HOVERMAP ST-X PRECISION AND ACCURACY WHITE PAPER

DOCUMENT NUMBER: INF-002
REVISION NUMBER: 1.2
RELEASE DATE: 14 FEB 2024

PREPARED BY:
EMESENT PTY LTD
LEVEL G, BUILDING 4, KINGS ROW OFFICE PARK
40-52 MCDOUGALL ST, MILTON, QLD, 4064 AUSTRALIA

EMAIL: CUSTOMER-SUCCESS@EMESENT.IO
PHONE: +61 7 3548 9494

Using this manual

Hovermap is a powerful system that can be used as a Lidar mapping payload but also as an advanced autopilot for drones. It is therefore recommended to read the user manual thoroughly to make use of all its capabilities in a safe and productive way.

Disclaimer and safety guidelines

This product is not a toy and must not be used by any person under the age of 18. It must be operated with caution, common sense, and in accordance with the instructions in the user manual. Failure to operate it in a safe and responsible manner could result in product loss or injury.

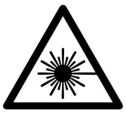
By using this product, you hereby agree that you are solely responsible for your own conduct while using it, and for any consequences thereof. You also agree to use this product only for purposes that are in accordance with all applicable laws, rules and regulations.

The use of Remotely Piloted Aircraft Systems (RPAS) may result in serious injury, death, or property damage if operated without proper training and due care. Before using an RPAS, you must ensure that you are suitably qualified, have received all necessary training, and read all relevant instructions, including the user manual. When using an RPAS, you must adopt safe practices and procedures at all times.

Warnings

- This document is legally privileged, confidential under applicable law and is intended only for the use of the individual or entity to whom it is addressed. If you have received this transmission in error, you are hereby notified that any use, dissemination, distribution or reproduction is strictly prohibited. If you are not the intended recipient, please notify the sender and delete the message from your system.

- Always be aware of moving objects that may cause serious injury, such as spinning propellers or other components. *Never* approach a drone while the propellers are spinning or attempt to catch an airborne drone.



Class 1 Laser Product
(21 CFR 1040.10
and 1040.11)

WARNING
HAZARDOUS MOVING PARTS
KEEP FINGERS AND OTHER
BODY PARTS AWAY

Contents

1. Introduction

The Hovermap ST-X is Emesent's flagship product, with best-in-class precision and accuracy. To ensure that each ST-X produces point clouds of the highest quality, each unit goes through extensive testing at Emesent's dedicated production, calibration, and test facility located in Brisbane, Australia.

This white paper details one of the key acceptance tests each payload goes through and presents detailed precision and accuracy metrics derived from the test data for a sample unit. The results presented in this paper can guide the collection of data to produce high-quality point clouds and can serve as a reference for best practices.

2. Precision vs Accuracy

The following are the most widely used metrics when evaluating a mobile mapping system such as the Hovermap ST-X.

- **Precision:** The degree of repeatability of a measurement. It corresponds to the 'fuzziness' of the surfaces in the point cloud.
- **Accuracy:** The degree of closeness of a particular measurement to the true value. It corresponds to the average distance between the points and the true location of the surfaces in the point cloud.

