



Technical Study

Maximizing Accuracy: Pipeline Measurement Using Above-Flow Sensors

Comparing Structured Light laser profiling, LiDAR and Photogrammetry for Pipeline Inspection.

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CEO's Foreword

Accuracy and Why It Matters

At RedZone, we believe accuracy is more than just a technical benchmark—it's the foundation of informed decisions, safer communities, and sustainable infrastructure. Every inspection we perform and every report we generate is grounded in our commitment to delivering the most precise, actionable data possible.

As you read this study, you'll see the lengths we go to ensure accuracy in every detail, providing clarity for today and confidence for the future. Because when it comes to managing critical infrastructure, the right data can make all the difference.

Thank you for trusting us to lead the way in accuracy and performance.

Dave Petrosky
President and CEO

Abstract

Accuracy Unleashed

In the rapidly advancing field of sewer and pipeline inspection, choosing the right technology to ensure accurate and actionable data has never been more critical.

Municipalities and engineering teams are facing increasing pressure to maintain aging infrastructure, meet regulatory standards, and manage resources efficiently. This whitepaper explores the strengths and specific use cases for LiDAR, structured light laser profiling, and photogrammetry—three of the industry's most advanced tools for pipeline assessment—highlighting the importance of accuracy in each.

Through rigorous testing and real-world data, we examine how each technology performs across varying pipe sizes, environments, and conditions. Our findings reveal where each tool excels: LiDAR's suitability for large-diameter pipes, laser profiling's unmatched precision in smaller pipes where surface detail is essential; and photogrammetry's role in creating comprehensive digital twins that bring pipelines into a fully measurable 3D environment.

These technologies empower decision-makers to reduce costs by targeting rehabilitation only where it's needed, enhance safety by accurately detecting potential vulnerabilities, and optimize infrastructure maintenance planning over time.

In addition to comparing the accuracy of measurement technologies, this whitepaper addresses the broader implications of data accuracy on operational efficiency and budgeting. By understanding where each method outperforms, readers can maximize inspection ROI.

1. Introduction to Inspection Technologies

Accurate data is the cornerstone of effective pipeline management. For municipalities and engineers tasked with maintaining complex sewer systems, selecting the right inspection technology directly influences safety, budgeting, and long-term infrastructure planning. As pipelines age and demands on urban infrastructure grow, the need for accurate and reliable inspection data has never been more critical. This whitepaper examines three core technologies—LiDAR, Laser Profiling (2D structured light), and photogrammetry—and their unique abilities to capture the details critical to maintaining pipeline integrity. The goal of our research was to answer these key questions:

1. What is the accuracy of LiDAR in small-diameter pipelines?
2. What is the best equipment to utilize in large-diameter pipelines?
3. At what pipe size does LiDAR become more accurate than laser Profiling?
4. Is photogrammetry evolving to be a viable alternative to LiDAR and laser profiling?

For over a decade, RedZone Robotics has set the standard in sewer inspection technology, driving innovation to meet the demands of municipalities and engineering firms worldwide. As specialists dedicated to underground infrastructure, we've refined our solutions to deliver the most reliable, accurate data, empowering our clients to make informed, proactive decisions about critical pipeline maintenance and rehabilitation. Our experience in this field has taught us that accuracy isn't just about hitting a benchmark—it's about ensuring every detail is captured so that communities can trust in the safety and longevity of their underground assets.

For municipalities and engineering teams tasked with managing aging sewer networks, the stakes are high. Inaccurate data can lead to costly misjudgments, from unnecessary repairs to missed vulnerabilities that could result in catastrophic failures.

Before evaluating how these technologies perform under real-world and controlled testing conditions, it is essential to establish a common baseline. Manufacturers of LiDAR, laser profiling, and photogrammetry systems publish accuracy specifications that describe what each sensor is designed to achieve under ideal or lab-controlled environments. These stated accuracies form the foundation of expectations used in procurement decisions, specification writing, and inspection planning. The following table summarizes the manufacturer-quoted accuracy values for the sensor technologies evaluated in this study and serves as a reference point against which actual performance will later be assessed.

