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# Evaluating Spatial Fidelity of Mobile LiDAR Scanning in Crime Scene Reconstruction: An Experimental Study Using Polycam

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**Abstract**

**Background:** Accurate crime scene documentation is essential for reliable reconstruction and courtroom interpretation. Traditional two-dimensional methods often fail to capture depth and spatial relationships, leading to potential misinterpretation of evidence. Mobile LiDAR scanning offers a cost-effective alternative to professional laser scanners, but its forensic reliability requires validation.

**Methods:** A simulated bloodstain pattern was created under controlled laboratory conditions using red acrylic paint to replicate forensic evidence. The pattern was scanned with Polycam's LiDAR function on a smartphone. Measurements from 3D models were compared with manual tape measurements. Accuracy and reproducibility were assessed using descriptive statistics, mean error, standard deviation, accuracy percentage, and root mean square error (RMSE).

**Results:** Polycam's LiDAR scanning produced metrically accurate and reproducible 3D models, achieving 95–99% measurement accuracy across repeated trials. RMSE values confirmed consistency, with deviations remaining within forensic tolerance.

**Conclusion:** Mobile-based LiDAR scanning provides a reliable, low-cost, and accessible tool for forensic documentation. It preserves spatial arrangements, supports evidence interpretation, and enhances courtroom visualization. These findings support the integration of mobile LiDAR into forensic practice, particularly in resource-limited settings.

**Keywords:** Crime Scene Reconstruction; Mobile LiDAR; Polycam; Spatial Fidelity; Forensic Documentation;

## 1. Introduction

Accurate crime scene documentation is fundamental to forensic reconstruction and courtroom interpretation. Traditional two-dimensional methods such as photography, videography, and sketches often fail to capture depth and spatial relationships, which can lead to misinterpretation of evidence [1,2].

Advances in digital technologies have introduced three-dimensional reconstruction as a reliable alternative, enabling investigators to produce metrically accurate digital replicas of crime scenes [2,3].

Recent comparative studies highlight that smartphone-based LiDAR scanning can achieve deviations of less than 1–2% compared with conventional measurement methods [4]. Validation work on handheld LiDAR devices has confirmed their precision and reproducibility in forensic contexts [5]. Polycam, a mobile application, has broadened access to 3D scanning by offering a user friendly and cost effective platform for forensic documentation [6]. These models preserve spatial fidelity and enhance courtroom visualization, allowing judges and lawyers to interact with reconstructions and better understand the evidence [7].

The integration of advanced forensic platforms now combines photogrammetry, machine learning, and dynamic modelling to reconstruct traffic accidents and crime scenes, offering comprehensive solutions beyond legacy single function tools [8]. Emerging approaches such as AI based segmentation and simulation further expand the scope of digital forensic reconstruction [9]. Collectively, these developments have given rise to "3D Forensic Science" (3DFS), a distinct field that integrates 3D imaging, printing, and visualization into forensic practice, ensuring standardized terminology and evidence bases for use in the criminal justice system [10].

**Research Gap Identification**

Although professional laser scanners and photogrammetry have been validated extensively in forensic documentation, there is limited empirical evidence on the accuracy and reproducibility of consumer-grade mobile LiDAR applications s uch as Polycam. Existing studies focus on high-end equipment, leaving a gap in evaluating whether smartphone-based LiDAR can meet forensic standards of precision and reliability.

**Aim of the Study:**

The aim of this study was to assess the spatial accuracy and reliability of 3D models generated using Polycam for crime scene reconstruction. Specific objectives included:

- Creating 3D digital models of a simulated bloodstain pattern.
- Comparing manual measurements with those obtained from the 3D models.
- Calculating spatial deviation using statistical methods, including RMSE.

## 2. Methodology

### Study Design and Setting

This study employed an experimental quantitative design with repeated measures to assess the spatial accuracy and reproducibility of mobile LiDAR scans. The experiment was conducted under controlled laboratory conditions in Chennai, Tamil Nadu, India.

Figure 1 Long-shot view of simulated bloodstain pattern created using red acrylic paint on cloth, prepared under controlled laboratory conditions for LiDAR accuracy testing.

Figure 2 Top-view image of the same simulated bloodstain pattern created using red acrylic paint, highlighting splatter distribution for measurement analysis.