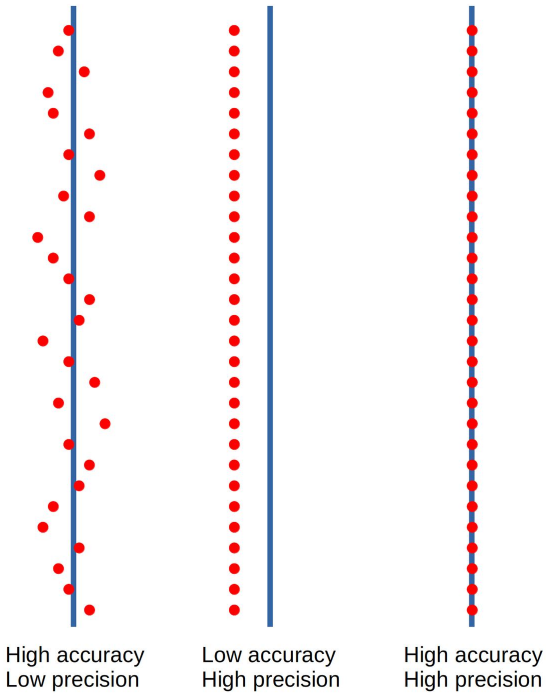


Figure 1 Precision vs Accuracy

2.1 Calculating Precision

Point cloud precision is calculated by extracting points from the point cloud that correspond to planar features, fitting a plane to those points, and then fitting a normal distribution to the point-to-plane error. The resulting standard deviation (σ) is reported as the precision. A precision value of 5mm indicates that 68% of points were within 5mm of the plane, and 95% of the points were within 10mm of the plane.

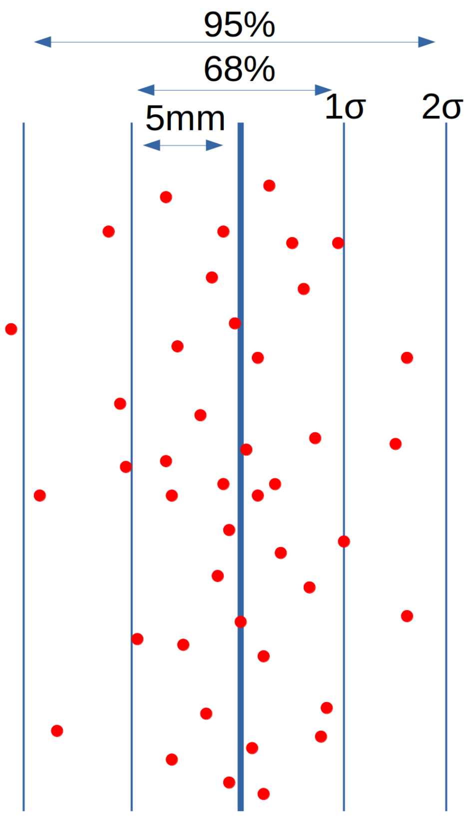


Figure 2 Calculating precision

2.2 Calculating Accuracy

Point cloud accuracy is calculated using cloud-to-cloud distances between the Hovermap point cloud and a reference point cloud. The cloud-to-cloud distance is a distribution of point-to-cloud distances between the point cloud under consideration (represented as red dots below) and the reference point cloud (represented as blue). Assuming that both point clouds are in the same reference frame, the point-to-cloud distance for each point is calculated by finding the nearest point in the reference point cloud and calculating the distance between the two points. The distribution of distances can then be used to quantify the accuracy of the system.

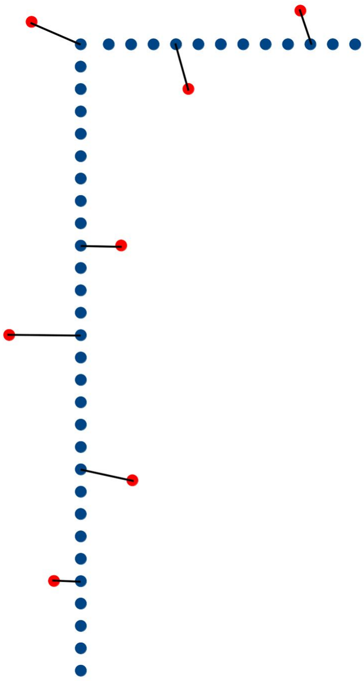


Figure 3 Calculating accuracy

3. Handheld Scan Testing

Each payload manufactured at Emesent's dedicated production, calibration, and test facility goes through a suite of tests as part of the quality assurance process.