Sensor	Manufacturer's stated Accuracy
Lidar 1	+/- 30mm
Lidar 2	+/- 30mm
Laser Profiling	+/- 5mm

Table 1: Manufacturers' stated accuracy for various inspection technologies tested.

2. Above-the-Flow Sensors Tested

LiDAR: Light Detection and Ranging

LiDAR is a remote sensing technology that utilizes laser pulses to accurately measure distances and create detailed 3D topography of environments. In sewer and pipeline inspections, a LiDAR sensor is mounted on an inspection platform and emits thousands of laser pulses per second, scanning the interior of the pipe. When these laser pulses strike the pipe walls, they reflect back to the sensor, allowing for precise distance calculations via time-of-flight measurement.

The collected data forms a "point cloud," a dense array of 3D points that represent the pipe's geometry. This point cloud enables the identification of structural features, deformations, and corrosion within the pipe. LiDAR's ability to cover large areas quickly makes it particularly effective in inspecting larger-diameter pipes, where comprehensive mapping is essential.

To enhance the accuracy and usability of the data, specialized software processes the point cloud, filtering out noise and integrating multiple scans into a cohesive model.

Laser Profiling for 2D Cross sections

Laser profiling (Structured light technology) uses projected laser light viewed by an offset camera to capture surface geometry. In pipeline inspections, a ring of laser light is projected onto the pipe wall. As the circular pattern deforms when encountering variations in the pipe's geometry, specialized high-resolution cameras capture the changes.

The data collected is used to construct a 3D representation of the pipe's interior. This process involves sophisticated algorithms that interpret the distortions in the projected patterns, enabling engineers to visualize and measure even the most intricate features.

One of the significant advantages of laser profiling is its capacity to deliver reliable results in complex environments where detail is paramount.

Photogrammetry for Digital Twins

Photogrammetry is a powerful imaging technique that involves triangulating detailed surface geometry using multiple offset images of an object or environment. In the context of pipeline inspections, multiple high-resolution cameras (in most cases at least four) are mounted on inspection platforms that traverse

the interior of the pipe. As these platforms move through the pipeline, they take numerous images from various angles.

The key to photogrammetry lies in the ability to analyze images to extract three-dimensional information. Advanced software algorithms identify common reference points across the images, triangulating their positions to reconstruct the 3D geometry of the pipeline. This process results in a highly detailed digital model that showcases not only the pipe's dimensions but also any defects, irregularities, or corrosion visually present on the surfaces.

As a newer technology, photogrammetry is increasingly being integrated into pipeline inspection workflows, complementing traditional methods and providing new avenues for analysis.

3. Methodology

1. Establish a Baseline

To ensure a high level of precision, we began by undertaking a high-resolution scan of the test pipeline using a metrology grade scanner, the HandyScan Black series, which has a quoted accuracy of ±0.2mm. This technology was selected for its industry-leading resolution, and the scan provided a baseline against which all subsequent tests could be measured.

2. Define Testing Regimen

We tested a range of sensor technologies, including multiple LiDAR systems, laser profiling, and photogrammetry setups. Each sensor was mounted on platforms typically used in real-world inspections, such as robotic crawlers and floating platforms, and operated at the speeds typical for these environments. The goal was to ensure that the testing conditions mirrored the challenges faced in actual inspection scenarios—taking into account variables like the speed of data acquisition and platform movement.

3. Digitize & Analyze

After scanning the pipeline with each sensor, the data was processed through our standard reporting tools, just as we would for any real inspection. This involved digitizing the point cloud data or laser profiling recordings, generating 3D models, and producing inspection reports based on the sensor outputs. The reports were then analyzed for completeness, resolution, and data accuracy.

4. Compare to Baseline

Once the data had been digitized and processed, we began a comparative analysis. Each sensor’s output was measured against the baseline scan, with deviations from the baseline calculated to determine the degree of accuracy. This step was critical in identifying how each sensor performed under the same conditions and how they compared in terms of accuracy and reliability.

4. Results

Test 1: Accuracy of LiDAR in Mid-size Pipes

Objective

The goal of this test was to determine the effectiveness of LiDAR in a 42” (~1050mm) pipe as compared to laser profiling and photogrammetry.

