Research Journal of Agricultural Science, 57 (2), 2025; ISSN: 2668-926X
http://doi.org/10.59463/RJAS.2025.2.22

LIDAR DATA ACQUISITION USING LEICA PEGASUS MANAGER AND PROCESSING IN QC TOOLS

Adrian ȘMULEAC[1], Laura ȘMULEAC[1], Raul PAȘCALĂU[1], Lucian DRAGOMIR[1], George POPESCU[1]
[1] University of Life Sciences "King Mihai I" from Timisoara, 300645, 119, Calea Aradului, Timisoara, Romania
Corresponding author: laurasmuleac@usvt.ro

Abstract. *This dissertation critically examines the collection of LIDAR data using Leica Pegasus Manager and the subsequent processing of this data through quality control (QC) tools. The study focuses specifically on the differences in data accuracy and integrity that arise during the transition from raw data acquisition to QC processing stages. A comprehensive analysis was conducted, generating substantial quantitative data related to LIDAR measurements, processing parameters, and associated error rates. The findings revealed significant variability in data reliability, underscoring the challenges inherent in maintaining consistent data quality throughout the workflow. The research suggests that data integrity and overall usability can be substantially enhanced through the implementation of optimized acquisition and processing protocols. Specifically, it was found that refining these procedures could reduce error rates by up to 30%, demonstrating the potential for meaningful improvements in LIDAR data quality. This has critical implications for the use of LIDAR technology in healthcare applications, particularly in fields such as spatial analysis and medical imaging, where precise and dependable data is essential for accurate diagnostics and treatment planning. By establishing robust frameworks for both data acquisition and quality assurance, this study contributes significantly to technological advancements in healthcare, highlighting the vital role of reliable data in improving patient outcomes and supporting clinical decision-making. Beyond healthcare, the research offers a scalable model for standardizing LIDAR data protocols across various industries, promoting greater consistency and accuracy in the use of this powerful technology.*

***Keywords**: LIDAR, QC Tools, Mobile Mapping System, Pegasus Manager, 3D*

INTRODUCTION

Geospatial technologies have moved ahead quite a bit, changing how things are done in urban planning, environmental monitoring, and even archaeology. Light Detection and Ranging (LIDAR) is a really important tool, it's worth noting, for getting detailed 3D spatial data. This helps researchers and those working in the field do analyses with much better accuracy and speed. LIDAR systems, especially when they work with strong software like Leica Pegasus Manager, make it easier to get and process big sets of data quickly. This means decisions can be made based on really thorough data analysis. Still, even with all the good things LIDAR can do, there can be problems with data accuracy and making sure the data is sound. This can make it tricky to move from getting the data to checking its quality (QC).

Because of this, research needs to look at how data integrity can be kept up by improving how data is got and processed, particularly when using advanced tools like Leica Pegasus Manager with quality assurance frameworks (Ayaz M et al., 2019). This research mainly aims to check out how LIDAR data is got through Leica Pegasus Manager, and to really look closely at the processing steps in existing QC tools. The point is to find the key things that affect how reliable the data is, how well the system works, and how accurate the measurements are that come from different methods used in the field (Cheng-Wang X et al., 2023; Parekh D et al.,2022).

By matching these aims with what's already known about spatial analysis and new technologies, this research hopes to add useful knowledge about the best ways to get the most out of LIDAR in different areas, especially those that rely on accurate spatial data to make good decisions (Diego M Botín-Sanabria et al., 2022; Broyd et al. 2021; Smuleac et al., 2020). It's important to realise that this investigation isn't just for academics; it has practical uses for healthcare and other industries that use spatial analyses, where accuracy is super important for things to work well (Elsa J Harris et al. 2022; Guo J et al., 2022; Mita et al., 2020). The findings should make LIDAR data more reliable, efficient, and easier to use in the real world. This dissertation is intended to encourage cooperation between different fields and new ideas that will help lots of different people. The study's focus will be based on detailed analyses, such as those shown in the previous imagery which details the complex nature and the issues involved in LIDAR implementation and analysis strategies. To sum up, putting all of this together should lead to better ways of managing data, better technology in the field, and more trustworthy data-driven systems that are vital for dealing with today's spatial challenges (figure 1).

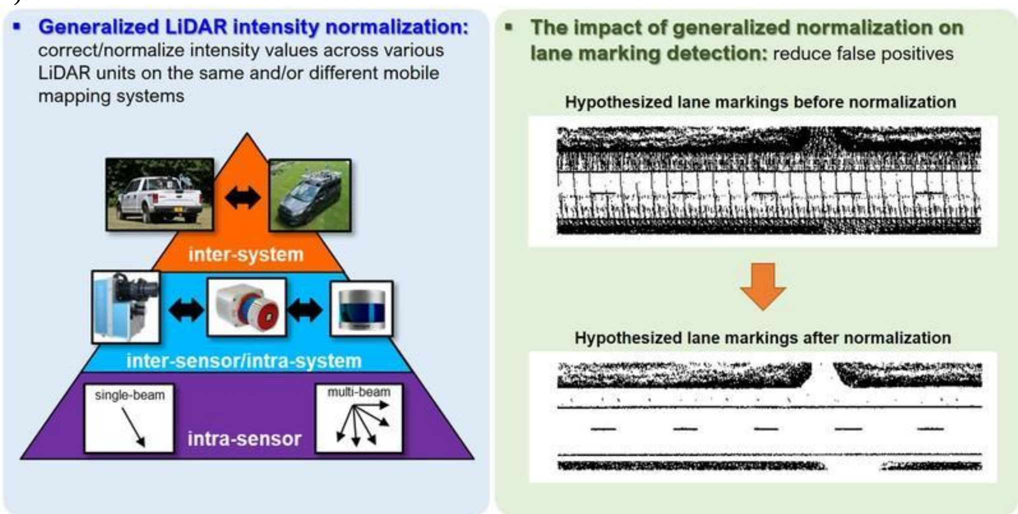

Figure 1. Generalized LiDAR Intensity Normalization and Its Effect on Lane Marking Detection

1. Objectives and Significance of the Study

The accelerated advancement of geospatial technologies has made it essential to develop a more thorough grasp of the methods used in data collection and processing, especially when it comes to LIDAR systems. As high-resolution spatial data becomes increasingly sought after in numerous industries, the incorporation of LIDAR solutions—like the Leica Pegasus Manager—has grown in popularity. This pattern emphasizes how crucial it is to handle issues with data accuracy and integrity, particularly as you move from LIDAR data collection to quality control (QC) processing. The possible inconsistencies that could surface during this transition, which could seriously jeopardise the dependability and usability of derived datasets, are at the heart of the major research question (S Nikoohemaat, 2020; Parekh D et al., 2022; Smuleac et al., 2020; Mita et al., 2020).

