Automatic geodetic monitoring with total stations based on the open source software library JAG3D

Case study of a rockfall in Trier/Germany

Frederik SCHULTE[1,3*], **Leon SCHNEIDER**[1], **Michael LÖSLER**[2], **Stefan PRINTZ**[1], and **Daniel CZERWONKA-SCHRÖDER**[1]

[1] *Bochum University of Applied Sciences, Bochum, Germany (leon0.schneider@stud.hs-bochum.de, stefan.printz@hs-bochum.de, daniel.czerwonka-schroeder@hs-bochum.de)*

[2] *Frankfurt University of Applied Sciences, Frankfurt am Main, Germany (michael.loesler@fb1.fra-uas.de)*

[3] *University of Innsbruck, Innsbruck, Austria (frederik.schulte@uibk.ac.at)*

[*] *Corresponding Author*

Abstract

This paper presents an advanced methodology for automatic geodetic monitoring using total stations, employing the open-source software library JAG3D. As part of the BMBF-funded AImon5.0 research project, an extensive installation of geodetic measuring systems was set up in Trier (Germany). In addition to a permanent laser scanner, GNSS, inclination sensors and numerous meteorological sensors, a total station has been installed, whose data acquisition and evaluation has been further developed as part of an automated pipeline based on open data interfaces and open-access analytical software. Our approach demonstrates the practical application of JAG3D in geodetic monitoring by detailing the system's setup, data acquisition processes, and analysis procedures. The results underline the software's capability to handle large datasets and provide accurate deformation measurements. This automated system enhances efficiency and reliability, allowing for timely responses to geological hazards. In the Trier case study, the system successfully detected hourly displacement magnitudes in the rock formation, which were critical for early warning and mitigation strategies. This paper examines the challenges encountered, including environmental influences and complexities in automation, and discusses the approaches taken to address them. The findings highlight the potential of open-source solutions in geodetic monitoring, promoting wider accessibility and adoption in various geotechnical applications.

Keywords: Deformation analysis, Monitoring, Total station, JAG3D

1 Introduction

In recent years, the frequency and magnitude of gravitational mass movements such as landslides, slope failures, debris flows, and rockfalls has increased. This phenomenon is primarily driven by climate change and the complex interactions among various interdependent factors under its influence (Brasseur et al., 2023). When monitoring these phenomena, methods from engineering geodesy can make a crutial contribution by producing qualitative, high-resolution and reliable 4D (3D + time) earth surface data. The purpose of monitoring is not only to document the status quo, but is also a key component of risk management to identify hazards at an early stage and initiate mitigation strategies.

This paper is part of the AImon5.0 research project (Czerwonka-Schröder et al., 2025) funded by the German Federal Ministry of Education and Research (BMBF). The project focuses on real-time monitoring of gravitational mass movements, with particular emphasis on the use of permanent laser scanners (PLS). This technology enables the continuous acquisition of high-resolution 4D point clouds, which are essential for the accurate analysis of changes in at-risk objects. The analysis of this type of data is complex, so AI-based methods are being developed to automatically identify relevant events and process the data for decision-making.

An important aspect of the project is a test installation at the *Trierer Augenscheiner*, a geologically exposed rock massif that has already been affected by gravitational mass movements in the recent past. In addition to permanent laser scanning, a total station is being used at this site to verify the laser scanner measurements and ensure the accuracy and consistency of the data.

One of the main challenges in comprehensive geomonitoring projects is the integration of different sensor types. In many cases, users find themselves in a proprietary hardware and software ecosystem where the integration of sensor data into a homogeneous monitoring result is complex and inflexible. Existing software solutions often function as "black box" systems, restricting user access to parameterization. Additionally, poorly documented or inaccessible data interfaces and exchange formats hinder customization for project-specific requirements. Significant licensing costs are added to the already considerable hardware costs, as many systems use project or sensor-based billing models. These fundamental barriers make it difficult to implement monitoring projects in a scalable and economically efficient manner.