One of the tests performed is a handheld scan which is used to evaluate how well a payload is calibrated. The following images show the trajectory and resultant point cloud for a Hovermap ST-X payload. The scan took approximately 2.5 minutes to complete, starting from the facility's car park, with neighboring buildings over 100m away being visible, and ending inside the calibration and test area. This area is an open warehouse measuring 37m x 30m x 8m, augmented with several calibration targets.

> **Note**
> Ground control points or GPS are not used at any point to eliminate drift.

> **Note**
> The images show the trajectory of the handheld scan in white. In addition, the roof of the facility has been removed for visualization purposes.

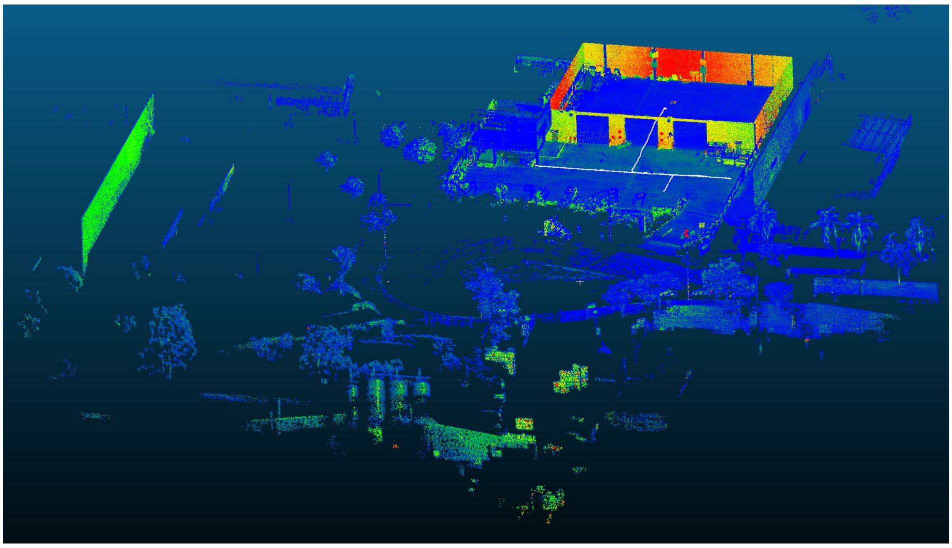


Figure 4 General view

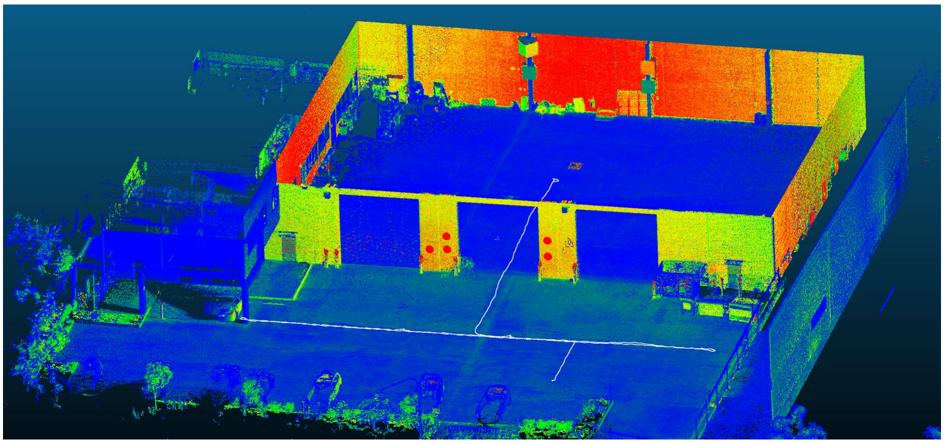


