

## **BEYOND THE COMPASS: UNVEILING THE DEPTHS OF ERROR MANAGEMENT AND ACCURACY ASSESSMENT IN SURVEYING PRACTICE**

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### **Abstract**

*Error management and accuracy assessment are fundamental aspects of surveying, crucial for ensuring the reliability and precision of measurements essential for various applications. This paper explores the significance of error management and accuracy assessment in the context of surveying instruments. It delves into the theoretical foundations of errors in surveying, examines precision and accuracy concepts, and discusses strategies for minimizing errors and enhancing measurement accuracy. The paper also addresses error propagation in survey networks and adjustment methods for refining surveying measurements. Real-world case studies highlight the importance of accuracy assessment in surveying projects, construction site monitoring, and environmental monitoring. Hands-on practical exercises and technology integration in accuracy assessment are also discussed. Overall, this paper underscores the critical role of error management and accuracy assessment in ensuring the reliability and credibility of spatial data crucial for informed decision-making and effective project execution.*

*Error management, Accuracy assessment, Surveying practice, Topographic maps, Quality assurance*

### **Introduction:**

Error management and accuracy assessment are fundamental aspects of surveying, critical for ensuring the reliability and precision of measurements essential for various applications (Wolf & Ghilani, 2017). Surveying, a discipline reliant on precise measurements and spatial data, necessitates a comprehensive understanding of the sources of error inherent in the measurement process and strategies to mitigate them (Moffitt & Bossler, 2016).

This paper aims to explore the significance of error management and accuracy assessment in the context of surveying instruments. By delving into the theoretical

foundations of errors in surveying, it seeks to elucidate the different types of errors encountered during measurements and the methodologies employed to minimize their impact (Mikhail et al., 2001). Furthermore, the paper will investigate the critical concepts of precision and accuracy, examining their roles in ensuring the reliability and validity of survey data (National Research Council, 1983).

### **Theoretical Foundations:**

Surveying involves a range of observational techniques and measurement tools, each susceptible to inherent errors despite technological advancements (Kennedy & McInnes, 2010). These errors, categorized as gross, systematic, and random, pose challenges to achieving precise and accurate measurements (El-Rabbany, 2006). Gross errors, resulting from human oversight or instrument malfunctions, can significantly distort survey results and necessitate vigilant error detection mechanisms (FIG, 2006). Systematic errors, arising from consistent inaccuracies in measurement instruments or environmental factors, demand meticulous calibration and control procedures to minimize their effects (Wang & Liu, 2019). Conversely, random errors, inherent to the measurement process, introduce variability and uncertainty, necessitating statistical techniques for error quantification and mitigation (ASPRS, 2015).

Surveyors employ an array of strategies to mitigate errors and enhance measurement accuracy, including instrument calibration, redundancy in measurements, quality control protocols, and statistical analysis techniques (Online Resources, Professional Organizations). By adopting these measures, surveyors can improve the reliability and consistency of survey data, bolstering confidence in decision-making processes across diverse sectors.

In summary, error management and accuracy assessment constitute integral components of the surveying discipline, underpinning the reliability and credibility of spatial data crucial for informed decision-making and effective project execution.

### **Propagating Certainty: Analyzing Error in Survey Networks**

Error propagation in a survey network refers to how uncertainties in individual survey points contribute to uncertainties in derived quantities, such as distances, angles, or elevations (Wolf & Ghilani, 2017). The overall error in the survey network is influenced by various factors, including instrumental errors, observational errors, propagation of

systematic errors, uncertainties in control points, and considerations of geodetic datum and reference frame (National Research Council, 1983).

To manage error propagation, surveyors often employ statistical methods, conduct rigorous quality control, and utilize redundancy in measurements (Kennedy & McInnes, 2010). Additionally, incorporating error ellipses or confidence intervals in final results provides a more realistic representation of the uncertainties in the survey network (ASPRS, 2015).

Properly treating propagated errors in a survey involves several strategies to minimize their impact and provide a more accurate representation of the final results. Some common approaches include introducing redundancy in measurements, weighting observations, conducting statistical analysis, implementing quality control procedures, and developing error budgets (El-Rabbany, 2006; FIG, 2006). By employing these methods, surveyors can effectively manage and mitigate propagated errors, leading to more reliable and accurate survey outcomes (Wang & Liu, 2019). Incorporating advanced surveying instruments and environmental considerations further enhance the accuracy of survey results (Moffitt & Bossler, 2016).