Results

These results show that LiDAR is less suitable for use in mid-size (20–60” / 500–1500 mm) pipes. The fundamental issue lies in the nature of LiDAR technology. While it excels in large-diameter environments where expansive geometric data is required, LiDAR struggles to capture the fine surface details necessary for mid-size pipe inspections. The high degree of deviation seen in our test confirms that LiDAR lacks the precision needed for detailed geometry, particularly when compared to laser profiling and photogrammetry.

Sensor	+/- 95% Confidence	Accuracy as % of Diameter
Lidar 1	+/-10.7 mm	+/- 0.99%
Lidar 2	+/-21.3mm	+/- 1.96%
Photogrammetry	+/-2.1mm	+/- 0.2%
Laser Profiling	+/-1.7 mm	+/- 0.16%

Table 2: Results of the testing within the 42” (1080mm) pipeline showing 95% confidence Interval as well as accuracy as a percentage of the pipe size.

LiDAR's difficulty in capturing fine surface details when the target is less than 40” (~1m) from the sensor arises from several inherent limitations in the technology. The larger footprint blurs the sensor’s ability to detect subtle changes in surface geometry, such as fine cracks or corrosion, which are critical to accurately assessing the condition of the pipe.

Laser profiling, on the other hand, emit tightly focused patterns and are specifically designed to maintain high resolution at close distances. This makes them far more effective at capturing the fine surface details required in confined spaces.

Conclusions

LiDAR’s limitations in close-range environments, particularly in mid-size pipelines, stem from its inability to maintain high resolution due to beam divergence, inconsistent signal returns,

reduced sampling density, and problems with reflective interference. While LiDAR excels in larger-diameter pipes and open environments, these factors make it an unreliable tool for capturing the fine surface details critical to mid-size pipe inspections, yielding an 95% confidence of up to $\pm 21\text{mm}$ ($\pm 1.96\%$).

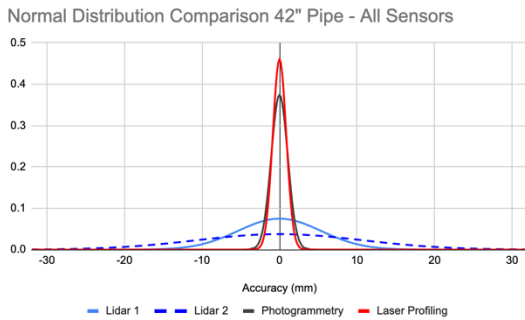


Figure 1: Normal distribution graph showing the standard deviation for each sensor, with Laser profiling and photogrammetry significantly outperforming LiDAR.

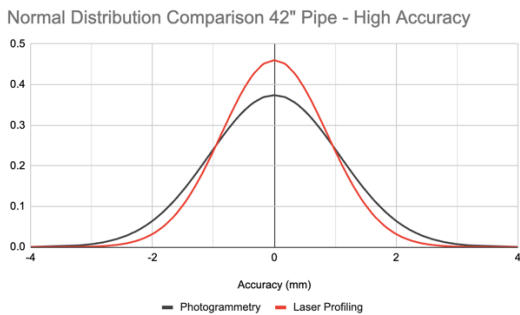


Figure 2: Normal distribution graph showing the standard deviation for high accuracy, with structured light and photogrammetry

Laser profiling’s ability to generate fine surface details makes it ideal for inspections in confined spaces like mid-size pipelines. The laser line projection method of laser profiling enables accurate detection of even minute surface imperfections, delivering average accuracy of $\pm 1.7\text{mm}$ ($\pm 0.16\%$) with 95% confidence.

Photogrammetry, though slightly less accurate on average than laser profiling at $\pm 2.1\text{mm}$ ($\pm 0.2\%$), also demonstrated a significant advantage over LiDAR, providing a robust combination of visual and geometric data that can supplement traditional inspection methods.

This test supports our stance that laser profiling is superior to LiDAR in most mid-size pipe applications. The five- to tenfold improvement in accuracy over LiDAR underscores the critical importance of selecting the right technology for the right environment. However, LiDAR can still offer unique advantages when certain field conditions are present, or when complex internal geometry requires a 3D model.