Therefore, we aim to address the lack of open, modular software solutions that support vendor-independent integration and enable flexible data analysis. Open source software offers a promising approach. It creates transparency and makes it possible to respond precisely to project or application-specific requirements. It also eliminates the reliance on project-specific solutions: Once a software solution has been developed, it can be deployed across various projects, independent of geographic location or specific project requirements, thereby obviating the need to develop new software from scratch for each application. This increases the range of applications and reduces integration time and costs for each monitoring task.

The research project will develop a application-orientated approach to integrating global navigation satellite systems (GNSS), PLS, inclination sensors and total station data into a common global coordinate framework. This approach will significantly improve the comparability and quality of results.

In this article, we examine the integration of a total station into a workflow based on open-source software. The chosen software platform is JAG3D, a established solution developed by the Steinbeis Transfer Centre Applied Geodesy. JAG3D allows the combination of different observation methods such as levelling, direction and distance measurements as well as GNSS baseline measurements. The software has proven itself worldwide due to its flexibility and wide range of applications in the field of geomonitoring and industrial metrology.

Based on this, we formulate the key research question of the article: Is it possible to effectively use open source software for geodetic monitoring? We present a workflow from data acquisition to analysis and visualisation. The aim is to provide the scientific community with an example of an automated workflow that demonstrates the integration of heterogeneous sensor data and shows the potential applications.

This contribution is organised as follows: Section 2 provides a brief overview of the JAG3D software package and the implemented approach for analysing deformations. The developed workflow for automated monitoring, including instrument communication and data management, is presented in Section 3. It was successfully tested on a rockfall in Trier and Section 4 shows some preliminary results. The study concludes with a discussion in Section 5 on the benefits of utilizing JAG3D, including cost-effectiveness, adaptability, and community support, suggesting a robust framework for future geodetic monitoring projects.

2 Java·Applied·Geodesy·3D

Java·Applied·Geodesy·3D (JAG3D) is an open source software for geodetic network adjustment and deformation analysis. The software estimates the coordinates of redundantly observed points by combining levelling data, classical terrestrial observations, laser-tracker measurements as well as data obtained form GNSS using the principle of least-squares adjustment. As shown by Durand et al. (2022), large-scale networks can be fully spatially estimated by introducing a topocentric coordinate system that takes into account the curvature of the Earth. For a detailed description of the implemented mathematical model, the interested reader is referred to the contribution by Lösler et al. (2023). The application consists of three logical components, namely the graphical user interface (GUI), the adjustment kernel, and the project management system. The project management is realised by an embedded relational SQL database management system. The user interface as well as the adjustment kernel are independent of each other and interact with the database. The database contains all project-specific settings and data and can be operated on and modified with any tool that supports the structured query language. Thus, JAG3D's graphical user interface is not required to administrate the database or to adjust a network. This emphasises the suitability of JAG3D in automated applications such as continuous monitoring tasks.

The implemented concept of the deformation analysis is based on the original observations $\mathbf{l}_i$ of $i = 1, 2$ epochs to be analysed, and estimates the reference points $\mathbf{x}_\mathrm{R}$, which are assumed to be stable, as well as the object points $\mathbf{x}_{\mathrm{O}_i}$ of each epoch. The related functional model reads (Jäger et al., 2005, p. 274)

$$\begin{bmatrix}\mathbf{l}_1\\ \mathbf{l}_2\end{bmatrix} + \begin{bmatrix}\mathbf{v}_1\\ \mathbf{v}_2\end{bmatrix} = \begin{bmatrix}\mathbf{A}_{\mathrm{R}_1} & \mathbf{A}_{\mathrm{O}_1} & \mathbf{0}\\ \mathbf{A}_{\mathrm{R}_2} & \mathbf{0} & \mathbf{A}_{\mathrm{O}_2}\end{bmatrix} \begin{bmatrix}\hat{\mathbf{x}}_\mathrm{R}\\ \hat{\mathbf{x}}_{\mathrm{O}_1}\\ \hat{\mathbf{x}}_{\mathrm{O}_2}\end{bmatrix}, \qquad (1)$$