### **Adjusting for Precision: Refining Surveying Measurements through Advanced Techniques**

Accuracy assessment is crucial in surveying and mapping, especially when using technologies like Global Navigation Satellite Systems (GNSS), total stations, and theodolites. When utilizing GNSS for positioning, parameters such as Root Mean Square Error (RMSE) and Circular Error Probable (CEP) are commonly used to quantify the accuracy of horizontal and vertical positions (Wang & Liu, 2019). RMSE provides an average magnitude of differences between observed and predicted positions, while CEP describes the radius of a circle within which a specified percentage of positions are expected to fall (El-Rabbany, 2006). Additionally, parameters like Positional Dilution of Precision (PDOP) assess the geometry of satellite positions in the GNSS constellation, influencing the accuracy of position fixes (Kennedy & McInnes, 2010).

In the case of total stations and theodolites, accuracy assessment parameters such as Angular Root Mean Square Error (ARMSE) and Mean Angular Error (MAE) are relevant for evaluating angular measurements (Moffitt & Bossler, 2016). ARMSE provides the average magnitude of differences between observed and predicted angular values, while MAE represents the average difference between these values. Furthermore, the

consistency of internal angles in closed traverses is assessed to ensure accurate angular measurements (Wolf & Ghilani, 2017).

When assessing the accuracy of linear measurements with total stations or theodolites, parameters such as Linear Error can be utilized. Linear Error evaluates the accuracy of linear features by measuring the distance between true and mapped locations of these features (American Society for Photogrammetry and Remote Sensing, 2015). These accuracy assessment parameters play a crucial role in ensuring the reliability and quality of surveying measurements, regardless of the technology employed.

Adjusting measurements in surveying is crucial to improve accuracy and ensure data alignment with known constraints. Various methods are commonly employed for this purpose, each offering unique advantages based on the specific requirements of the surveying task at hand (National Research Council, 1983).

One widely used method is Least Squares Adjustment, which utilizes mathematical optimization techniques to minimize the sum of squares of residuals (Wolf & Ghilani, 2017). By balancing adjustments to measurements, this method provides an optimal solution that enhances overall accuracy and reliability.

For adjusting angular measurements in closed traverses, surveyors often employ the Bowditch Rule (Compass Rule) (Thornton-Smith, 1949). This rule proportionally distributes angular errors to traverse angles, iteratively adjusting each angle to minimize discrepancies and improve alignment with known constraints.

Similarly, the Transit Rule is utilized for adjusting linear measurements in closed traverses (Thornton-Smith, 1949). It distributes closure errors proportionally among measured distances, ensuring that the adjusted solution conforms more closely to the actual conditions on the ground.

Other methods, such as Adjustment by Interpolation, Weighted Least Squares Adjustment, Conditional Adjustment, Constraint Adjustment, and Optimal Adjustment, offer additional flexibility and precision in adjusting measurements (weighted-regression, 2016). By incorporating redundancy in measurements and conducting independent checks during the adjustment process, surveyors can further enhance the accuracy and reliability of the final surveying data.

These adjustment methods collectively play a crucial role in refining surveying measurements, ensuring accuracy, and aligning data with known constraints or conditions. By employing appropriate adjustment techniques based on the specific

characteristics of the surveying task, surveyors can confidently produce high-quality and reliable surveying results (Wolf & Ghilani, 2017).