**Participants/Materials**

- LiDAR-enabled smartphones
- Polycam mobile application
- Microsoft Excel software for statistical analysis
- Simulated bloodstain pattern created using **red acrylic paint** with predefined reference points

**Data Collection Procedures**

A mock bloodstain pattern was prepared using red acrylic paint to simulate forensic evidence. Known reference points were marked, and manual measurements of linear distances between selected points were recorded using measuring tapes. The same pattern was scanned repeatedly using Polycam's LiDAR function. Measurements extracted from the 3D models (e.g., A–C, A–D, A–E, G–F) were compared with real-world manual values. Eleven repeated models (BS Model 01–11) were generated, and values were tabulated for analysis.

**Statistical Analysis Methods**

Descriptive statistics were performed using Microsoft Excel. Mean error, standard deviation, accuracy percentage, and root mean square error (RMSE) were calculated to evaluate measurement accuracy and reproducibility.

Formulas applied included:

Mean Error (Equation. 1):

$$\text{Mean Error} = \frac{\sum(\text{OBSERVED VALUE} - \text{REAL VALUE})}{n}$$

Standard Deviation (Equation. 2):

$$\text{Standard Deviation} = \sqrt{\frac{\sum(e_i - e)^2}{n-1}}$$

Root Mean Square Error (Equation. 3):

$$\text{RMSE} = \sqrt{\frac{\sum(OBSERVED - REAL)^2}{n}}$$

Accuracy Percentage (Equation. 4):

$$\text{Accuracy \%} = \left(1 - \frac{NRMSE}{Mean\ of\ reall\ values}\right) \times 100$$

**Limitations**

This study was limited to a single simulated scene. Environmental factors (lighting, surface texture) and operator movement may influence scanning accuracy. Further validation across diverse forensic scenarios is recommended.

**Ethical Considerations**

Ethical review and approval were waived for this study due to the use of simulated bloodstains created with red acrylic paint under controlled laboratory conditions. No human participants, human tissue, or animals were involved. An official ethics waiver certificate was issued by the Institutional Ethics Committee, Dr. M.G.R. Educational and Research Institute, Chennai, India.

## 3. Results

**Measurement Accuracy**

Polycam's LiDAR scanning produced metrically accurate 3D models across repeated trials. Comparison of observed values with manual tape measurements showed deviations within acceptable forensic tolerance. Accuracy ranged between 95% and 99%, with mean errors consistently below 0.3 cm.

Table 1Observed and real measurement values (in cm) for BS Models 01–11 at point A–C, showing deviations between Polycam LiDAR scans and manual tape measurements.

| MODEL NAME | OBSERVED VALUES (in CM) | REAL VALUES (in CM) |
|---|---|---|
| BS MODEL - 01 | 10.60 | 10.50 |
| BS MODEL - 02 | 10.70 | 10.50 |
| BS MODEL - 03 | 10.70 | 10.50 |

| | | |
|---|---|---|
| BS MODEL - 04 | 10.60 | 10.50 |
| BS MODEL - 05 | 10.50 | 10.50 |
| BS MODEL - 06 | 10.60 | 10.50 |
| BS MODEL - 07 | 10.80 | 10.50 |
| BS MODEL - 08 | 10.60 | 10.50 |
| BS MODEL - 09 | 10.70 | 10.50 |
| BS MODEL - 10 | 10.80 | 10.50 |
| BS MODEL - 11 | 10.50 | 10.50 |

Table 2 Observed and real measurement values (in cm) for BS Models 01–11 at point A–D, showing deviations between Polycam LiDAR scans and manual tape measurements.

| MODEL NAME | OBSERVED VALUES (in CM) | REAL VALUES (in CM) |
|---|---|---|
| BS MODEL - 01 | 46.40 | 46.40 |
| BS MODEL - 02 | 46.10 | 46.40 |
| BS MODEL - 03 | 46.40 | 46.40 |
| BS MODEL - 04 | 46.20 | 46.40 |
| BS MODEL - 05 | 46.60 | 46.40 |
| BS MODEL - 06 | 46.10 | 46.40 |
| BS MODEL - 07 | 46.50 | 46.40 |
| BS MODEL - 08 | 46.40 | 46.40 |
| BS MODEL - 09 | 46.70 | 46.40 |
| BS MODEL - 10 | 46.20 | 46.40 |
| BS MODEL - 11 | 46.30 | 46.40 |