where nuisance parameters are assumed to be eliminated. The vector $\mathbf{v}_i \sim \mathrm{N}\left(\mathbf{0}, \mathbf{C}_{\mathbf{l}i}\right)$ denotes the normal distributed residuals where $\mathbf{C}_{\mathbf{l}i}$ is the positive definite dispersion matrix defining the stochastic model. The design matrix $\mathbf{A}$ is separated into two parts. Whereas $\mathbf{A}_{\mathrm{R}_i}$ refers to the reference points, $\mathbf{A}_{\mathrm{O}_i}$ relates to the object points. The reference points $\mathbf{x}_\mathrm{R}$ connect both epochs and define the uniform datum of the deformation network. The object points $\mathbf{x}_\mathrm{O}$ are considered unstable and treated as independent in each epoch.

In order to evaluate the stability of the reference points, the functional model (1) is extended, i. e.,

$$\mathbf{l} + \mathbf{v} = \mathbf{A}\hat{\mathbf{x}} + \mathbf{B}_j \hat{\nabla}_j. \qquad (2)$$

Here, the matrix $\mathbf{B}_j$ is the extension of the design and the vector ∇_j parameterises the potential displacement of the j-th reference point in $\mathbf{x}_\mathrm{R}$. If the j-th reference point is stable, i. e. $\hat{\nabla}_j \sim \mathrm{N}\left(\mathbf{0}, \mathbf{C}_{\hat{\nabla}_j}\right)$, the test statistic

$$T_j = \frac{\hat{\nabla}_j^\mathrm{T} \mathbf{C}_{\hat{\nabla}_j}^{-1} \hat{\nabla}_j}{m} \sim F_{m,\infty} | H_0 \qquad (3)$$

follows a central $F_{m,\infty}$-distribution with $m = \mathrm{rg}\, \mathbf{C}_{\nabla j}$ numerator and ∞ denominator degrees of freedom (Lehmann and Lösler, 2017).

The null hypothesis is rejected in favour of the alternative hypothesis, if the test statistic exceeds the critical value c computed for a type I decision error with probability α. The reference point corresponding to the largest test statistic exceeding the critical value, i. e. $\max T_j > c$, is to be considered unstable and treated as object point within the next network adjustment. This consecutive procedure is repeated until a stable reference point field is identified and is fully equivalent to the data snooping procedure proposed by Baarda (1967).

Based on the identified stable reference point field, the deformations of the object points are evaluated. Let the k-th difference vector between the corresponding object points be defined as

$$\hat{\nabla}_k = \mathbf{F}_k \begin{bmatrix}\hat{\mathbf{x}}_{\mathrm{O}_1}\\ \hat{\mathbf{x}}_{\mathrm{O}_2}\end{bmatrix} = \hat{\mathbf{x}}^k_{\mathrm{O}_2} - \hat{\mathbf{x}}^k_{\mathrm{O}_1}, \qquad (4)$$

where $\mathbf{F}_k = \begin{bmatrix}\mathbf{0} & -\mathbf{I}^k_1 & \mathbf{0} & \ldots & \mathbf{0} & \mathbf{I}^k_2 & \mathbf{0}\end{bmatrix}$ is a coefficient matrix.

According to Eq. (3), the test statistic under the null hypothesis, which states that no deformation occurred, follows an $F_{m,\infty}$-distribution. If this test statistic exceeds the critical value, i. e. $\max T_k > c$, the null hypothesis is rejected in favour of the alternative hypothesis, and the k-th object point is considered as deformed. A detailed description of the implemented deformation analysis is given by Lösler et al. (2017).