### **Real-World Case Studies:**

Areas of application of accuracy assessment are numerous to mention and some considered here include; Error Analysis: Errors, such as misclassifications or omissions, are analyzed spatially to identify patterns and understand the sources of inaccuracies (Raven, 2000). This information is crucial for improving classification algorithms and refining the accuracy of future assessments (Fischer et al., 2014; Beaubien & Baker, 2004). Decision-Making: Policymakers, environmental scientists, and resource managers rely on accurate land cover information for decision-making (Heitzmann et al., 2019). Knowing the accuracy of the classification ensures the reliability of the data used for various applications, such as monitoring deforestation, assessing urban sprawl, or managing natural resources (Grossman et al., 2009). Monitoring spatial-temporal changes Over Time: Accuracy assessment is an ongoing process, especially when monitoring changes over time (Henninger & Mandl, 2000). Regular assessments help track the accuracy of land cover classifications as the Earth's surface evolves. Accuracy assessment in this context ensures that the information derived from satellite imagery is trustworthy and can be used with confidence for environmental monitoring and decision-making. It also provides insights into the limitations of the classification process, guiding improvements in both data collection methods and analysis techniques. In a land surveying project, accuracy assessment is crucial for ensuring the reliability and precision of the collected spatial data. Example illustrating the importance of accuracy assessment in a land surveying context: A surveying firm is commissioned to create detailed topographic maps of a large area for urban planning purposes. The maps need to include accurate information about elevation, terrain features, and infrastructure. The surveyors use total stations, GPS receivers, and other surveying instruments to collect data on elevation points, property boundaries, and infrastructure details. The collected data is processed using specialized software to create a detailed topographic map. This involves interpolating elevation values, adjusting coordinates, and integrating information from different surveying instruments. A subset of control points is selected, and their accuracy is independently verified through high-precision measurements or known reference points. These control points represent key features on the map, such as property corners or elevation benchmarks. The accuracy assessment identifies discrepancies between the surveyed control points and their expected positions. Errors, such as systematic shifts or inconsistencies, are analyzed to understand their causes. Based on the accuracy

assessment results, necessary adjustments are made to the survey data and mapping algorithms. This may involve refining elevation models, adjusting boundary coordinates, or correcting for systematic errors. The accuracy assessment becomes part of the quality assurance process, ensuring that the final topographic map meets specified accuracy standards. It provides a measure of the map's reliability for users who will rely on it for various applications, including engineering design, infrastructure planning, and environmental analysis. The accuracy assessment results are shared with the client, providing transparency about the reliability of the survey data and the resulting topographic map. This builds confidence in the accuracy of the deliverables and enhances the credibility of the surveying firm. In land surveying projects, legal boundaries and land-use planning often rely on accurate spatial data. Accurate surveys contribute to legal documentation, property delineation, and compliance with zoning regulations. In this example, accuracy assessment ensures that the topographic map generated through the land surveying project is reliable, precise, and suitable for its intended purposes. It also supports the surveyors in continually improving their methods and maintaining high standards in their deliverables. Construction site monitoring involves the systematic observation and assessment of various aspects of a construction project to ensure it progresses safely, efficiently, and in compliance with design and regulatory requirements. Here are key elements and methods involved in construction site monitoring: Site Safety Monitoring: Regular safety inspections to identify and mitigate potential hazards. This includes checking for proper use of personal protective equipment, adherence to safety protocols, and evaluating the overall safety culture on the construction site. Tracking the progress of construction activities against the project schedule. This involves comparing planned milestones with actual achievements, identifying delays or advancements, and ensuring that the project stays on track. Inspection of materials, workmanship, and construction processes to ensure they meet the specified quality standards. This includes regular testing of materials, structural inspections, and verification of construction methods. Ensuring that construction activities comply with environmental regulations. This involves monitoring the impact of construction on air and water quality, noise levels, and wildlife habitats, and implementing measures to minimize environmental impact. Monitoring soil conditions and stability to ensure the safety of foundations and slopes. This may involve measuring ground settlement, monitoring groundwater levels, and conducting geotechnical surveys. Employing sensors and monitoring systems to assess the health and stability of structures during and after construction. This includes monitoring movements, vibrations, and changes in structural behavior. Using surveying techniques, such as total stations, GNSS, and laser scanning, to monitor site topography, alignment, and changes over time. This helps ensure that construction aligns with the design plans and identifies any deviations. Remote Sensing Technologies: Employing

drones and satellite imagery for aerial monitoring. This provides an overview of the entire construction site, helps track progress, and identifies potential issues. Maintaining detailed records of construction activities, inspections, and monitoring results. This documentation is essential for accountability, dispute resolution, and post-construction analysis. Regular communication with project stakeholders, including owners, contractors, and regulatory authorities. Timely reporting on project status, issues, and resolutions ensures transparency and collaboration. Monitoring weather conditions to anticipate potential challenges and delays. Extreme weather events can impact construction activities, and early awareness allows for proactive measures. Ensuring that construction activities adhere to local building codes, zoning regulations, and other legal requirements. Compliance monitoring helps avoid legal issues and potential project delays. Effective construction site monitoring integrates various technologies and methodologies to provide a comprehensive understanding of project status, risks, and compliance. It contributes to the successful and safe completion of construction projects.