Test 2: Accuracy of LiDAR in Large-Diameter Pipelines

Objective

In this second test, our goal was to investigate whether LiDAR’s accuracy surpasses that of laser profiling technology in larger diameter pipelines, specifically a 118" (3000mm) interceptor pipe. The hypothesis we sought to prove is that, as pipe diameter increases, LiDAR’s margin of error becomes proportionally smaller, making it more effective in capturing large-scale geometries. Given that larger pipes are critical infrastructure, understanding the performance of different sensor technologies in these environments is essential for ensuring reliable inspections.

Results

These results confirm our hypothesis: as the diameter of the pipe increases, LiDAR’s accuracy improves relative to laser profiling. In a 118" (3000mm) pipe, the absolute deviations of each sensor may seem larger than those seen in smaller pipes; however, when considered as a percentage of the pipe diameter, LiDAR’s deviation of $\pm 6.6\text{mm}$ ($\pm 0.22\%$ of the diameter, with 95% confidence) demonstrates a lower margin of error compared with the mid-size pipeline test deviation of $\pm 21\text{mm}$ (1.96% of the diameter).

Sensor	95% Confidence	Accuracy as % of Diameter
Lidar 1	+/- 5.5 mm	+/- 0.18%
Lidar 2	+/- 6.6 mm	+/- 0.22%
Laser Profiling	+/- 3.4 mm	+/- 0.11%

Table 3: Results of the testing within the 3000mm pipeline showing 95% confidence Interval as well as accuracy as a percentage of pipe size.

Conclusions

This test highlights how LiDAR becomes increasingly accurate and operationally practical as pipe diameters increase. In the 118" (~3000mm) pipeline evaluated, LiDAR achieved a strong accuracy of approximately $\pm 0.2\%$ of pipe size across both LiDAR sensors, a figure that will continue to improve in even larger diameters where broader geometry is the primary concern. While Laser Profiling still provides marginally higher accuracy in certain large-pipe scenarios, its performance is often limited by operational constraints, such as the need for a more central positioning in the flow, something that has been achieved through the use of prolonged manned entry to assemble

centralizing equipment within the unforgiving environments. These real-world considerations often outweigh its theoretical accuracy advantage. In practice, LiDAR becomes the more deployable and consistent option for inspecting large-diameter interceptors.

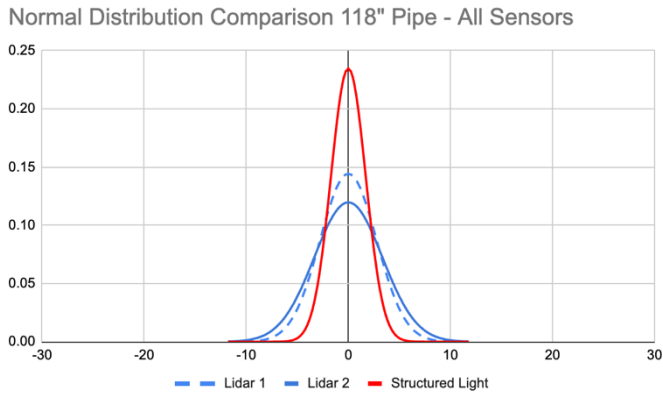


Figure 3: Normal distribution graph of sensor accuracy in a 3-meter pipe, showing LiDAR’s improved performance in large-diameter environments.

Laser profiling, while still useful in certain applications within large pipes, is less suited to environments where the focus is on overall structural mapping rather than surface detail. It was able to achieve $\pm 3.4\text{mm}$ ($\pm 0.11\%$) accuracy. In summary, LiDAR’s strengths in large-diameter pipes make it the technology of choice for interceptor-sized pipelines and other large sewer infrastructure, offering a balance of accuracy and deployment capability that laser profiling cannot match in these conditions.