If the test statistic in Eq. (3) is rejected, the distribution of T follows a non-central $F_{m,\infty,\lambda}$-distribution with non-centrality parameter (Baarda, 1967, pp. 27f)

$$\lambda = \tilde{\nabla}^\mathrm{T} \mathbf{C}_{\hat{\nabla}}^{-1} \tilde{\nabla}. \qquad (5)$$

The non-centrality parameter is not known because the expectation $\mathrm{E}\left\{\hat{\nabla}\right\} = \tilde{\nabla}$ of the true deformation is generally unknown. However, by specifying the type I and type II decision errors α and β, the non-centrality parameter $\lambda(m, \alpha, \beta)$ is obtained. Substituted into Eq. (5) yields the minimum detectable deformation $\nabla(\alpha, \beta)$ w.r.t. the stipulated probability levels as a measure of the internal reliability (Knight et al., 2010). As $\nabla(\alpha, \beta)$ is independent of the observations, it provides an indicator for the size of detectable deformations w.r.t. the network configuration and the stochastic model. During the planning and optimization process of geodetic and deformation networks, JAG3D provides $\nabla(\alpha, \beta)$ as a measure of sensitivity to evaluate the accuracy and the reliability of the network.

3 General Workflow

This section presents the automated workflow for deformation analysis, integrating total station measurements into JAG3D for efficient geodetic network monitoring. The developed scripts are freely available on GitHub[1]. Two main components are provided there. The first component (I) involves the main JAG3D-Batch process. The second component (II) extends this functionality by enabling control of a Leica total station on a Raspberry Pi, ensuring automation of the entire monitoring workflow on a microcomputer.

In the following the workflow is shown in Figure 1 and divided into several tasks marked with [brackets]. Initially, all targets must be measured once during the setup of the deformation-network to ensure that observation elements for all targets are available [1]. The script, originally developed for a monitoring project at Bochum University of Applied Sciences, utilizes the GeoCom2 library, which encapsulates serial communication between a Python script and a Leica total station. This library provides access to the Leica GeoCOM Reference Manual functions (Leica Geosystems, 2006), enabling automated instrument positioning and measurement execution. By establishing a serial connection, the library transmits commands as character strings to the total station, waits for a response, and returns the measurement object to our JAG3D-Batch script. This structured communication process ensures the sequential acquisition of all target points while maintaining compatibility with older instruments.

If the atmospheric correction and mapping reduction have not yet been applied within the instrument, they should be performed at this stage to avoid introducing systematic deviations into the adjustment [2]. After correction, the observations are transmitted to the batch process (I) for congruence analysis.

To perform deformation analysis, users should first create a JAG3D project manually. It is recommended to perform this setup via the GUI. Approximate

[1]github.com/Frederik-Schulte/JAG_Batch

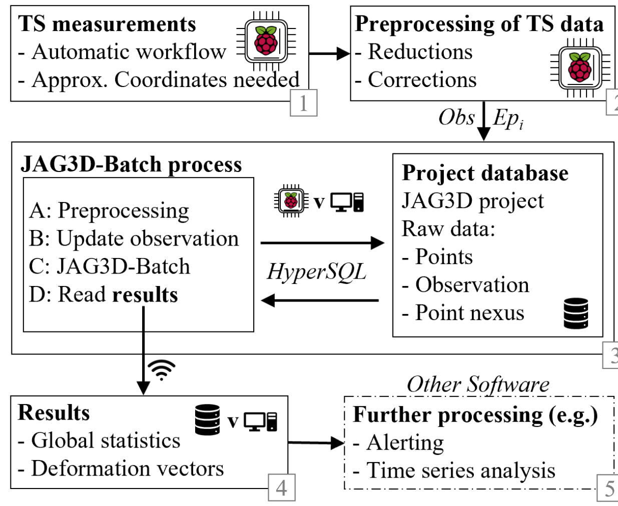

Figure 1. Schematic representation of the automatic, open source monitoring process with JAG3D using an Raspberry Pi