Table 3 Observed and real measurement values (in cm) for BS Models 01–11 at point A–E, showing deviations between Polycam LiDAR scans and manual tape measurements.

| MODEL NAME | OBSERVED VALUES (in CM) | REAL VALUES (in CM) |
|---|---|---|
| BS MODEL - 01 | 6.30 | 6.00 |
| BS MODEL - 02 | 6.30 | 6.00 |
| BS MODEL - 03 | 6.20 | 6.00 |
| BS MODEL - 04 | 6.20 | 6.00 |
| BS MODEL - 05 | 6.30 | 6.00 |
| BS MODEL - 06 | 6.00 | 6.00 |
| BS MODEL - 07 | 6.30 | 6.00 |
| BS MODEL - 08 | 6.10 | 6.00 |
| BS MODEL - 09 | 6.20 | 6.00 |
| BS MODEL - 10 | 6.10 | 6.00 |
| BS MODEL - 11 | 6.10 | 6.00 |

Table 4 Observed and real measurement values (in cm) for BS Models 01–11 at point G–F, showing deviations between Polycam LiDAR scans and manual tape measurements.

| MODEL NAME | OBSERVED VALUES (in CM) | REAL VALUES (in CM) |
|---|---|---|
| BS MODEL - 01 | 104.80 | 104.5 |
| BS MODEL - 02 | 104.30 | 104.5 |
| BS MODEL - 03 | 104.30 | 104.5 |
| BS MODEL - 04 | 104.60 | 104.5 |
| BS MODEL - 05 | 105.00 | 104.5 |
| BS MODEL - 06 | 104.30 | 104.5 |
| BS MODEL - 07 | 104.90 | 104.5 |
| BS MODEL - 08 | 104.80 | 104.5 |
| BS MODEL - 09 | 105.00 | 104.5 |
| BS MODEL - 10 | 104.30 | 104.5 |
| BS MODEL - 11 | 103.80 | 104.5 |

Table 5 Summary of error statistics (mean error, standard deviation, RMSE, NRMSE, and accuracy percentage) for measurement points A–C, A–D, A–E, and G–F, comparing Polycam LiDAR measurements with manual tape values.

| Reference Points | Mean Error between points | Standard deviation between points | RMSE between points | NRMSE between points | Accuracy% |
|---|---|---|---|---|---|
| A-C | 0.145454545 | 0.100856333 | 0.175809815 | 0.175809815 | 98.4 |
| A-D | -0.045454545 | 0.218403297 | 0.19306146 | 0.19306146 | 99.6 |
| A-E | 0.190909091 | 0.104450945 | 0.215322169 | 0.215322169 | 96.5 |
| G-F | 0.054545455 | 0.38301436 | 0.369274473 | 0.369274473 | 99.7 |

**Reproducibility**

Repeated scans (BS Models 01–11) demonstrated high reproducibility. RMSE values confirmed consistency across trials, with minimal variation between observed and real measurements. Accuracy percentages for different measurement points were:

- A–C: **98.4%**
- A–D: **99.6%**
- A–E: **96.5%**
- G–F: **99.7%**

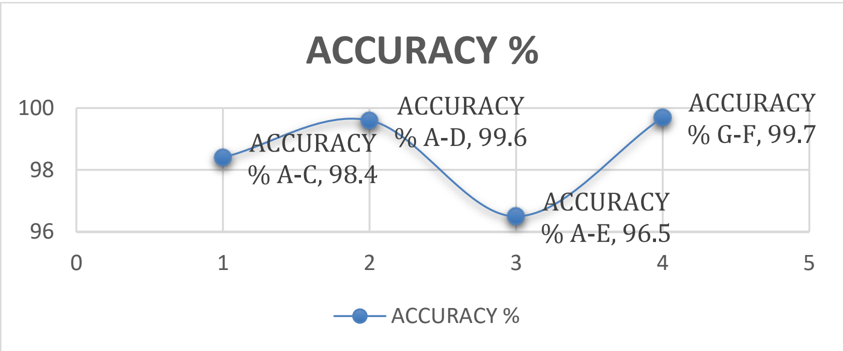


Figure 3 Accuracy percentages of Polycam LiDAR measurements compared with manual tape values across different points (A–C, A–D, A–E, G–F), showing deviations between 96.5% and 99.7%.