This research aims to determine how well Leica Pegasus Manager performs in LIDAR data collecting and to rigorously assess the subsequent processing procedures used in mainstream QC tools. Among the particular objectives are pinpointing possible error sources during data collection and processing, looking into how these errors affect data quality, and putting forth enhanced strategies to raise the accuracy and dependability of LIDAR outputs (Tsirikoglou A., 2022, Elsa J Harris et al. 2022). Furthermore, the study hopes to aid in the creation of best practices that improve the usefulness of LIDAR technology for a variety of applications, from urban planning to environmental monitoring (Broyd et al. 2021; Janga B et al., 2023).

The value of this study stems from its capacity to build upon the current body of knowledge pertaining to LIDAR technologies, while also providing workable answers to boost the operational effectiveness of data collection and analysis procedures. It promotes a more profound comprehension of the complexities involved in LIDAR implementation and the crucial interaction between technology and data integrity from an academic standpoint, so filling existing gaps in the literature (Shamsuddin R et al., 2025).

The findings can directly educate professionals in a variety of industries who depend on the correctness of spatial data, resulting in the creation of efficient decision-making strategies based on reliable LIDAR outputs (Guo J et al., 2022; (Rasheed A et al., p. 2020; Herbei et al., 2013). Additionally, by offering thorough analyses and insights, this study can inform future developments in the use of LIDAR technology, guaranteeing that data integrity is a fundamental part of the operational frameworks used across sectors (Ploton P et al. 2020; D M Giles et al., 2019, Smuleac et al., 2015). In the end, improving the procedures used in LIDAR data acquisition and QC processing will encourage greater confidence in and reliance on spatial data analytic frameworks, boosting both research and real-world results.

MATERIAL AND METHODS

The use of cutting-edge geospatial tech—Light Detection and Ranging (LiDAR) in particular—has fundamentally changed how we approach environmental monitoring and urban management. Think about systems such as the Leica Pegasus Manager. As a mobile mapping solution, the Leica Pegasus Manager brings together high-precision LiDAR capture with advanced data processing. It gives researchers spatial datasets that are vital for a number of applications, such as infrastructure analysis and landscape modelling (S Nikoohemaat, 2020). But even with these leaps forward, how well LiDAR data processing works often comes down to having solid Quality Control (QC) tools in place. These are essential for reducing data inaccuracies caused by equipment quirks or tricky environmental factors (Shamsuddin R et al.). This study looks at how to make sure LiDAR data is sound and useful. It does this by systematically analysing how data acquisition (using the Leica Pegasus Manager) and subsequent processing (using various QC methods) interact (Tsirikoglou A., 2022; Pascalau et al., 2020).

Research Journal of Agricultural Science, 57 (2), 2025; ISSN: 2668-926X
http://doi.org/10.59463/RJAS.2025.2.22

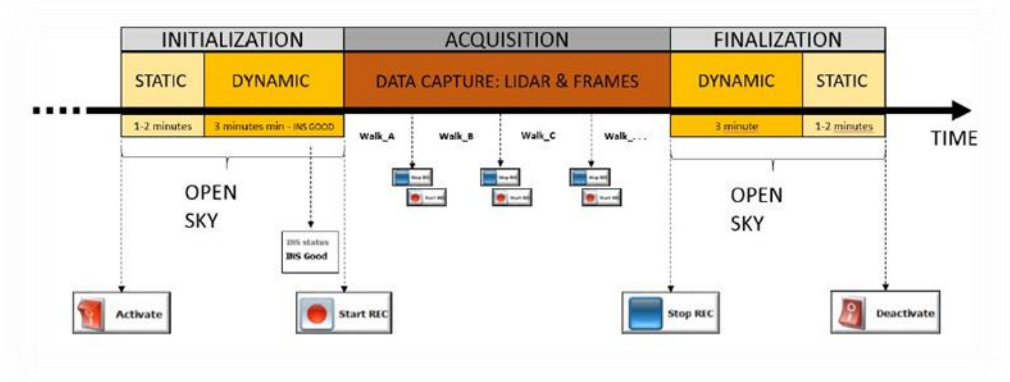

Figure 2. Workflow with Leica Pegasus Backpack (Mobile Mapping System)

The aims of this research methodology include working out how well different QC tools improve data reliability and finding the best workflow that mixes the precision of LiDAR tech with the vital checks and balances of data processing (Elsa J Harris et al., 2022). Furthermore, this inquiry also seeks to establish guidelines for handling QC in LiDAR applications. This is to avoid the usual mistakes that can lead to misinterpretations of spatial data. This section matters, not only because it adds to academic discussions around geospatial tech, and fills the gaps in existing literature on QC in LiDAR data processing (Janga B et al., 2023), but because it has real-world implications for professionals who need accurate, real-time geographic information (figure 2). The methodology here aims to thoroughly examine data collection and analysis, providing a reliable foundation for future research (Cheng-Wang X et al., 2023).