coordinates for the reference points ($\hat{\mathbf{x}}_R$) and the object points for both epochs ($\hat{\mathbf{x}}_{O_1}, \hat{\mathbf{x}}_{O_2}$) must be imported. Additionally, point nexuses of $\hat{\mathbf{x}}_{O_1}$ and $\hat{\mathbf{x}}_{O_2}$ are required for the computation of deformation vectors ($\hat{\nabla}_j$). The type I and II errors must also be specified. With these inputs, the mathematical model of the deformation network can be pre-analyzed in terms of accuracy, reliability, and sensitivity. This approach enables the assessment of the geodetic datum, network configuration, and observation uncertainties, ensuring optimal network design before the beginning of the measurements. To conduct a deformation analysis, the observations from the first two epochs ($\mathbf{l}_1, \mathbf{l}_2$) with their statistical uncertainties are required, and all points must be present in these initial epochs. Once all necessary data is included in the project database, the automation process can begin [3]. Since the reference epoch remains constant, only the observations from the new epoch ($\mathbf{l}_2$) are required. During preprocessing [A], SQL commands are generated to update the observations in the JAG3D-project database. Additionally, points not measured during the control epoch are identified, and corresponding deactivation commands are generated. This approach avoids deleting old data from the database, allowing points to remain inactive until measurements for them are available in a subsequent epoch. In the next step [B], a connection to the HyperSQL project database is established and the commands generated in [A] are executed to include the new control epoch ($\mathbf{l}_2$) in the database.

In [C] the JAG3D adjustment kernel is started via a system call, to perform the deformation analysis with the new epoch. Finally, the project database can be accessed again to extract the results of the deformation analysis [D]. Any table values can then be exported or viewed via the JAG3D-GUI. The script only outputs the global a-posteriori variance factor $\hat{\sigma}^2$, deformation vectors $\hat{\nabla}_k$ for all points, the a-priori test statistics T_j, and the results of hypothesis tests [4]. The output can be adapted with minimal modifications to the code.

These results can be transmitted via internet to a database for further processing using additional open source software, enabling tasks such as alarm generation or time series analysis [5]. The entire workflow can be automated using open source tools like Node-RED or Cron, which can execute the described process at predefined, regular intervals (e.g., every 60 minutes). The combination of multiple total station control scripts (II) and the JAG3D-Batch script (I) enables the application with multiple stations in a deformation measurement. The script additionally already provides functionality for importing and adjusting height differences, such as those from hose balances. Theoretically, all observations supported by JAG3D can be integrated into the automated workflow. This enables cost-effective and professional monitoring of highly complex deformation tasks.

4 Monitoring of a rockfall in Trier

Following the presentation of the mathematical foundations of deformation analysis and the implementation of automation using JAG3D in previous sections, this section introduces a practical application of these methods. A research project at Bochum University of Applied Sciences in *Schwelm, Germany* has successfully implemented remote control of a total station using a Raspberry Pi. This system has been monitoring a building for several years with minimal operational issues, demonstrating its reliability. The automated deformation analysis with JAG3D was implemented within the framework of the AImon5.0 project, building upon the feasibility studies conducted by Lösler et al. (2010) during measurement campaigns in *Wettzell, Germany*.

The monitoring is located at the *Trierer Augenscheiner*, where a potential rockfall poses a threat to the infrastructure which is placed below and frequently used by the public. The geological formation together with the network configuration is illustrated in Figure 2. The main setup is described by Czerwonka-Schröder et al. (2025), while this study focuses specifically on the total station monitoring component. The measurements are conducted from the southern side of the *Mosel* river, using a Leica TM30 total station. This setup enables real-time data acquisition, correction, analysis, and visualization via an online portal. To detect displacements within the monitored area while maintaining a stable geodetic reference frame, 22 prisms (Leica GPR1) were installed on both sides of the river. The total station was calibrated before deployment. To further minimize instrument-related influences, each measurement epoch consists of a two-face observation of each point (Deumlich and Staiger, 2002). Due to the large target distances of up to 400 m, the influence of atmospheric refraction has a significant impact on distance measurements. Therefore, these measurements are corrected in post-processing using data from a weather station, applying the formulas by Ciddor (1996). A correction of the distance-observations into a global geodetic reference system is not required, as a topocentric coordinate system is used, as outlined in Section 2.