Figure 3 illustrates accuracy percentages of Polycam LiDAR measurements compared with manual tape values across different points, showing deviations between **96.5% and 99.7%**.

**Statistical Findings**

- Mean Error values remained below **0.3 cm** across all trials.
- Standard Deviation values indicated minimal spread in repeated measurements.
- RMSE values (0.176–0.369 cm) confirmed high consistency, supporting reproducibility.
- Accuracy percentages consistently exceeded **95%**, validating measurement reliability.

### Overall Finding

The study confirms that mobile LiDAR scanning using Polycam can generate reproducible 3D models with high spatial fidelity. The accuracy and consistency achieved across multiple trials support its application in crime scene reconstruction, courtroom visualization, and evidence interpretation.

## 4. Discussion

### Interpretation of Results

The study demonstrated that Polycam's mobile LiDAR scanning achieved high spatial accuracy across repeated trials. For point A–C (10.5 cm real), the RMSE was 0.176 cm with an accuracy of 98.4%. For A–D (46.4 cm real), RMSE was 0.193 cm with accuracy 99.6%. For A–E (6.0 cm real), RMSE was 0.215 cm with accuracy 96.5%, while G–F (104.5 cm real) showed RMSE 0.369 cm and accuracy 99.7%. These consistently low RMSE values confirm reproducibility and indicate that Polycam can reliably capture spatial fidelity in controlled forensic simulations.

### Comparison with Existing Literature

Previous studies on professional laser scanners and photogrammetry have reported deviations of less than 1–2% in forensic measurements. The present findings align closely, with Polycam achieving deviations well within this range. Earlier evaluations of mobile LiDAR highlighted potential issues such as registration drift and environmental sensitivity, yet the reproducibility observed here demonstrates that consumer-grade applications can approach professional standards under controlled conditions. This supports the growing evidence that mobile LiDAR can serve as a cost-effective alternative for preliminary forensic documentation.

### Limitations and Implications

The study was restricted to a single simulated bloodstain pattern created with red acrylic paint. Environmental factors such as lighting, surface texture, and operator movement were not systematically varied, which may influence accuracy in real-world scenarios. Despite these limitations, the implications are significant:

- Mobile LiDAR scanning offers cost-effective accessibility, reducing reliance on expensive forensic-grade scanners.
- High accuracy (≥96.5%) supports its use in courtroom visualization and evidence preservation.
- However, challenges remain regarding chain of custody, CJIS compliance, and admissibility under the standard, which must be addressed before widespread evidentiary use.

### Future Research Directions

Further validation across diverse forensic scenarios is required to establish broader applicability. Future studies should:

- Evaluate Polycam in outdoor and complex crime scenes with varied lighting and surface textures.

- Investigate the impact of operator training and scanning technique on measurement accuracy and reproducibility.
- Assess long-term storage protocols, chain-of-custody requirements, and legal admissibility of mobile LiDAR data.
- Explore integration with AI-based segmentation, trajectory analysis, and advanced forensic platforms to expand functionality.

## 5. Conclusion

This study evaluated the spatial accuracy and reproducibility of mobile LiDAR scanning using Polycam for forensic documentation. Across eleven repeated models, measurement deviations remained minimal, with RMSE values ranging from **0.176 cm to 0.369 cm** and accuracy percentages consistently above **96%**. These results confirm that Polycam can generate metrically accurate and reproducible 3D models under controlled conditions.

The practical implications are significant: mobile LiDAR offers a cost-effective and accessible alternative to professional scanners, enabling rapid documentation of crime scenes and enhancing courtroom visualization through interactive 3D reconstructions. While promising, the findings also highlight the need for further validation across diverse forensic scenarios and careful consideration of evidentiary standards such as chain of custody and admissibility.

In summary, Polycam demonstrates strong potential as a supplementary tool in forensic practice, bridging the gap between traditional 2D documentation and advanced 3D reconstruction, and contributing to the emerging field of digital forensic science.

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