THREE- AND FOUR-DIMENSIONAL TOPOGRAPHIC MEASUREMENT AND VALIDATION

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Topic Nr.	PIs	Title
32278_1	*Prof. Norbert Haala, Prof. Timo Balz*	***Topographic Mapping - Validation; TMV***
32278_2	*Prof. Stefano Tebaldini, Prof. Mingsheng Liao*	***Multi-baseline SAR processing for 3D/4D reconstruction; MBSAR***
32278_3	*Prof. Ramon Hanssen, Prof. Xiaoli Ding*	***Towards Near-Real Time InSAR Deformation estimation; NRT***

EXECUTIVE SUMMARY

The main objectives will include: absolute geo-coordinate estimation of artificial targets in optical and SAR imagery and the validation of their accuracy Digital elevation model (DEM) generation and validation Improving of existing methods using multi-baseline SAR for 3D and 4D information retrieval Near-real time surface motion estimation with multi-baseline InSAR Glacier motion and 3D subsurface information retrieval Development of new validation methods for surface motion estimation Polarimetric TomoSAR analysis for forest parameter retrieval Stereo-Radargrammetry analysis for incoherent forest height change retrieval InSAR techniques provide researchers a set of tools for topographic mapping, as well as for monitoring deformations on the Earth surface. In Dragon-1 and Dragon-2, the focus was on DEM generation and surface motion estimation with medium resolution InSAR. Since, Dragon-3, SAR datasets of high spatial and temporal resolution (TerraSAR-X, COSMO-SkyMed) are available and with the availability of Sentinel-1 data, a global time-series coverage is now reality.

With the availability of a global coverage with Sentinel-1, the continuous surface motion estimation with SAR becomes a topic of great interest. Therefore, in this proposed project, the focus is now switching to a more complete and near real-time retrieval of 3D and 4D information from multi-baseline SAR. To reach a near real-time surface motion estimation, a continuous update of the data stack in processing is required, which also requires a continous and automatic update in the processing parameters. Also, based on the experiences gained during Dragon 1-3, the validation of the 3D and 4D results is crucial. Moreover, polarimetric SAR tomography to investigate distributed media, such as forests and ice is getting more important. Using long wavelength systems, full-polarimetric TomoSAR can be used to reconstruct the 3D backscattering profile in forest. This is especially valuable for the estimation of biomass in tropical and boreal forests. Generally, the global estimation of the Earths biomass can be considered to be incomplete and, literally, only scratching the surface. With TomoSAR, not only the height of canopies can be measured, but a complete three dimensional backscattering profile is possible. In this context, this proposal will respond to the ESA mission objectives in following aspects: Continuing of the successful research cooperation since Dragon-1 Test and validate the expected accuracy of DEMs derived with different techniques Provide a common testing ground and baseline to test against for newly developed methods and for new satellite missions Evaluating the expected DEM precision derived from different EO data from ESA, TPM, and Chinese missions. Developing techniques for the continuous surface motion surveillance with Sentinel-1 Developing techniques and applications for the available and upcoming sensors, i.e. BIOMASS and Chinese D-InSAR system Developing relevant algorithms and data processing procedures The project covers various topics from the Dragon-4 domains, especially: Solid Earth & associated disaster risk reduction - DEMs, landslides, subsidence, and infrastructure Ecosystems including forest & grasslands - 3D structure methods and research CAL/VAL Extend cooperation on geometric and radiometric calibration.

ABSTRACT 32278_1: "Topographic Mapping - Validation; TMV"	
European Principal Investigator	***Chinese Principal Investigator***
Prof. Norbert Haala	Prof. Timo Balz
(Universität Stuttgart,GERMANY)	(Whuan University,CHINA)

With the increasing amount of available remote sensing data suitable for topographic measurement and surface motion estimation, and with the parallel ongoing increase in related research, thorough validation of results is getting increasingly important. In this context, our goal is to validate the topographic mapping accuracy of various ESA, TPM, and Chinese satellite system on test sites in the EU and China, define and improve the validation methodologies for topographic mapping, and develop and setup test sites for the validation of different surface motion estimation techniques.

The main objectives will include:

- absolute geo-coordinate estimation of artificial targets in optical and SAR imagery and the validation of their accuracy
- Digital elevation model (DEM) generation with optical and SAR data using different techniques
- Validation of the DEM accuracies
- Surface motion estimation from interferometric SAR and pixel tracking
- Development of new validation methods for surface motion estimation
- Validating the surface motion estimation with traditional and newly developed methods

Primarily the already available test sites of the University Stuttgart in Vaihingen (Germany) and the test site of the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing of Wuhan University nearby Mount Song (China) will be used for this purpose. For these test sites, the necessary ground-truth is already available.

