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Doctoral dissertation review

Damian Tondaś, M.Sc.

under the title:

"Integration of GNSS and InSAR observations for monitoring deformations in mining areas".

The review was prepared by order of the Chairman of the Council of the Discipline of Civil Engineering, Geodesy and Transportation, Wrocław University of Life Sciences, dated June 26, 2023 (IDDD.0000.410.5.2023).

1. General characterization of the scope and content of the dissertation

The reviewed work was developed by a PhD student at the Institute of Geodesy and Geoinformatics, Faculty of Environmental Engineering and Geodesy, Wrocław University of Life Sciences - Mr. Damian Tondaś, M.Sc. under the guidance of the supervisors, Prof. Witold Rohm, Ph.D., and Jan Kapłon, Ph.D., Professor, UPWr. The work was submitted as a series of three articles published (the first) or under review (the second and the third) in international journals, and is accompanied by a self-report in the form of a manuscript, to which the mentioned 3 publications are attached:

1. Tondaś D., Kapłon J., Rohm W.: Ultra-fast near real-time estimation of troposphere parameters and coordinates from GPS data. *Measurement*, 162, 107849, 2020
DOI:10.1016/j.measurement.2020.107849
2. Tondaś D., Kazmierski K., Kapłon J.: Real-time and near real-time displacement monitoring with GNSS observations in the mining activity areas. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *In review*.
3. Tondaś D., Ilieva M., van Leijen F., van der Marel H., Rohm W.: Kalman filter-based integration of GNSS and InSAR observations for local nonlinear strong deformations. *Journal of Geodesy*, *In review*

The manuscript of the dissertation covers a total of 150 pages and includes a table of contents, a list of abbreviations used, a list of 108 literature sources, Appendix A containing all three publications of the series in the journal template, Appendix B containing statements of the co-authors of each publication on the percentage contribution to their creation.

The main objective of the work was to develop a coherent method for integrating permanent GNSS observations with remote InSAR technologies, so that it would be possible to continuously monitor also nonlinear in time vertical displacements forming, for example, in regions influenced by underground coal mining. This main goal was set after a very good, in-depth demonstration of the research niche, outlined against the background of an analysis of the advantages and disadvantages of the various known surface displacement measurement technologies. The author not only characterized these methods, but tried to compare them with each other, also against the background of previous research conducted in the world in terms of their possible integration. Thus, he demonstrated criticality and good preparation for independent study of research issues and their creative analysis.

The first publication focused on the development of a methodology for estimating troposphere parameters with minimal delay. The original methodology developed made it possible to use with increasing efficiency (for an increasing number of GNSS stations) continuous measurement with 15 min delay using the NRT method for estimation of troposphere parameters and coordinates. As a result, this can lead, according to the Author, to a fourfold acceleration of obtaining precise results of GNSS observations. Thus, the developed technology is novel compared to other already known technologies for developing NRT measurement results.

The second publication continued the topic of measurements by GNSS technology using NRT and additionally RT. The main objective of the publication was to systematize the current knowledge of permanent, long-term land displacement measurements in terms of reliability and accuracy of GNSS services. To validate the quality of RT and NRT measurements, an independent P-P system was created. The study was carried out in coal mining areas selected in Upper Silesia. The results included the presentation of the obtained accuracies, the time required to detect significant displacements and the reliability with which the minimum, determinable displacements are detected. The following minimum detectable displacements were obtained in the NRT system: 5mm-north, 7-east and 11mm-vertical, respectively, while in the RT system, respectively: 10mm, 15mm and 20mm. Above all, however, it was shown that calculations for NRT-S are possible with a much shorter delay (2 hours) than P-P services (2 weeks). The studies discussed in this publication had novel elements consisting of proprietary solutions carried over from the solution developed in the first publication in permanent measurements. Mainly, however, they provided some valuable structuring of knowledge and demonstration of the quantitative capabilities of the two technologies studied.

The third paper, currently under review, in the *Journal of Geodesy*, presents the author's own original solution for integrating GNSS measurements with InSAR technology in application to long-term displacement measurements in areas with significant and time-varying displacements, which are characterized by ground motions in areas influenced by mining operations. An in-house algorithm has been used to fuse the time series of topocentric coordinates determined by GNSS technologies with the time series of DInSAR, considering both orbits of the LOS signal. Time gaps in the InSAR imagery were smoothed, and artifacts resulting from troposphere attenuation and phase unwrapping errors were smoothed using a Kalman filter. The author states in his conclusions that the application of the Kalman filter

results in an approximate 1.5-fold improvement in the accuracy of determining displacements in the E and U directions, compared to the standard DInSAR decomposition method. He considered one of the most important advantages of using the Kalman filter to be the ability to fill any gaps in the observation series. The author anticipates that the applied proposal for the fusion of observations from both sources can be supplemented in the future with other types of data, such as those from leveling, lidar, etc.