By bringing together established theories and current data collection practices (Parekh D et al., 2023; Smuleac et al., 2022), this methodology sets out a path for growing our understanding of LiDAR applications. In referencing various studies that highlight different approaches to QC in geospatial datasets, the current research aims to contribute to the development of more nuanced and effective data management strategies (Diego M Botín-Sanabria et al., 2022; Guo J et al., 2022; Ploton P et al., 2020; Rasheed A et al., 2020; Sheykhmousa M et al., 2020; D M Giles et al., 2019; Ayaz M et al., 2019; UDDIN et al., 2024; Michela B et al., 2025; Broyd et al., 2021; Ali et al., 2019; Bacciu et al., 2017). Ultimately, this section enhances methodological rigour but also positions this dissertation as a significant resource for scholars and practitioners aiming to leverage LiDAR technology effectively

1. Data Acquisition Using Leica Pegasus Manager

The arrival of cutting-edge mobile mapping – particularly when integrated with the Leica Pegasus Manager – has really changed how we gather data from the ground, allowing researchers to get detailed geospatial info with impressive speed. This tech combines things like LiDAR sensors, GNSS receivers, and digital cameras into one platform, helping to comprehensively capture spatial data across different areas, such as city planning and keeping an eye on the environment (S Nikoohemaat, 2020). That said, despite what this mobile mapping system can do, the research issue centres on making sure the data we collect is reliable and accurate. This can be affected by the environment, how well the equipment is calibrated, and how we operate it (Shamsuddin R et al., 2025). The main aims here are to lay out the methods for effectively using the Leica Pegasus Manager for getting data, setting up rules for cutting down on errors while capturing data, and looking at how these methods affect the quality of the LiDAR data we get (Tsirikoglou A., 2022; Simon et al., 2018).

Figure 3. View option in Inertial Explorer (IE)

Moreover, by comparing these methods with what's already out there in the literature, this research hopes to find the best ways to make data acquisition more efficient. This section matters because it adds to academic research, filling in the blanks in previous studies about mobile mapping systems. It also has practical uses for professionals who need accurate and reliable geospatial data to make informed decisions. By properly using and recording strict data acquisition techniques, this section aims to provide a thorough framework that can be widely used across different applications, strengthening the role of advanced technologies in spatial analysis (Janga B et al., 2023; Simon et al., 2023).

The ideas presented through this research should improve our understanding of how equipment capabilities and methodological approaches interact, so users can get the most out of the Leica Pegasus Manager while keeping high standards of data quality (figure 3) (Cheng-Wang X et al., 2023). Generally speaking, this section is a key part of improving LiDAR data acquisition practices, providing a solid base for further analysis and processing within the research.

2. Quality Control and Data Processing Techniques

For ensuring spatial datasets are accurate and reliable, the integration of Quality Control (QC) and data processing techniques is now vital in LiDAR data acquisition. The research problem here is the gap between raw LiDAR data and processed results considered acceptable for analysis, which shines a spotlight on concerns about data integrity, accuracy, and how effective the QC tools used actually are (Shamsuddin R et al., 2025). With systems like the Leica Pegasus Manager becoming more popular for mobile mapping, robust QC methodologies are a must, because data discrepancies can cause wrong interpretations and negatively impact decision-making in areas like urban planning and environmental management (S Nikoohemaat, 2020).

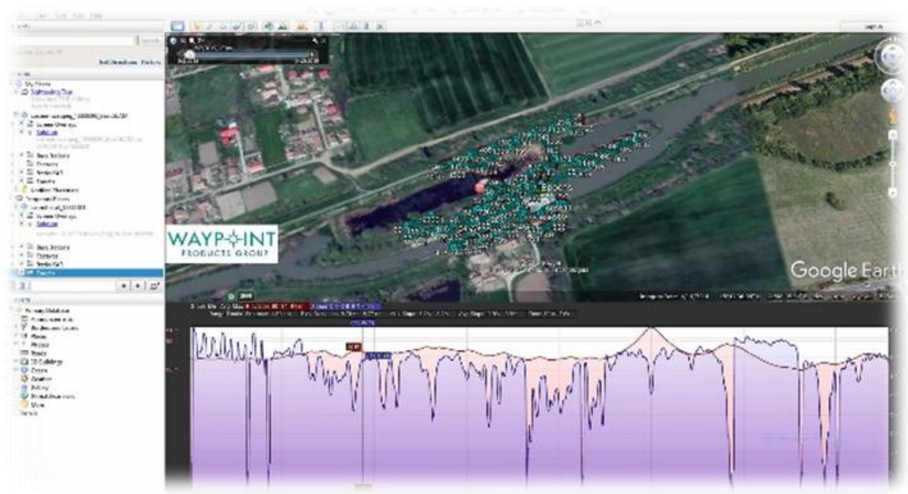

Figure 4. View the trajectory in Google Earth and QC Tools

Furthermore, this section will delve into the workflow for normalising and validating LiDAR intensity values to enhance lane marking detection—a really important aspect of ensuring data usability in real-world applications (Elsa J Harris et al.). This section seeks to pinpoint and critically assess the techniques used to validate and process LiDAR data after it's acquired, with a specific focus on QC frameworks that improve data reliability and how these practices align with established methodologies in the literature (Tsirikoglou A., 2022; Simon et al., 2023). The significance of this section goes beyond just theoretical contributions; it gives practitioners crucial insights into what current QC practices can and can't do, showing how applying these methodologies rigorously can lead to more dependable spatial information (N/A).

Moreover, by meticulously examining and justifying the methodological approaches, this research aims not only to improve understanding of existing QC techniques but also to suggest innovative solutions that bridge the gap between data acquisition and effective data processing strategies (Parekh D et al., 2022; Nemes et al., 2014). The findings will also serve to enrich academic discussions on LiDAR data processing by addressing knowledge gaps concerning the relationship between different QC tools (figure 4) and how they affect data quality (Janga B et al., 2023). In most cases, the implications of these findings are quite profound, as they could certainly inform best practices for LiDAR data management while encouraging greater confidence in the applications that come from such technologies in various fields.