Further test sites are to be developed. First, for urban subsidence, we will continue the processing and validation in Shanghai. Additionally, we will setup a test site in Wuhan for precise testing. Furthermore, smaller test sites are to be developed for extreme conditions. So, we will setup tests in the high mountain areas of the Chinese TianShan mountain range and in the extreme dry Gobi Desert.

This proposal will respond to the ESA mission objectives in following aspects:

- Evaluating the expected DEM precision derived from different EO data from ESA, TPM, and Chinese missions.
- Test and validate the expected accuracy of DEMs derived with different techniques
- Provide a common testing ground and 'baseline' to test against for newly developed methods and for new satellite missions
- Develop strategies for a more efficient validation of surface motion estimations from InSAR and other techniques

References:

M. Cramer, N. Haala, N, "DGPF Project: Evaluation of digital Photogrammetric Aerial-based Imaging Systems – Overview and Results from the Pilot Center," Photogrammetric Engineering & Remote Sensing Vol. 76, No. 9, September 2010, pp. 1019-1029.

A. Ferretti, G. Savio, R. Barzaghi, A. Borghi, S. Musazzi, F. Novali, C. Prati, F. Rocca, "Submillimeter Accuracy of InSAR Time Series: Experimental Validation," IEEE Transactions on Geoscience and Remote Sensing, Vol. 45(5), 2007, pp. 1142-1153.

N. Haala, H. Hastedt, K. Wolff, C. Ressl, S. Baltrusch, "Digital Photogrammetric Camera Evaluation - Generation of Digital Elevation Models," Photogrammetrie - Fernerkundung – Geoinformation (PFG). Heft 2 pp. 99 -115, 2010.

N. Haala, "The Landscape of Dense Image Matching Algorithms," in Photogrammetric Week '13, Ed. D. Fritsch, Wichmann, Berlin/Offenbach, pp. 271-284, 2013.

D. Perissin, C. Prati, F. Rocca, D. Li, M. Liao, "Multi-track PS analysis in Shanghai," Proc. of ENVISAT, 2007.

F. Rottensteiner, G. Sohn, J. Jung, M. Gerke, C. Baillard, S. Benitez, U. Breitkopf, "The ISPRS benchmark on urban object classification and 3D building reconstruction," in ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., I-3, pp. 293-298, 2012.

ABSTRACT 32278_2: "Multi-baseline SAR processing for 3D/4D reconstruction; MBSAR"	
European Principal Investigator	***Chinese Principal Investigator***
Prof. Stefano Tebaldini	Prof. Mingsheng Liao
(Politecnico di Milano,ITALY)	(Whuan Univesity,CHINA)

The main objectives will include:
- multi-baseline SAR for 3D and 4D information retrieval
- Tomographic SAR analysis in urban areas
- Polarimetric TomoSAR analysis for forest parameter retrieval
- Stereo-Radargrammetry analysis for incoherent forest height change retrieval
- Glacier motion and 3D subsurface information retrieval

InSAR techniques provide researchers a set of tools for topographic mapping, as well as for monitoring deformations on the Earth surface. In Dragon-1 and Dragon-2, the focus was on DEM generation and surface motion estimation with medium resolution InSAR. Since, Dragon-3, SAR datasets of high spatial and temporal resolution (TerraSAR-X, COSMO-SkyMed) are available and with the availability of Sentinel-1 data, a global time-series coverage is now reality.

In this proposed project, the focus is now switching to a more complete retrieval of 3D and 4D information from multi-baseline SAR. In this context, we will continue the research on PS-InSAR based techniques and continue the work on analyzing of landslides, subsidence due to mining or underground water extraction, and seismic activity. Additionally, we will further work on the urban tomographic SAR technics for high-resolution 3D/4D information retrieval.

Moreover, this proposal also focuses on the use of polarimetric SAR tomography to investigate distributed media, such as forests and ice. Using long wavelength systems, full-polarimetric TomoSAR can be used to reconstruct the 3D backscattering profile in forest. This is especially valuable for the estimation of biomass in tropical and boreal forests. Generally, the global estimation of the Earth's biomass can be considered to be incomplete and, literally, only scratching the surface. With TomoSAR, not only the height of canopies can be measured, but a complete three dimensional backscattering profile is possible.

Stereo-radargrammetry will also be considered, as a complementary technique to TomoSAR focused on forest height retrieval. Indeed, Radargrammetry outperforms interferometric radar because it does not require simultaneous passes and can therefore be used more readily over forested areas, and multiple times in response to time-specific events (such as illegal deforestation or damage from storms). By determining 3D information over large areas (100's square km), it can potentially provide rapid assessment of forest height change (but at a cost 20 times cheaper than airborne Lidar).

Finally, for ice sheets and land ice mass estimation, TomoSAR with long wavelengths allows the penetration of ice and the detection of sub-surface water content and sub-surface holes in the ice for a much more detailed estimation of the thawing. These applications, although in an early stage, are essential for a future better understanding of the global change.