Figure 5 Close up view

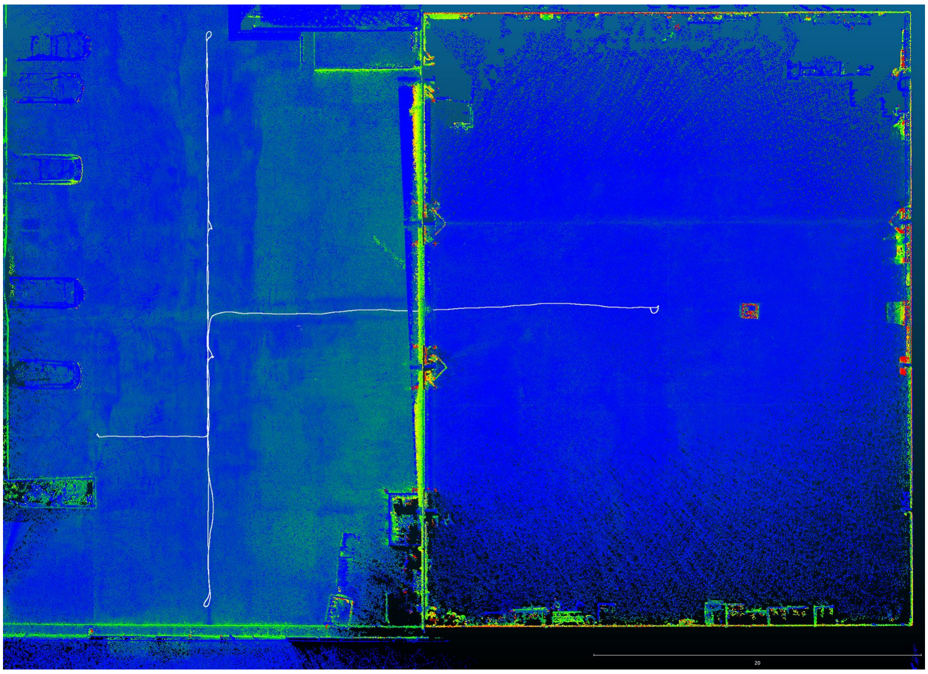


Figure 6 Overhead view

3.1 Reference Scan

A reference scan of the Emesent production, calibration, and test facility was taken using a Leica RTC360 to determine the accuracy of the payload. The reference scan consists of 4 individual scans taken on medium density for a total scan time of approximately 4 minutes, resulting in 99 million points.

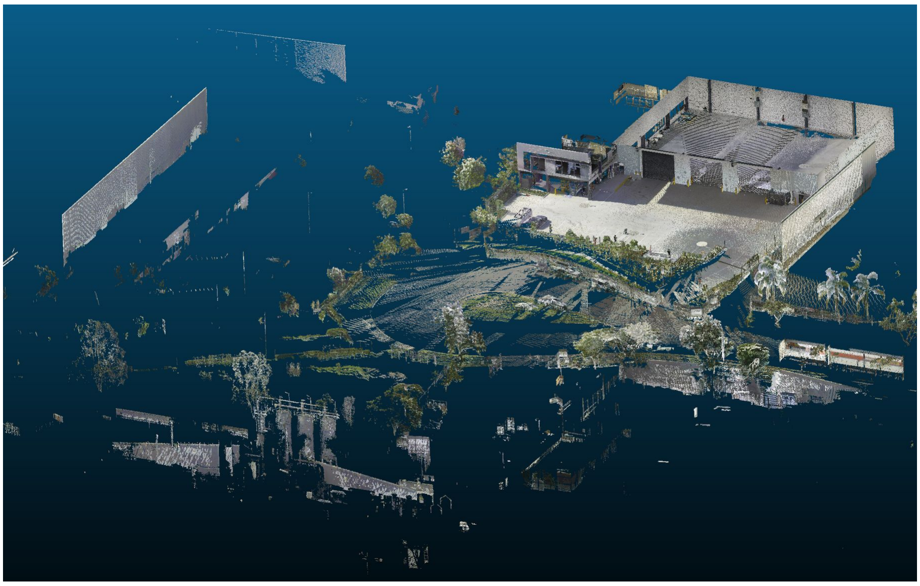


Figure 7 Emesent facility reference scan

4. Precision Results

Each handheld scan goes through an automated quality assessment where points that correspond to a set of 10 planes at various ranges and orientations are automatically extracted. A plane is fitted to each set of points, then the metrics on the point-to-plane error are used to pass or fail a payload. The below image shows the 10 test planes (colored red).

