

- The value of InSAR is the areal coverage. By presenting a fusion algorithm for particular locations, this advantage seems not to be fully taken advantage of. What are the thoughts of the author?
- Mining induced ground movements are well studied and there exists a range of forward prediction models. What are the thoughts of the author to integrate this model information as expert knowledge in the analysis? Could this additional information result in benefits?
- How would we optimize the sensor network, in particular the number of the GNSS stations and its locations, by using the results of the author?

Final Conclusion

In my opinion, the doctoral dissertation fulfills the requirements for a doctoral degree in particular under Article 13 of the Act of March 14, 2003 Ustawa o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki (tekst jedn. Dz.U. z 2017 poz. 1789).

Despite my smaller comments, I judge this thesis as very good and evaluate the thesis

Positive with honors (very good).

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