In this context, this proposal will respond to the ESA mission objectives in following aspects
- Continuing of the successful research cooperation since Dragon-1
- Investigating the possibility for advanced SAR processing, considering both coherent (InSAR, TomoSAR) and incoherent (stereo-radargrammetry) techniques
- Developing techniques and applications for the available (i.e. Sentinel-1) and upcoming sensors, i.e. BIOMASS, SAOCOM-CS, Tandem-L, and Chinese D-InSAR system
- Developing relevant algorithms and data processing procedures

The work on this proposal will be supported by the following projects:
- Landslide monitoring and early warning by coupling InSAR observation and geological model, funded by National Key BasicResearch Program of China, 01/01/2013-01/08/2017.(Contract No.: 2013CB733205, PI: Mingsheng Liao)
- Urban target interpretation and dynamic monitoring from high-resolution SAR imagery, funded by Nature Science Foundation, China, 01/01/2014 -12/30/2018.(Contract No.: 61331016, PI: Mingsheng Liao)
- Monitoring bridge deformation by using high-resolution time-series InSAR analysis, funded by Nature Science Foundation, China, 01/01/2016 -12/30/2019.(Contract No.: 41571435, PI: Mingsheng Liao)

ABSTRACT 32278_3: "Towards Near-Real Time InSAR Deformation estimation; NRT"	
European Principal Investigator	***Chinese Principal Investigator***
Prof. Ramon Hanssen	Prof. Xiaoli Ding
(Delft University of Technology,Netherlands)	(PolyU Shenzhen Research Institue,CHINA)

Monitoring the kinematic behaviour of millions of ground points and targets anywhere on Earth is feasible on a weekly/tri-weekly basis using Synthetic Aperture Radar Interferometry (InSAR). The standard approach for multi-epoch InSAR processing is to estimate the unknown parameters (e.g. the kinematic deformation time series, as well as topographic and atmospheric contribution) based on the entire set of observations in a 'batch'-approach, i.e., in one overall adjustment.

However, with the advent of routinely acquiring missions such as Sentinel-1, there is a need for efficient algorithms to allow for the digestion of new acquisitions, preferably in an efficient and recursive way. Such methods should provide updates of the parameters of interest, identify the birth of new, or decay of old, coherent scatterers, but also allow for a change in the parameterization of the estimation problem. Thus, instead of a batch approach, methodology should be more 'recursive' in nature. This is a challenging and far from trivial task, that requires robust statistical methods as well as efficient numerical/computational implementations and data flow.

In this study, we attempt to develop and demonstrate methodology to achieve this Near-Real time InSAR time series analysis. We focus on four aspects.

1) the improvement of InSAR processing, which will be built upon Doris (Delft object-oriented radar interferometric software, http://doris.tudelft.nl), as well as advanced processing methods such as HKPU's TCP-InSAR. The Sentinel-1a data processing toolbox will be developed and involved to work with these software tools.

2) the parameter estimation. The mathematical estimation of the InSAR parameters is essentially an ill-posed problem, considering the intrinsic uncertainty in resolving the 2-pi phase ambiguities. We are aiming at high-precision parameter estimation based on an optimal functional and stochastic model. Especially for recursive estimation, and for problems where the parameterization may change from point to point, or from epoch to epoch, this requires a fundamental approach.

3) quality assessment and quality control (QA/QC). The quality description of InSAR results/estimates is composed of precision and reliability. Precision is the dispersion of a stochastic variable around its expectation value, whereas reliability expresses the detectability of model imperfections and their influence on the parameter estimates. We use numerical simulation methods to achieve proper quality description and control, and we use internal/cross validation methods to evaluate the InSAR results. Where possible, ancillary data (e.g. optical, GPS, Lidar and leveling) will be used for validation, but the methodology is aimed towards QA/QC which is stand-alone. Special emphasis in this context is placed on the inclusion of expert knowledge in the estimation problem.

4) interpretation. InSAR is able to reveal geophysical phenomena, such as earthquakes, volcano deformation, or subsidence, and retrieve their long-term historical evolution. According to the analysis on InSAR time series, for instance, the driving mechanisms can be well described, and the anomalous changes can be recognized. However, when applied to problems of, e.g., infrastructural monitoring, there may not be any spatial consistency between measurement points, and therefore interpretation of the signals (distinguishing real anomalous deformation from noise) is cumbersome. We aim to significantly increase the positioning accuracy of (effective) scatterers, and link these positions to real-world objects, in order to make the results more interpretable.

These four aspects will be covered in the main work packages of the project.

Funding of the project will come from (a) internal funding of TU Delft, (b) funding via the Wuhan-TU Delft Joint Research Center, (c) proposals submitted to national agencies of the project partners.