Accuracy assessment plays a pivotal role across various domains, including environmental monitoring, decision-making processes, and land surveying projects. In environmental monitoring, accuracy assessment ensures the reliability of satellite-derived information, facilitating informed decision-making for policymakers and resource managers. Regular assessments enable tracking changes over time, crucial for understanding evolving environmental dynamics and guiding effective interventions (National Research Council, 1983).

In the context of land surveying projects, accuracy assessment is fundamental for ensuring the precision and reliability of spatial data. For instance, in a scenario where a surveying firm is tasked with creating detailed topographic maps for urban planning purposes, accuracy assessment becomes an integral part of the quality assurance process. By independently verifying control points and analyzing discrepancies, surveyors can refine data collection methods and mapping algorithms to meet specified accuracy standards (Wolf & Ghilani, 2017).

Construction site monitoring relies on accurate and systematic observation to ensure project progress aligns with safety, quality, and regulatory requirements. Key elements include site safety monitoring, progress tracking, material inspection, environmental compliance, and structural stability assessment. Employing a combination of surveying techniques, remote sensing technologies, and regular inspections, construction site monitoring facilitates proactive risk management and compliance with legal standards (Thornton-Smith, 1949; weighted-regression, 2016).

Overall, accuracy assessment serves as a critical component in diverse applications, contributing to the reliability, safety, and efficiency of processes. By continually evaluating and refining data quality and measurement techniques, stakeholders can confidently rely on accurate information for decision-making, planning, and regulatory compliance across various fields (National Research Council, 1983)

### Hands-On Practical Exercises

In various fields and disciplines, hands-on exercises are indispensable for honing practical skills and bridging the gap between theoretical knowledge and real-world application. Through hands-on exercises, individuals can directly apply theoretical concepts in practical scenarios, reinforcing learning and deepening understanding. Additionally, engaging in physical tasks aids in the development of muscle memory and coordination, particularly crucial in professions such as sports, arts, and technical fields where precision is paramount (National Research Council, 1983).

Procedure	Theodolite	Total Station	GNSS Receiver
<b>Setup and Calibration</b>	1. Choose a stable setup location.	1. Choose a stable setup location.	1. Choose an open area with clear sky visibility.
	2. Level the theodolite using leveling screws.	2. Level the total station using built-in level vials.	2. Place the GNSS antenna on a tripod or stable surface.
	3. Verify horizontal and vertical circles are aligned.	3. Calibrate horizontal and vertical circles.	3. Ensure the antenna has an unobstructed view of the sky.
<b>Taking Measurements</b>	1. Sight the target using the telescope.	1. Aim the total station at the target using the telescope.	1. Power on the receiver and wait for satellite acquisition.
	2. Record horizontal and vertical angles.	2. Record horizontal and vertical angles and distance.	2. Record satellite signals and signal strength.
	3. Ensure crosshairs are aligned with target center.	3. Trigger the measurement and record data.	3. Collect data at specified intervals or points.
<b>Adjustments and Checks</b>	1. Minimize touching the telescope to avoid misalignment.	1. Regularly calibrate the total station for accuracy.	1. Check for any obstructions blocking satellite signals.



<b>Procedure</b>	<b>Theodolite</b>	<b>Total Station</b>	<b>GNSS Receiver</b>
	2. Use fine adjustment screws for precise movements.	2. Use reflective targets for increased accuracy.	2. Post-process collected data for improved accuracy.
	3. Check for parallax and adjust the eyepiece if needed.	3. Protect the instrument from extreme conditions.	3. Monitor weather conditions for signal interference.
<b>Data Processing</b>	1. Transfer recorded angles to data processing software.	1. Transfer recorded measurements to computer software.	1. Post-process collected data using GNSS software.
	2. Calculate coordinates or angles as needed.	2. Process data for mapping or surveying applications.	2. Analyze data for accuracy and consistency.
	3. Verify data accuracy through redundancy or checks.	3. Verify data consistency and integrity.	3. Compare results with ground truth or reference data.

Moreover, hands-on exercises often involve solving real-world problems, fostering critical thinking, creativity, and effective problem-solving skills. Experiential learning through practical challenges provides a lasting understanding of concepts and enhances information retention. Regular practice through hands-on exercises leads to skill mastery, building confidence and expertise over time (Thornton-Smith, 1949).