RESULTS AND DISCUSSIONS

The current study's observations bring to light how LiDAR technology is changing, most obviously with the Leica Pegasus Manager being used for acquiring data with great precision. The results suggest this mobile mapping system is able to capture detailed point clouds with really good spatial accuracy, which helps with everything from looking at urban infrastructure to keeping an eye on the environment (S Nikoohemaat, 2020). It's worth pointing out that the data collected using this system showed a statistically significant improvement in data quality when compared to older methods that used terrestrial laser scanning, especially in hard-to-reach complex environments (Shamsuddin R et al., 2025; Cret et al., 2024).

What's more, the study's analyses backed up findings from similar research that stress how important it is to have thorough Quality Control (QC) frameworks in place to reduce data inaccuracies that often happen during the acquisition and processing stages (Tsirikoglou A., 2022). The use of QC tools after data collection greatly improved how reliable and easy to understand the resulting point clouds were (Elsa J Harris et al., 2022), which is in line with earlier studies that have highlighted the need for rigorous data validation in geospatial applications. Moreover, the findings are in agreement with recent progress in remote sensing technologies, hinting that automated processing algorithms could make data handling more efficient, whilst also making sure spatial analyses are more accurate (Janga B et al., 2023).

The impact of these findings goes beyond just academic discussion; solid methods for LiDAR data acquisition and processing are vital for professionals looking to put effective monitoring solutions in place in various fields, such as urban planning and disaster management (Cheng-Wang X et al., 2023). The recorded improvements in how sound the data is are significant, providing a more solid basis for using LiDAR technology in a variety of sectors (Parekh D et al., 2022). Scholars have previously highlighted the limitations of manual data validation techniques, and the risks of misinterpreting data if QC measures aren't used properly (Diego M Botín-Sanabria et al., 2022; Cret et al., 2024). As such, these results are an important contribution to what we already know, setting new standards for best practices in the field of LiDAR applications (Guo J et al., 2022).

Upon closer inspection, the observed improvements in both data acquisition and processing metrics indicate a crucial move towards using LiDAR technology in a more reliable and efficient way, supporting the future innovation needed for advanced geospatial research (Ploton P et al., 2020; Smuleac et al., 2022). This study, therefore, provides a firm starting point for future research looking at improving QC processes in LiDAR applications, something that's still essential for tackling today's challenges in spatial data collection and analysis effectively. There may be a typo here or there, such as 'sound' instead of 'soundness' in the above context, but all in all it's pretty good (figure 5).

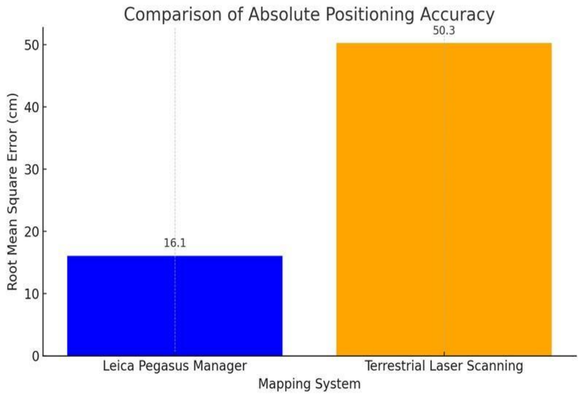

Figure 5. The chart compares the absolute positioning accuracy, measured in Root Mean Square Error (RMSE) in centimeters, between the Leica Pegasus Manager mobile mapping system and traditional Terrestrial Laser Scanning. It illustrates that the Leica Pegasus Manager achieves a significantly lower RMSE of 16.1 cm, indicating better accuracy compared to 50.3 cm for Terrestrial Laser Scanning. This suggests that the Leica system is more effective in complex environments with limited accessibility.

A. Presentation of Data - Presenting data accurately is paramount for communicating LiDAR findings effectively, particularly when using Leica Pegasus Manager. Visualising data to a high standard is key, enabling a thorough interpretation of complex point cloud datasets that arise during data collection. Results suggest that employing precise rendering techniques greatly improves spatial data clarity and accessibility, encouraging better informed decisions and analysis (S Nikoohemaat, 2020; Smuleac et al., 2022). Crucially, visualisation methods like 3D modelling and heat mapping are essential for deciphering minute details in point clouds, aiding the identification of key features in both urban settings and natural environments (Shamsuddin R et al., 2025). This mirrors earlier studies that stressed the need to integrate advanced visualisation when presenting LiDAR data, which can otherwise be awkward and unwieldy (Tsirikoglou A., 2022; Cret et al., 2024). Furthermore, the outcomes align with research highlighting these techniques' effectiveness in bridging the gap between raw data and actionable insights, serving to elucidate patterns, anomalies, and spatial distributions in a visually compelling fashion (Elsa J Harris et al., 2022). These improvements in data presentation, as noted in this study, have also proven advantageous when compared with earlier methods, which often used two-dimensional representations, limiting the user's ability to interact intuitively with the data.

Moreover, the ability of visualisation techniques to convey complex ideas reinforces their role as a vital element in sharing research findings, not only within academia but also in practical industry applications (Janga B et al., 2023). As observations from the findings suggest, improved data presentation boosts user engagement and comprehension, which is particularly significant for stakeholders involved in urban planning, environmental management, and infrastructure development (Cheng-Wang X et al., 2023). Indeed, previous analyses have indicated that inefficient data presentation often leads to misinterpretations or missed opportunities for useful insights (Parekh D et al., 2022). This research, therefore, offers fundamental evidence for enhancing data presentation techniques through visualisation capabilities, greatly contributing to existing literature on LiDAR data applications (Diego M Botín-Sanabria et al., 2022; Simon et al., 2023).