To systematically record deformation events with the total station, a measurement interval of 1 hour was chosen. The data acquisition campaign started on December 12, 2023. At this stage, no precise information on the displacement behaviour of the monitored area was available. Therefore, all points south of the *Mosel* were initially designated as reference points, while those to the north, where the rocks are, were treated as object points for deformation measurements. Due to the resulting suboptimal network geometry, the JAG3D project created for the deformation analysis was utilized to perform a pre-analysis, assessing whether the network could provide sufficiently reliable data. Consequently, the study area was monitored using this network design for the first few months. Once the initial time series, including deformation vectors and statistical global and point-wise tests, became available, the geodetic datum of the network was reconfigured using the JAG3D-GUI. Subsequently, all data were reprocessed with the new datum to establish a consistent

Figure 2. 3D visualization of the AImon5.0 monitoring project at the *Trierer Augenscheiner*. A potential rockfall event is automatically monitored over several years using a total station. Background map: (Google Earth, 2025)

time series. A further datum change was necessary when a rockfall event occurred during the night of August 25, 2024 to August 26, 2024. Points within the influence area of this event were plastically deformed, making previously stable datum points unusable. The deformation was successfully detected, as shown in Figure 3. The time series of point U08, which, as seen in Figure 2, was directly affected by the rockfall, is presented there. It shows a significant deformation of about 15 mm, which also led to the rejection of the statistical test. Since most other points in the monitoring area remained stable, the deformation can be quickly localized based on the data. Thus, the JAG3D-Batch was able to demonstrate its functionality under real-world conditions.

Another advantage of using JAG3D was the ability to establish a topocentric coordinate system and perform a comprehensive 3D deformation analysis with integration into a global reference frame. This approach enabled direct comparison and validation of total station measurements with data from two GNSS receivers deployed in the field (see Figure 2).

As of early February 2025, approximately 10,000 epochs have been successfully processed without any failures in the JAG3D-Batch processing. This result underscores the reliability of the low-cost, open source system for large-scale monitoring applications.

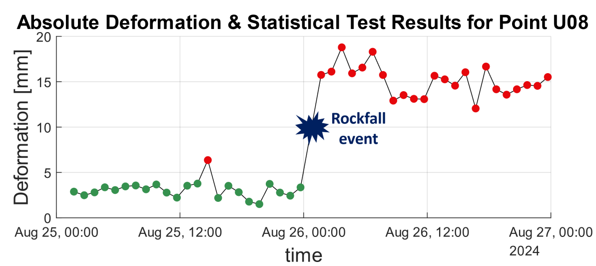

Figure 3. Time series of point U08 from August 25, 2024, to August 26, 2024. This point was directly affected by the rockfall. In addition to the deformation, the result of the statistical test for deformation is shown. Green indicates that the point has not shifted statistically significantly, while red indicates that it has shifted statistically significantly. The authors interpret that the single significant change on August 25 was likely caused by an unaccounted systematic atmospheric influence.

5 Summary and Outlook

In this paper, an automatic open-source monitoring system was presented. A python library was developed that enables a Raspberry Pi to control a Leica total station and automatically collect measurement data. These data can subsequently be automatically processed either directly on the microcomputer or on a PC using the JAG3D software. The results can be visualized as a time series, and the workflow was successfully tested in the AImon5.0 project using a total station-based monitoring setup. Additionally, the acquired data were used to verify 4D point clouds recorded with a PLS system. The developed scripts have been published, to make them available to the scientific community and other applications.

In future work, inclination and GNSS sensors should not only serve as control elements but also be directly integrated into the network adjustment. This extension could help better estimate environmental influences, particularly refraction effects, which can have a significant impact, especially over water, thereby making the results more robust against outliers. Furthermore, the developed workflow with JAG3D could also be applied to process PLS measurements, for example, through direct target measurements (Schröder et al., 2022) or by performing a preliminary analysis using pseudo-observations (Raffl and Holst, 2024). This could lead to an even broader adoption of this concept.