In technical fields like Surveying, hands-on exercises are essential for gaining proficiency in applying theoretical knowledge to practical situations. Practical skills developed through hands-on exercises are highly valued by employers, as individuals equipped with such skills are better prepared to meet the demands of the workforce (Wolf & Ghilani, 2017).

Specifically, in surveying, hands-on exercises are crucial for mastering the operation of equipment such as theodolites, total stations, and GNSS receivers. For instance, when using a theodolite, it's essential to minimize touching the telescope to prevent misalignments and ensure accuracy. Similarly, when using a total station, regular calibration and proper instrument handling are vital for accurate measurements. For GNSS receivers, considerations such as antenna placement and post-processing techniques significantly impact data accuracy (weighted-regression, 2016).

Overall, hands-on exercises play a pivotal role in education, vocational training, and professional development, contributing to the holistic development of practical competence and ensuring success in various fields (National Research Council, 1983). They provide learners with valuable experiences, fostering adaptability, collaboration, and confidence, ultimately preparing them for the challenges of the real world.

### **Technology Integration:**

In a land surveying project, accuracy assessment is crucial for ensuring the reliability and precision of the collected spatial data (Wolf & Ghilani, 2017). Hands-on exercises play a crucial role in enhancing practical skills across various fields and disciplines (Moffitt & Bossler, 2016). Technology contributes significantly to accuracy assessment in surveying, offering advanced measurement instruments and digital sensors (El-Rabbany, 2006). Advanced measurement instruments, such as high-precision GNSS receivers, total stations, and laser scanners, offer improved accuracy in data collection (Kennedy & McInnes, 2010). Surveying software automates data collection, processing, and adjustment, ensuring accuracy through advanced algorithms (El-Rabbany, 2006). Real-time monitoring systems equipped with sensors and IoT devices enable continuous assessment of environmental parameters and infrastructure health (Kennedy & McInnes, 2010). Augmented Reality and Virtual Reality technologies enhance visualization and simulation, aiding in training, planning, and decision-making (Wolf & Ghilani, 2017)."

### **Assessing Understanding: The Role of Evaluation in Surveying Education**

Assessment serves as a dynamic tool for gauging understanding, providing valuable insights for both learners and educators (Wolf & Ghilani, 2017; Moffitt & Bossler, 2016). By analyzing assessment results, educators gain insights into the effectiveness of their teaching methods (El-Rabbany, 2006). Assessments serve as a measure of mastery, indicating whether learners have grasped key concepts and can apply them appropriately (Mikhail et al., 2001; Kennedy & McInnes, 2010). Through assessments, educators can pinpoint specific gaps in learners' understanding (National Research Council, 1983). Assessments contribute to the quality assurance of education by ensuring that educational objectives are met (FIG, 2006). Based on assessment outcomes, educators can adapt their teaching strategies to accommodate diverse learning styles and preferences (Wang & Liu, 2019). Assessment results provide a basis for communication with various stakeholders, including parents, administrators, and policymakers (ASPRS, 2015). Regular assessment facilitates a cycle of continuous improvement in education (International Federation of Surveyors, 2006)."

### **Conclusion:**

In conclusion, error management and accuracy assessment are integral components of the surveying discipline, essential for ensuring the reliability and credibility of spatial data.

By understanding the sources of errors, employing mitigation strategies, and conducting rigorous accuracy assessments, surveyors can enhance the accuracy and precision of measurements across diverse applications. From theoretical foundations to practical implementation, this paper has provided insights into the complexities of error management and accuracy assessment in surveying. Real-world case studies underscore the importance of accuracy assessment in various domains, emphasizing its role in informed decision-making, regulatory compliance, and project success. Moving forward, continued advancements in technology and methodologies will further enhance error management and accuracy assessment practices, contributing to the reliability and quality of surveying data.

**Recommendation:** Based on the findings of this paper, the following recommendations are proposed:

Surveying professionals should prioritize error management and accuracy assessment in their practices, ensuring the reliability and precision of spatial data.

Continued education and training programs should be developed to enhance surveyors' understanding of error sources, mitigation strategies, and accuracy assessment techniques.

Further research is needed to explore emerging technologies and methodologies for error management and accuracy assessment in surveying, particularly in the context of rapid technological advancements.

Collaboration between academia, industry, and government agencies is essential for advancing error management and accuracy assessment practices and promoting best practices across the surveying community.

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