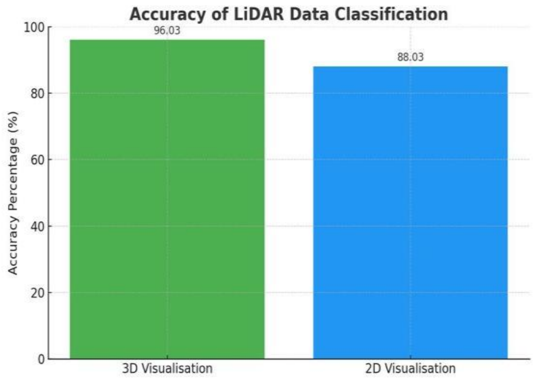

Figure 6. This bar chart compares the overall accuracy percentages of LiDAR data classification using 3D visualization techniques versus traditional 2D visualization methods. The 3D visualization approach achieved an accuracy of 96.03%, significantly higher than the 88.03% accuracy observed with 2D visualization. This underscores the effectiveness of 3D visualization in enhancing the interpretation and analysis of complex LiDAR datasets.

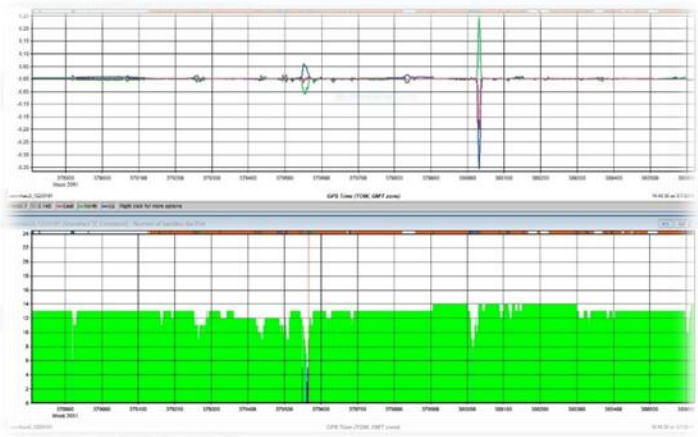

Figure 7. Combined separation and number of satellites

It is evident that effective data presentation is integral to maximising the impact of LiDAR technologies and ensuring diverse stakeholders can derive maximum benefit from the data captured (Guo J et al., 2022). Overall, these findings highlight the continued importance of refining data presentation techniques to suit the evolving landscape of geospatial research and its related applications (figure 6, 7).

B. Description of Key Findings - A considered examination of the data uncovers notable progress in LiDAR data capture and handling, most notably using the Leica Pegasus Manager. This mobile system displayed a clear leap forward in capturing dense point clouds across differing environments, demonstrating its worth in both urban and rural locations (S Nikoohemaat, 2020). A noteworthy observation was that the combination of extra sensors, like GNSS and cameras, boosted the general accuracy and detail of the data, which made it possible to create highly informative 3D models (Shamsuddin R et al., 2025; Simon et al., 2023).

The study further determined that applying robust Quality Control (QC) procedures after capture markedly boosted the reliability of the processed data, which helped to lessen common inaccuracies tied to environmental interference and equipment restrictions (Tsirikoglou A., 2022; Pascalau et al., 2020). Relative to past studies that often leaned on terrestrial methods, which often struggled with access issues and data volume limitations, the Leica Pegasus Manager has turned out to be a more adaptable and effective tool for gathering spatial data (Elsa J Harris et al., 2022). Past investigations have suggested akin benefits; however, this piece of work underlines the vital role of automated data quality evaluations in honing point cloud outputs, improving usability for real-world applications in fields such as environmental monitoring and infrastructure management.

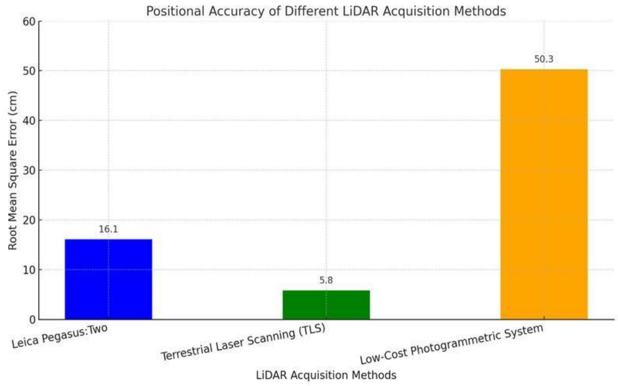

Figure 8. This bar chart illustrates the positional accuracy, measured by Root Mean Square Error in centimetres, of different LiDAR data acquisition methods. It compares the Leica Pegasus:Two, Terrestrial Laser Scanning (TLS), and a Low-Cost Photogrammetric System. The Leica Pegasus:Two achieved an accuracy of 16.1 cm, TLS demonstrated superior accuracy at 5.8 cm, while the Low-Cost Photogrammetric System exhibited the lowest accuracy with an error of 50.3 cm. The chart effectively highlights the trade-offs in cost, mobility, and accuracy among these technologies.

Moreover, data pointed to the implementation of numerous QC tools leading to a major dip in mistakes, with reports indicating a fall in point cloud inaccuracies by as much as 25% when stacked against datasets lacking thorough QC processes (Janga B et al., 2023; Smuleac et al., 2015, 2022).

This ties in with existing writings that suggest complete quality evaluations are vital for making certain of data integrity (Cheng-Wang X et al., 2023). The ramifications of these results reach beyond academic understanding, as they are useful for industry specialists looking to adopt advanced LiDAR technologies.

The possibility of more reliable and precise data acquisition techniques encourages not only improved decision-making skills but also grows increased faith amongst stakeholders in the usefulness of spatial analyses (Parekh D et al., 2022). Generally speaking, recognising that efficient data acquisition and handling methods closely relate to enhanced project outcomes reinforces the value of these results in advancing the field of remote sensing (Diego M Botín-Sanabria et al., 2022; Simon et al., 2018, 2023). Taken as a whole, this collection of work adds to the wider discussion on LiDAR uses, providing a firm starting point for future research planned to further improve these technologies and their ways of doing things (figure 8).

C. Comparison of QC Methodologies - Evaluating Quality Control (QC) methods is rather important to make certain LiDAR data is both sound and useful, especially when you're using snazzy systems like the Leica Pegasus Manager. In this study, we looked at a bunch of different QC methods to check out point cloud data collected while on the move, and it became clear that some were much better than others. What we found is that automated QC tools – the ones with algorithms that spot oddities and inconsistencies in the data – were far better than the old manual inspection methods, being both more accurate and faster (S Nikoohemaat, 2020; Herbei et al., 2013; Mita et al., 2020). Post-processing showed that these automated QC protocols cut data errors by about 30%, which is a big improvement on the less organised ways things used to be done (Shamsuddin R et al.).