Funding

The BMBF (Federal Ministry of Education and Research) is funding the joint project AImon5.0 as part of the funding measure „Digital GreenTech - Umwelttechnik trifft Digitalisierung“ under the funding code 02WDG1696.

References

Baarda, W. (1967). *Statistical Concepts in Geodesy*. Publications on Geodesy, 2(4). Netherlands Geodetic Commission, Delft.

Brasseur, G. P., Jacob, D., and Schuck-Zöller, S. (2023). *Klimawandel in Deutschland: Entwicklung, Folgen, Risiken und Perspektiven*. Springer Berlin Heidelberg.

Ciddor, P. E. (1996). Refractive index of air: new equations for the visible and near infrared. *Appl Opt*, 35:1566–1573.

Czerwonka-Schröder, D., Schulte, F., Albert, W., Hosseini, K., Tabernig, R., Yang, Y., Höfle, B., Holst, C., and Zimmermann, K. (2025). AImon5.0 – Real-time monitoring of gravitational mass movements for critical infrastructure risk management with AI-assisted 3D metrology. In *6th Joint International Symposium on Deformation Monitoring (JISDM)*, Kahlsruhe.

Deumlich, F. and Staiger, R. (2002). *Instrumentenkunde der Vermessungstechnik*. Wichmann, Heidelberg, 9th edition.

Durand, S., Lösler, M., Jones, M., Cattin, P.-H., Guillaume, S., and Morel, L. (2022). Quantification of the dependence of the results on several network adjustment applications. In García-Asenjo, L. and Lerma, J. L., editors, *5th Joint International Symposium on Deformation Monitoring (JISDM)*, pages 69–77, Valencia.

Google Earth (2025). Trier, Germany. Google Earth [Version 7.3.6.10201]. Screenshot. Image-data: Landsat / Copernicus, ©2025 Airbus, data: SIO, NOAA, U.S. Navy, NGA, GEBCO. Available from: `https://earth.google.com/web/`. Accessed: 2025-02-21.

JAG3D (2024). Java·Applied·Geodesy·3D – `https://software.applied-geodesy.org`. Accessed: 2025-02-21.

Jäger, R., Müller, T., Saler, H., and Schwäble, R. (2005). *Klassische und robuste Ausgleichungsverfahren – Ein Leitfaden für Ausbildung und Praxis von Geodäten und Geoinformatikern*. Wichmann, Heidelberg.

Knight, N. L., Wang, J., and Rizos, C. (2010). Generalised measures of reliability for multiple outliers. *J Geod*, 84(10):625–635.

Lehmann, R. and Lösler, M. (2017). Congruence analysis of geodetic networks – hypothesis tests versus model selection by information criteria. *J Appl Geod*, 11(4):271–283.

Leica Geosystems (2006). Leica TPS1200 GeoCOM Reference Manual - Version 1.10.

Lösler, M., Eschelbach, C., and Haas, R. (2017). Kongruenzanalyse auf der Basis originärer Beobachtungen. *zfv*, 142(1):41–52.

Lösler, M., Eschelbach, C., Mähler, S., Guillory, J., Truong, D., and Wallerand, J.-P. (2023). Operator-software impact in local tie networks: Case study at Geodetic Observatory Wettzell. *Appl Geomat*, 15:77–95.

Lösler, M., Eschelbach, C., Schenk, A., and Neidhardt, A. (2010). Permanentüberwachung des 20 m VLBI-Radioteleskops an der Fundamentalstation in Wettzell. *zfv*, 135(1):40–48.

Raffl, L. and Holst, C. (2024). Extending geodetic networks for geo-monitoring by supervised point cloud matching. *J Appl Geod*.

Schröder, D., Anders, K., Winiwarter, L., and Wujanz, D. (2022). Permanent terrestrial LiDAR monitoring in mining, natural hazard prevention and infrastructure protection – Chances, risks, and challenges: A case study of a rockfall in Tyrol, Austria. In García-Asenjo, L. and Lerma, J. L., editors, *5th Joint International Symposium on Deformation Monitoring (JISDM)*, Valencia. Editorial Universitat Politècnica de València.