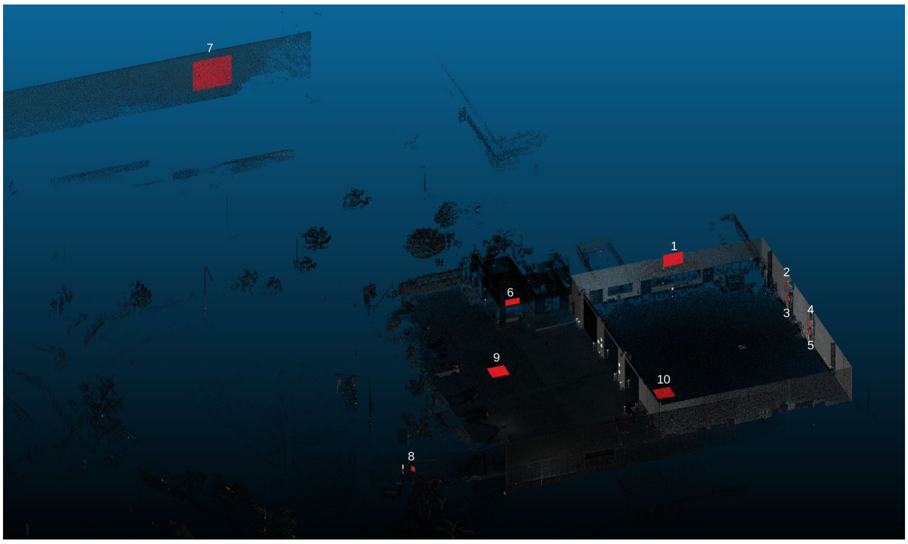


Figure 8 The test planes (shown in red)

The precision results for each plane are presented below, including the average range of the points associated with each plane. Note that range refers to the distance of the point from the Hovermap at the time the measurement was recorded.

Plane	Average range (m)	Precision (mm)
1	22.4	4.4
2	22.9	4.7
3	22.8	4.4
4	25.4	3.9
5	25.3	4.8

Plane	Average range (m)	Precision (mm)
6	14.9	4.3
7	87.1	10.5
8	31.0	5.5
9	3.9	3.9
10	13.5	5.7

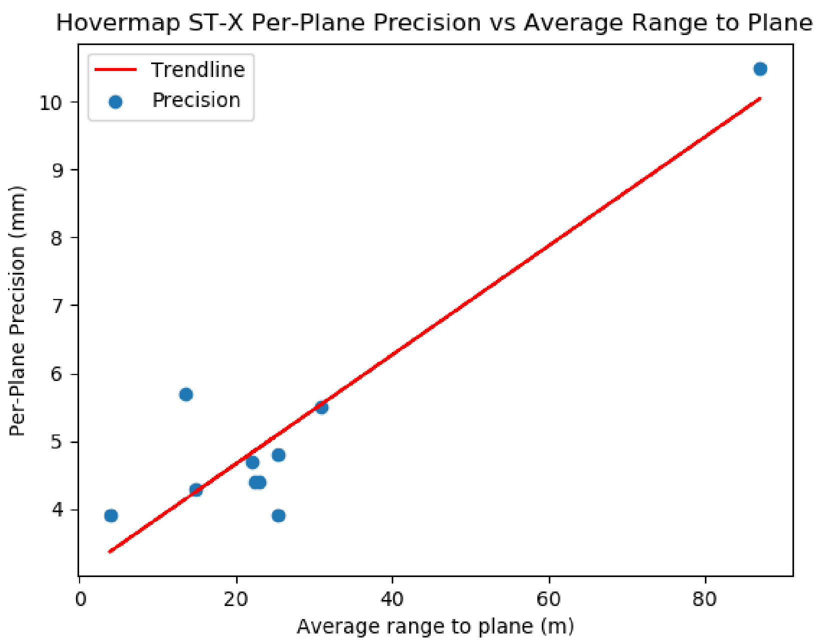


Figure 9 Per-plane results showing the average range and precision for all points intersecting with the plane

The correlation between the plane's range and the precision result is evident. A closer examination of the per-point results shows this relationship more clearly as presented below. The graph illustrates the average precision plotted against the point's range for all points intersecting with the plane.