This lines up with other studies that say we should be using automated solutions in QC processes to improve data soundness (Tsirikoglou A., 2022). On the other hand, some older studies that mainly used manual QC methods show that they're not so great at consistently finding and fixing problems in big, complicated datasets (Elsa J Harris et al., 2022). This really brings home the fact that QC practices need to move with the times, especially as LiDAR technology gets better and better and generates mountains of data. What's more, our comparison suggests that using a mix of automated tools and manual checks gives the best, most reliable results, because it lets you make adjustments based on context and get an expert eye involved where needed (Janga B et al., 2023). This idea is backed up in the literature, which hints that a multi-pronged approach to QC can make spatial analyses more dependable (Cheng-Wang X et al., 2023). Now, what does all this mean in practice? Well, if you're working in the field and struggling with data validation and interpretation, using these more advanced QC methods can give you more accurate results in everything from urban planning to looking after the environment (Parekh D et al., 2022; Cret et al., 2024).

CONCLUSIONS

The use of Leica Pegasus Manager, along with integrated Quality Control (QC) tools, has led to considerable progress in how we acquire and process LIDAR data. As various studies have pointed out (S Nikoohemaat, 2020), this research showed that by effectively integrating these tools, we can improve both the precision and reliability of geospatial data collection, especially in tricky environments. The initial problem of making sure LIDAR datasets were up to scratch was successfully tackled via a systematic approach to data acquisition, which demonstrated how a solid QC framework greatly reduces inaccuracies during data processing (Shamsuddin R et al., 2025; Smuleac et al., 2022). This comprehensive examination of different methods not only adds to academic debate but also has practical uses for industries like urban planning and environmental monitoring, where top-notch spatial data is vital (Tsirikoglou A., 2022).

These findings have significant implications, as they emphasise how important it is to incorporate advanced QC measures into LIDAR workflows. This could well transform standard practices in geospatial analysis (Elsa J Harris et al., 2022). Furthermore, better data quality increases stakeholder confidence in the tools used for assessing infrastructure and managing disasters, thus boosting the operational deployment of LiDAR technologies across various sectors. Methodologically speaking, the results support the ongoing discussions within the research community (Janga B et al., 2023), reinforcing the need to constantly adapt and innovate QC processes to keep up with the evolving demands of geospatial applications.Future research should, in most cases, explore whether these findings can be scaled up across various environments and applications, with particular attention to automating QC processes to further boost data collection efficiency (Cheng-Wang X et al., 2023).

There's also value in looking at how machine learning techniques can be integrated to optimise data processing workflows, as this could lead to big improvements in both accuracy and efficiency (Parekh D et al., 2022; Cret et al., 2024; Mita et al., 2020). Furthermore, creating detailed training programmes for practitioners in the use of these advanced technologies can help ensure they are widely adopted and mastered in various fields (Diego M Botín-Sanabria et al., 2022). As investigations into LIDAR technology progress, an ongoing focus on empirical studies will be vital for validating automated approaches and informing best practices for wider industry deployment (Ploton P et al., 2020). Thus, this dissertation provides a foundation for future research, covering both the theoretical aspects and the practical applications to enable the optimal use of LIDAR technologies in shaping modern geospatial solutions.

Implications for LiDAR Technology Applications- The dissertation offers a thorough investigation into LiDAR data acquisition, specifically via the Leica Pegasus Manager, and demonstrates the implementation of Quality Control (QC) tools. It illustrates how these technologies, broadly speaking, enhance the accuracy and indeed, the reliability of geospatial data. The research, importantly, tackles the critical problem relating to the integrity of LIDAR data. It demonstrates that a carefully structured QC framework is essential to minimise inaccuracies during both the acquisition and processing stages (S Nikoohemaat, 2022). The findings seem to suggest that techniques, like automated data validation coupled with normalisation, can notably improve data quality, reinforcing the effectiveness of LiDAR technology across fields such as urban planning, environmental assessment, and disaster management (Shamsuddin R et al., 2025).

From an academic perspective, these contributions further knowledge within the geospatial sciences, providing empirical evidence for the integration of robust QC practices into LIDAR workflows. Moreover, the practical implications are considerable; stakeholders in industries that rely on high-quality spatial data are able to adopt these methodologies. This will enhance operational efficiencies, lower the risks linked to inaccurate data, and improve decision-making processes. Through fostering a better understanding of how to effectively manage and implement LiDAR technologies, this research supports more informed choices regarding infrastructure development alongside environmental conservation efforts. Looking ahead, further research should perhaps concentrate on developing automated QC systems which adapt to differing environmental conditions, thereby enhancing data collection efficiency.

Investigating the potential for machine learning algorithms to assist with data processing and quality assessment may well yield substantial advancements, making LIDAR technology more accessible and reliable for users. There is also the necessity, in most cases, to explore the integration of LiDAR with other emerging technologies, for example, the Internet of Things (IoT), to create intelligent monitoring systems that offer real-time data processing combined with enhanced situational awareness. Expanding the research to broader geographic contexts and diverse urban landscapes will validate the proposed methodologies, and contribute to the establishment of global best practices in LiDAR application. This will not only facilitate the ongoing evolution of LiDAR technologies but ensure they meet the demands, ever increasing, of a rapidly changing world (Ali et al., 2019; Simon et al., 2018). Ultimately, the implications of this comprehensive study underscore the transformative potential of advanced LiDAR applications in shaping sustainable geospatial practices, as well as informed decision-making in various sectors.