Test 3: The Inflection Point between Laser Profiling and LiDAR

Objective

As sewer infrastructure ages and municipalities face the challenge of maintaining vast underground networks, the choice between using LiDAR or laser profiling for inspection becomes critical. For city engineers, the goal is clear: select the right tool to ensure accurate data collection that will inform rehabilitation, maintenance, and asset management decisions. However, the effectiveness of each technology, LiDAR and laser profiling, varies depending on pipe size and the specific needs of the inspection.

Procedure

In our next phase of testing, we employed a precision-machined test rig designed to provide highly accurate measurements across a range of pipe sizes, specifically targeting diameters of 20” (~500 mm), 40” (~1000 mm), 60” (~1500 mm), 80” (~2000 mm), and upward. This controlled environment allowed us to establish a consistent baseline of accuracy for each diameter, producing benchmark data for laser profiling technology. The laser data was then compared directly with LiDAR scans, enabling us to assess where each technology excels and where limitations arise.

Results

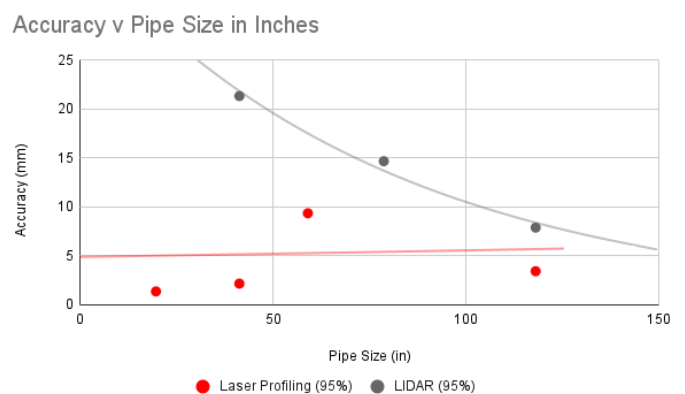


Figure 4: Absolute Accuracy vs. Pipe Size

Accuracy vs Pipe Size as a Percentage of Diameter

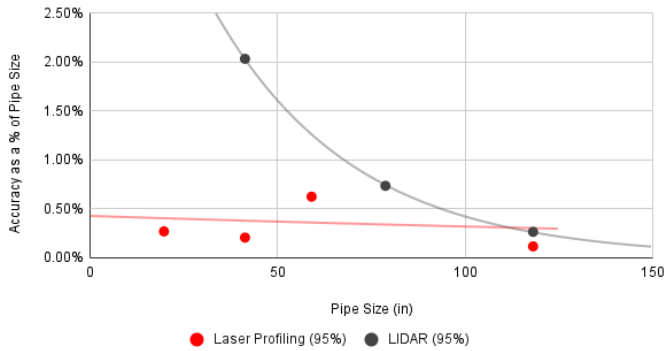


Figure 5: Accuracy as Percentage of Pipe Size

The graphs, when viewed side by side, tell a compelling story. The absolute accuracy graph shows the steep drop-off in laser profiling’s performance at larger diameters, while LiDAR’s accuracy curve remains relatively stable. In the percentage accuracy graph, laser profiling’s superiority in small diameters is evident, but as the pipe sizes increase, the technology becomes less reliable, leading to a marked crossover point in the neighborhood of 100” (2500 mm), where LiDAR’s percentage accuracy becomes more favorable.

Conclusions

In summary, in diameters below 100”, laser profiling outperforms LiDAR, achieving accuracy in the ±0.3-0.8% range, whereas LiDAR’s accuracy trends above that, exceeding ±3% in smaller diameters. At diameters above 100”, we measured LiDAR accuracy down to 0.22%, whereas laser profiling hovers in the 0.1% range.

By understanding this critical inflection point, municipalities can better allocate their resources, ensuring they’re using the most suitable technology for each pipeline, depending on its diameter. Depending on the information required to support decision-making, such as acquiring bend radius point clouds needed for rehab planning, a combination of methods—such as LiDAR and photogrammetry—may yield the most insight. This balance between detail-oriented laser profiling in smaller pipes and LiDAR’s consistency in larger pipes allows for more accurate assessments, preventing both overengineering and under-preparation. In turn, this leads to more efficient use of budget and manpower, while ensuring the long-term health of the city’s underground infrastructure.