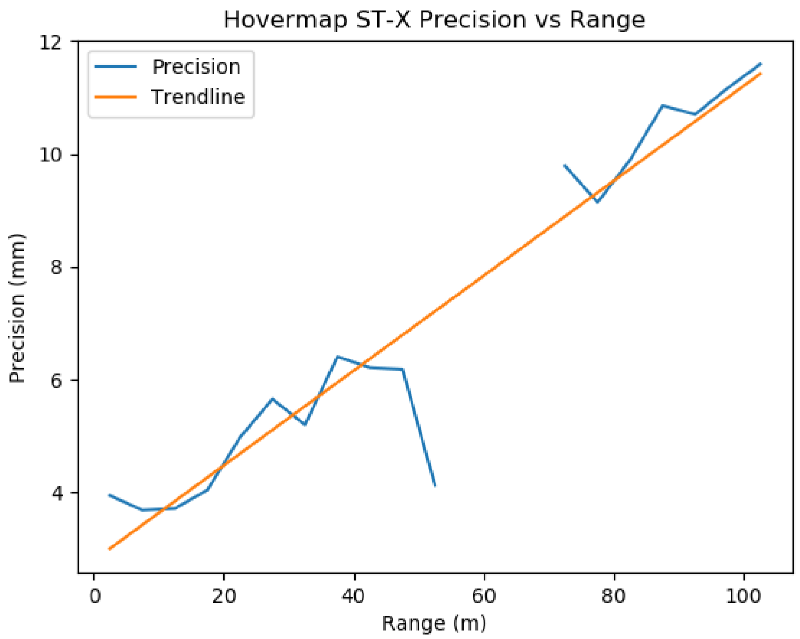


Figure 10 Precision vs Range. Trendline shown in red

5. Accuracy Results

To assess the accuracy of the Hovermap scan, it was initially aligned with the Leica reference scan using the Iterative Closest Point (ICP) algorithm, ensuring both point clouds are in a common reference frame.

Considering the gap when the Hovermap and reference scans were taken, sections of the Hovermap scan were removed to eliminate the impact of vegetation, vehicles, and other movable objects on the accuracy calculation. Areas corresponding to low point density in the reference scan were additionally removed to reduce their impact on the accuracy calculation.