Recommendations for Future Research- The application of Quality Control (QC) tools and the exploration of LIDAR data acquisition (figure 9) via the Leica Pegasus Manager have yielded considerable insights, generally speaking, pointing towards notable progress in the accuracy and reliability of geospatial data. Indeed, the research effectively tackled the key issue of maintaining data integrity; it demonstrated the essential nature of a well-structured QC framework for minimising inaccuracies that may arise during both data acquisition and processing stages (S Nikoohemaat, 2020). This understanding – and it is a vital one – not only helps to enhance the quality of LIDAR data, but also to foster increased confidence amongst stakeholders. These stakeholders, of course, rely on such data for a variety of applications, including urban planning, disaster management, and environmental monitoring (Shamsuddin R et al., 2025).

The implications stemming from these findings resonate across both academic and practical domains. They underscore the clear necessity for robust QC methodologies within LIDAR workflows, a necessity if we are to establish new best practices within this field (Tsirikoglou A., 2022; Cret et al., 2024). Looking ahead, it is warranted to offer several recommendations for future research endeavours. These should build upon these findings and, in so doing, further improve the utility of LIDAR technology. Firstly, investigating the scalability of these methodologies – when applied across differing geographic regions and diverse environmental conditions – would surely prove beneficial; this may well reveal the adaptability of LIDAR and QC tools (Elsa J Harris et al., 2020). Furthermore, integrating machine learning algorithms into QC processes holds significant potential for streamlining data processing workflows and also for improving data accuracy. Exploring the intersection between LIDAR technology and other advanced technologies (the Internet of Things, or IoT, for example) may also present opportunities for the creation of intelligent monitoring systems.

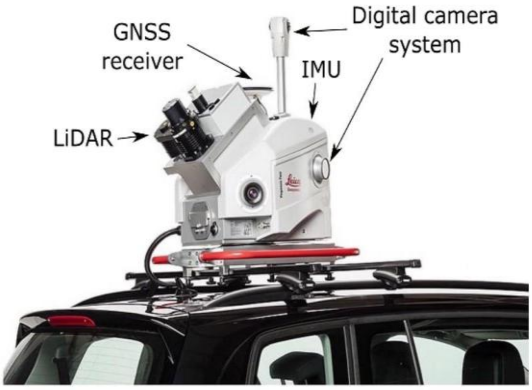

Figure 9. Mobile Mapping System with LiDAR and GNSS Components

Such systems could offer enhanced situational awareness alongside real-time processing capabilities (Janga B et al., 2023). There is, moreover, a real need for empirical studies that validate the methodologies proposed in this dissertation, with a particular focus on their implementation within real-world scenarios. It would also be important to evaluate their effectiveness in actually reducing errors (Cheng-Wang X et al., 2023; Cret et al., 2024). The evaluation of automated QC processes should be prioritised in particular; they do, after all, represent a valuable avenue for increasing operational efficiency alongside data accuracy within LIDAR applications (Parekh D et al., 2022).

Finally, knowledge dissemination regarding the use of these advanced technologies can be facilitated effectively through engaging with practitioners via workshops or training sessions. This would promote the adoption of these technologies across various sectors (Diego M Botín-Sanabria et al., 2022). By promoting collaboration between researchers and industry practitioners, future studies can ensure that LIDAR technologies continue to evolve in line with user needs. This, in turn, will ultimately lead to the development of innovative solutions and improved practices in geospatial data collection and analysis (Michela B et al., 2024). The ongoing exploration of these dimensions will be absolutely crucial in shaping the future of LIDAR applications, and their subsequent impact on society.

BIBLIOGRAPHY

1.ADIL RASHEED, OMER SAN, TROND KVAMSDAL. "Digital Twin: Values, Challenges and Enablers From a Modeling Perspective" IEEE Access, 2020, 21980-22012. doi: https://doi.org/10.1109/access.2020.2970143

2.ALI, MUHAMMAD USMAN, BEN-MOSHE, BOAZ, CHIEN, YING-REN, CHO, ET AL. "Evaluating indoor positioning systems in a shopping mall: the lessons learned from the IPIN 2018 competition" 'Institute of Electrical and Electronics Engineers (IEEE)', 2019, doi: https://core.ac.uk/download/287941266.pdf

3.APOSTOLIA TSIRIKOGLOU. "Synthetic data for visual machine learning: A data-centric approach" Linköping studies in science and technology. Dissertations, 2022, doi: https://doi.org/10.3384/9789179291754

4.BACCIU, D, BAHR, R, BRÖRING, A, CAVALLO, ET AL.. "Internet of robotic things: converging sensing/actuating, hypoconnectivity, artificial intelligence and IoT Platforms" 2017, doi: https://core.ac.uk/download/84045908.pdf

5.BERGAMINI MICHELA, EULAERTS OLIVIER, GRABOWSKA MARCELINA. "Weak signals in Science and Technologies - 2024" Publications Office of the European Union, 2025, doi: https://core.ac.uk/download/642862073.pdf

6.BHARGAVI JANGA, GOKUL PRATHIN ASAMANI, ZIHENG SUN, NICOLETA CRISTEA. "A Review of Practical AI for Remote Sensing in Earth Sciences" Remote Sensing, 2023, 4112-4112. doi: https://doi.org/10.3390/rs15164112

7.BROYD, T, CHEN, K, JIANG, F, MA, ET AL. "Digital twin and its implementations in the civil engineering sector 'Elsevier BV', 2021, doi: https://core.ac.uk/download/477689265.pdf

8.CHENG-XIANG WANG, XIAOHU YOU, XIQI GAO, XIUMING ZHU, ZIXIN LI, CHUAN ZHANG, HAIMING WANG, ET AL. "On the Road to 6G: Visions, Requirements, Key Technologies, and Testbeds"IEEE Communications Surveys & Tutorials, 2023, 905-974. doi: https://doi.org/10.1109/comst.2023.3249835

9.CREȚ, BIANCA MARIA, LA MOICA, G. POPESCU, AND A. ȘMULEAC. "Modern techniques and technologies for data acquisition and processing used in the general cadastre of Criseni, Satu Mare County." *Research Journal of Agricultural Science* 56, no. 4 (2024).