2. Substantive and formal evaluation

The integration of surface displacement detection (InSAR) methods with two-vector propagation with 3D precision displacement detection methods based on GNSS measurements has been heavily researched and developed, especially in the last five years. The author made a very good sense of this trend by citing available research results and citing several publications in this thematic group. This group has so far used both Kalman filter-based filtering methods and machine learning methods to estimate missing elements of a series of observations, as well as the displacement trend. This demonstrates a very good understanding of research trends in the discipline of civil engineering, geodesy and transportation. In his research, the author introduced a novel solution to shorten the delay in developing a series of GNSS observations considering the signal-delaying effect of the troposphere, as well as his own scripts to improve the fusion of both measurement methods. In addition, he demonstrated the ability to detect already very small increments of displacement, which gives room for detecting nonlinear in time surface movements. In mining areas, this is particularly important.

What deserves to be emphasized is the fact that Mr. Tondaś very skillfully and eruditely navigates both the subject of satellite radar interferometry and, perhaps even more extensively, the subject of GNSS measurements. The research niche of the dissertation has been very clearly indicated, and the developed algorithm for the fusion of GNSS methods with InSAR technology is an independent and creative contribution to the development of methods for the integration of the two techniques. In general, the research was conducted in accordance with the established methodology and the results were correctly discussed. The illustration of the research results supports their discussion well, and the conclusions drawn are based on the research conducted. It should be stated that in terms of the results obtained, the work bears the mark of originality and shows a great deal of research independence of the Author. The research hypothesis set at the outset was confirmed, which was duly proven in accordance with the research methodology.

Questions:

1. The author verified the vertical displacements determined by the developed algorithm with the results of GNSS measurements made with GNSS receivers located in the displacement field under test. Was there an attempt to use alternative control receivers

or a different configuration of them to test the repeatability of the algorithm verification result?

The form chosen by Mr. Tondaś, for his doctoral dissertation as a series of articles in high-quality scientific journals is also preferred by me. This is because it provides the opportunity to expose one's ideas to the evaluation of anonymous reviewers, specialists selected by the journals, and not just those reviewing the work of the discipline council's choice. This allows for a very objective evaluation of what is, after all, such an important output in the career of any scientist. Of course, on the other hand, there is a risk of thematic inconsistency in the publication cycle, as it is very difficult to plan and precisely implement it *a priori*. After all, it is about research carried out over several years. In the case of Mr. Tondaś's work, this risk has been well defused, and the entire manuscript, containing a discussion of the articles and the results obtained, in the right way, leads smoothly through the research process to the final conclusions. I hope that the publications currently in the review stage will also be successfully, soon published.

3. Specific comments

The layout of the work is clear, and the breakdown of the content makes it possible to follow the research well.

The editing of the text is very neat and unobjectionable, no errors or careless descriptions of drawings were noticed. Everything is legible and correctly formatted.

4. Final evaluation of the dissertation and conclusion

After an in-depth review of the dissertation of Mr. Damian Tondaś, M.Sc., I can conclude that he has well analyzed and demonstrated general knowledge in the field of displacement research in anthropogenically transformed areas. In his work, he defined the research question from the discipline of civil engineering, geodesy and transportation, established the research hypothesis, independently defined the methodology based on the use of the fusion algorithm of satellite radar interferometry and GNSS measurements using the Kalman filter. Finally, based on the research performed, he obtained confirmation of the hypothesis and drew conclusions based directly on the results of his own research. Thus, he demonstrated originality and independence in solving the research problem.

In conclusion, Mr. Damian Tondaś, M.Sc., demonstrated in the work the general theoretical knowledge of the discipline of civil engineering, geodesy and transportation, as well as the ability to conduct scientific work independently. The work shows the hallmarks of an original solution to a research problem.

To form an idea of the final value of the reviewed work, I have compiled below my subjective assessments in ten criteria that usually form the basis of reviews of scientific research.

Evaluation criterion	Evaluation		
	high	average	low
Careful editing of the work	X		
Graphic side of the work		X	
Literature and vocations		X	
Whether the correct assumptions were made with reference to the state of knowledge	X		
The author's ability to be critical of the state of the art	X		
Ability to prove and justify theses	X		
Have the results of the study been verified/confronted with the results of other researchers		X	
Selection of research methods	X		
Originality of solutions used in research		X	
Contribution of the doctoral student to the development of the discipline	X		

In the ten criteria adopted, I awarded 6 high, 4 medium and 0 low. Considering these notes, the work could be rated above good (4.5) if such ratings were formally accepted.

Taking into account the entire evaluation of the work and the above opinion, I conclude that the reviewed doctoral dissertation of Damian Tondaś, M.Sc., entitled "Integration of GNSS and InSAR observations for monitoring deformations in mining areas" meets the criteria of Article 187, paragraphs 1 and 2 of the Law of July 20, 2018 "Law on Higher Education and Science" (Journal of Laws 2022, item 574, as amended), for a candidate for the degree of Doctor of Technical Sciences. Accordingly, I submit a motion to the Council of the Discipline of Civil Engineering, Geodesy and Transportation, Wrocław University of Life Sciences to admit the dissertation to public defense.

A handwritten signature in blue ink, appearing to read 'Ryszard Hejmanowski', with a long horizontal flourish underneath.

Ryszard Hejmanowski