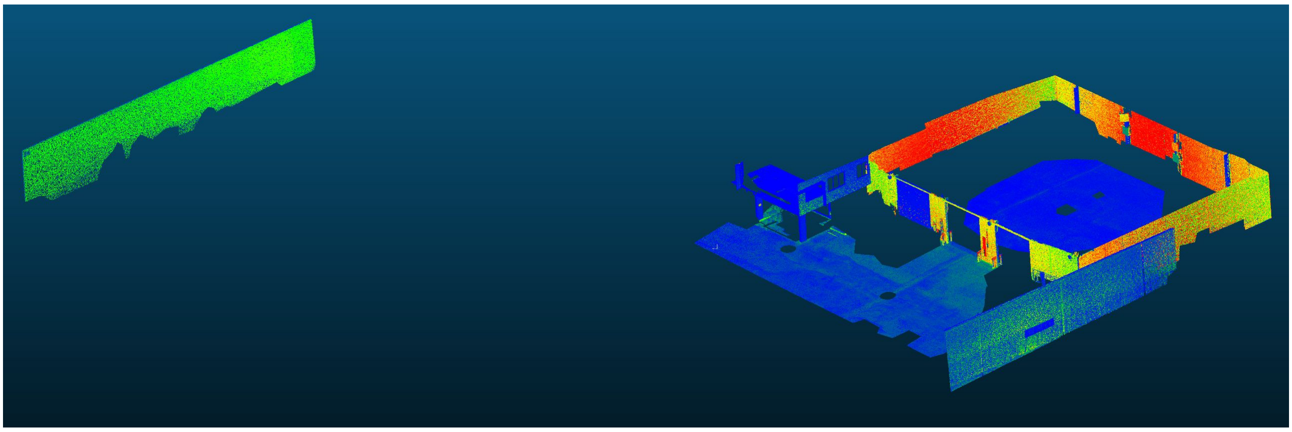


Figure 11 Cropped scan used for assessing accuracy

The graph presented below illustrates the cumulative distribution of the cloud-to-cloud distance between the Hovermap scan and the reference scan. It shows that 68% of points were within 6.7mm of the reference scan, with 95% falling within 13.9mm. It is important to note that this analysis covers points ranging from 1.5m up to 120m.

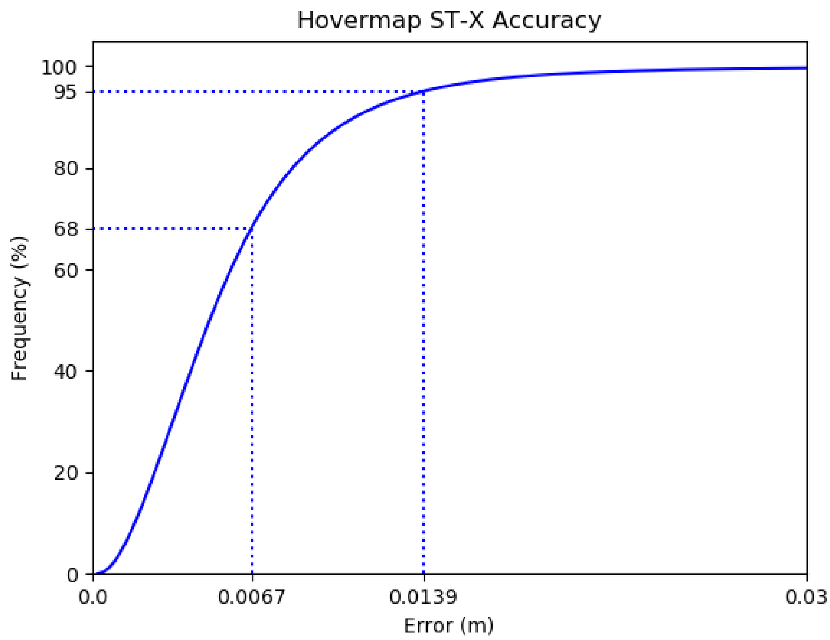


Figure 12 Accuracy frequency graph

6. Conclusion

This paper has provided comprehensive precision and accuracy results for the Hovermap ST-X under standard conditions. The ST-X demonstrated precision below 6mm on planes within average ranges of up to 30m. Additionally, the ST-X achieved a cloud-to-cloud accuracy of 6.7mm at 1-sigma and 13.9mm at 2-sigma when compared to a reference point cloud obtained using a survey-grade laser scanner.

7. Caveats

The findings presented in this white paper demonstrate the system's performance in a well-structured environment, captured via a walk-through of the scene. Like any SLAM system, the accuracy and precision of the system are influenced by various factors including the complexity of the environment, the duration and size of the mission, and so forth. Generally speaking, we anticipate precision to diminish in less favorable environments, while accuracy is likely to decrease in such environments as well as during longer transits.

PREPARED BY:
EMESENT PTY LTD
LEVEL G, BUILDING 4, KINGS ROW OFFICE PARK
40-52 MCDOUGALL ST, MILTON, QLD, 4064 AUSTRALIA

EMAIL: CUSTOMER-SUCCESS@EMESENT.IO
PHONE: +61 7 3548 9494