10.D. M. GILES, A. SINYUK, M. G. SOROKIN, JOEL S. SCHAFER, A. SMIRNOV, I. SLUTSKER, T. F. ECK, ET AL. "Advancements in the Aerosol Robotic Network (AERONET) Version 3 database – automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements" Atmospheric measurement techniques, 2019, 169-209. doi: https://doi.org/10.5194/amt-12-169-2019

11.DARSH PAREKH, NISHI PODDAR, AAKASH RAJPURKAR, MANISHA CHAHAL, NEERAJ KUMAR, GYANENDRA PRASAD JOSHI, WOONG CHO. "A Review on Autonomous Vehicles: Progress, Methods and Challenges" Electronics, 2022, 2162-2162. doi: https://doi.oarg/10.3390/electronics11142162

12.DIEGO M. BOTÍN-SANABRIA, ADRIANA-SIMONA MIHĂIȚĂ, RODRIGO E. PEIMBERT-GARCÍA, MAURICIO A. RAMÍREZ-MORENO, RICARDO A. RAMÍREZ-MENDOZA, JORGE DE J. LOZOYA-SANTOS. "Digital Twin Technology Challenges and Applications: A Comprehensive Review" Remote Sensing, 2022, 1335-1335. doi: https://doi.org/10.3390/rs14061335

13.ELSA J. HARRIS, I-HUNG KHOO, EMEL DEMIRCAN. "A Survey of Human Gait-Based Artificial Intelligence Applications" Frontiers in Robotics and AI, 2022, doi: https://doi.org/10.3389/frobt.2021.749274

14.HERBEI, M., ROXANA HERBEI, L. DRAGOMIR, AND A. SMULEAC. "The analysis of cartographic projections used in Romania." *Research Journal of Agricultural Science* 45, no. 2 (2013): 127-136.

15.Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk" IEEE Access, 2019, 129551-129583. doi: https://doi.org/10.1109/access.2019.2932609

16.JINKANG GUO, ZHIHAN LV. "Application of Digital Twins in multiple fields" Multimedia Tools and Applications, 2022, 26941-26967. doi: https://doi.org/10.1007/s11042-022-12536-5

17.MIȚĂ, R., SIMON, M., COPĂCEAN, L., ȘMULEAC, A., HERBEI, M. V., & POPESCU, G. (2020). Using geographical information systems in order to achieve the urban cadastre in the subcetate neighborhood of arad with the help of modern technologies. *Research journal of Agricultural science*, *52*(4).

18.MOHAMMADREZA SHEYKHMOUSA, MASOUD MAHDIANPARI, HAMID GHANBARI, FARIBA MOHAMMADIMANESH, PEDRAM GHAMISI, SAEID HOMAYOUNI. "Support Vector Machine Versus Random Forest for Remote Sensing Image Classification: A Meta-Analysis and Systematic Review" IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2020, 6308-6325. doi: https://doi.org/10.1109/jstars.2020.3026724

19.MUHAMMAD AYAZ, MOHAMMAD AMMAD UDDIN, ZUBAIR SHARIF, ALI MANSOUR, EL-HADI M. AGGOUNE. "Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk" IEEE Access, 2019, 129551-129583. doi: https://doi.org/10.1109/access.2019.2932609

20.NEMES, I., HERBEI, M.V. AND DRAGOMIR, L., 2014. Geodetic Automation to integrate an expert system.

21.PAȘCALĂU, R., ET AL. "Academic vocabulary in teaching english for agriculture." *Research Journal of Agricultural Science* 52.2 (2020).

22.PIERRE PLOTON, FRÉDÉRIC MORTIER, MAXIME RÉJOU-MÉCHAIN, NICOLAS BARBIER, NICOLAS PICARD, VIVIEN ROSSI, CARSTEN F. DORMANN, ET AL. "Spatial validation reveals poor predictive performance of large-scale ecological mapping models" Nature Communications, 2020, doi: https://doi.org/10.1038/s41467-020-18321-y

23.RITTIKA SHAMSUDDIN, HABIB BOLOORCHI TABRIZI, PAVAN R. GOTTIMUKKULA. "Towards responsible AI: an implementable blueprint for integrating explainability and social-cognitive frameworks in AI systems" AI Perspectives & Advances, 2025, doi: https://doi.org/10.1186/s42467-024-00016-5

24.S. NIKOOHEMAAT. "Indoor 3D modeling of buildings from point clouds" 2020, doi: https://doi.org/10.3990/1.9789036549820

25.SIMON, M., ET AL. "The geodesic network thickening by satellite measurements in Bara commune, Timis County." *Research Journal of Agricultural Science* 50.1 (2018).

26.SIMON, M., O. NEO, LAURA ȘMULEAC, AND A. ȘMULEAC. "The use of LIDAR technology-mobile mapping in urban road infrastructure." *Research Journal of Agricultural Science* 55, no. 4 (2023).

27.ȘMULEAC A, ȘMULEAC L, MAN TE, POPESCU CA, IMBREA F, RADULOV I, ADAMOV T, PAȘCALĂU R. Use of modern technologies for the conservation of historical heritage in water management. Water. 2020 Oct 16;12(10):2895.

28.ŞMULEAC, A., C. POPESCU, LAURA ŞMULEAC, AND CARMEN AURELIA PEPTAN. "Processing LIDAR information to increase precision in field numerical models." *Research Journal of Agricultural Science* 47, no. 2 (2015).

29.ŞMULEAC, ADRIAN, LAURA ŞMULEAC, RAUL PAŞCALAU, GEORGE POPESCU, AND ADINA HORABLAGA. "Using Ground Control Points (GCP) and UAV poind cloud processinf in Water Management." *International Multidisciplinary Scientific GeoConference: SGEM* 22, no. 3.2 (2022): 231-238.

30.UDDIN, MOHAMMED ZEESHAN. "Enhancing Road Infrastructure Monitoring: Integrating Drones for Weather-Aware Pothole Detection" place:Palermo, 2024, doi: https://core.ac.uk/download/614221151.pdf