Enhancing Maritime Safety with Real-Time Air Draft Measurements using LiDAR Technology

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Abstract
Ensuring the safe passage of ships through height-restricted waterways requires accurate and efficient air draft measurements. Air draft is defined as the vertical distance from the waterline to the highest fixed point on a vessel, a critical factor in determining whether a ship can safely pass under a bridge or overhead obstruction. While many bridges worldwide monitor air gap (the clearance between the water surface and the underside of a bridge), the system described in this paper is a world first to measure the air draft of moving ships in real time. By scanning each ship as they approach, it provides advanced warning of breaches of the air draft limit, ensuring corrective actions can be taken before a ship reaches the bridge, enhancing maritime safety by preventing allisions.

Traditional air draft management relies on manual reporting, often prone to errors due to miscalculations, changing cargo loads, or structural modifications. The automated system described here eliminates uncertainties by delivering precise, real-time measurements without human intervention. By providing consistent and objective data, it sets a new standard for safe navigation through height-restricted waterways.

This paper explores the system's design, including LiDAR (Light Detection and Ranging) operation and configuration, hardware, and data processing methodologies. It also details the challenges encountered during implementation, including wildlife interference and the impact of ship material properties on measurement accuracy. The accuracy of air draft declarations submitted by vessels is analysed based on scan results, highlighting discrepancies observed between reported and measured values. The results demonstrate the system's ability to identify the highest point of the vessel, including thin features such as flexible antennas, which the results suggest are often overlooked by the ship's crew when declaring air drafts.

Keywords: air draft, real-time, LiDAR, bridge, port operations.

1. Introduction

Air draft is defined as the distance of the highest point on a vessel above the waterline (Figure 1). As such, this differs with not only every vessel, but every transit of every vessel, as it relies on the vessel draft, which changes based on loading. Overhead structures have air draft limits, which vessels must remain under to ensure they meet the air draft clearance requirements for a safe transit.

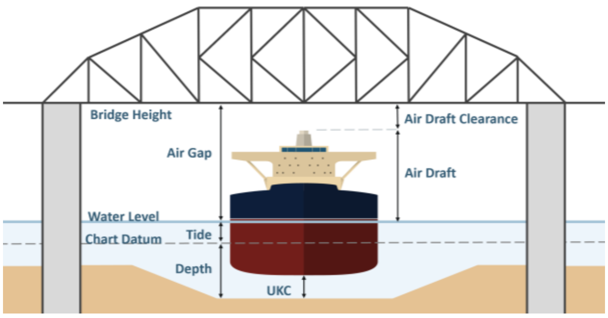

Figure 1 Cross sectional view of a ship passing under a bridge highlighting the difference between Air Gap, Air Draft Clearance and Air Draft. (Source: Author).

Ports Victoria identified a need to improve safety around air draft limited passages under the West Gate Bridge in Melbourne. The existing processes relied on self-declared air drafts submitted by ships and their agents, with no independent means to verify these values before reaching the West Gate Bridge.

OMC International was engaged to deliver a system capable of scanning vessels in transit and advising their measured air draft to VTS (Vessel Traffic Services) before the vessel reached the bridge.

The air draft system needed to assess a moving target, the ship, at variable distances, under all environmental conditions. The measurement had to be accurate, timely, and reliable enough to inform vessel stoppage decisions. The system also needed to be adaptable to variable air draft limits caused by occasional maintenance works on the bridge.

This paper outlines the motivation, design process, deployment locations, challenges encountered, and overall performance of the installed solution.

2. West Gate Bridge

The West Gate Bridge (WGB), shown in Figure 2, is a steel, box girder, cable-stayed bridge in Melbourne, Victoria, Australia, spanning the Yarra River just north of its mouth into Port Phillip Bay. It carries the West Gate Freeway and is a vital link between the Melbourne central business district (CBD) and western suburbs. An air draft limit of 50.10m is currently in place for all vessels transiting underneath (Ports Victoria, 2023). On average, 6 vessels over 100m in length transit under the bridge each day.

Figure 2 Photograph of a container ship passing under the West Gate Bridge. (Source: Author)

Vessels entering or exiting multiple berths must pass beneath the bridge, with those transiting Swanson Dock (container trade) and Appleton Dock (general trade) potentially being tall enough to encroach upon the air draft limit. Figure 3 shows a map of the Port of Melbourne, highlighting the major features of interest.

Figure 3 Map of the Port of Melbourne. Major berths are shown in green, the West Gate Bridge in pink, and the LiDAR scanner locations with red stars. (Source: Author)

3. Project Timeline

- May 2023 – Tender Awarded: Ports Victoria issued a request for tender for a real-time air draft system. OMC International was selected.
- July 2023 – Project Kick-Off: Initial system design. Hardware options and site feasibility were reviewed.
- January 2024 – Stage 1 Validation: A proof-of-concept LiDAR unit was manually deployed at Breakwater Pier to demonstrate that the LiDAR could accurately measure the height of a small sample of vessels.
- April 2024 – Breakwater Pier Installation: A fixed mount and scanner were installed on Breakwater Pier.
- July 2024 – Stage 2 Validation: A much larger sample size of vessels was obtained by automating the scan process, which didn't require a human presence on site and was adaptable to changes in the shipping schedule.
- July 2024 – South Wharf Installation: A second scanner was installed at South Wharf on the southern bank of the Yarra River adjacent to the Swanson Dock central channel marker.
- November 2024 – Stage 3 Validation: Final validation using both LiDAR, this provided the most comprehensive dataset and having two sensors provided the advantage of cross-referencing the results.
- 2025 – System goes live with Ports Victoria, with action taken when vessels breach the air draft limit.

4. System Design and Location Considerations

The system comprises the following core components:

- A long-range, weatherproof LiDAR unit capable of scanning vessels at distances up to 300+ metres.
- A weatherproof PTZ camera to provide visual images for comparison to LiDAR scans.
- Custom steel mounting brackets fixed to robust wharf infrastructure.
- A sealed enclosure housing power supply, battery backup, modem and edge computing hardware.

Melbourne's geography provides a fortunate vantage point to install sensors for inbound vessels at Breakwater Pier in Williamtown. The pier is home to a 15m high tower, shown in Figure 4, which is used for existing CCTV and metocean equipment and provides an excellent vantage point for observing ships. Crucially, the location also allows for data to be obtained, processed and communicated to ships in time to abort before they reach the West Gate Bridge. Vessels are scanned at 300-500m from Breakwater Pier.

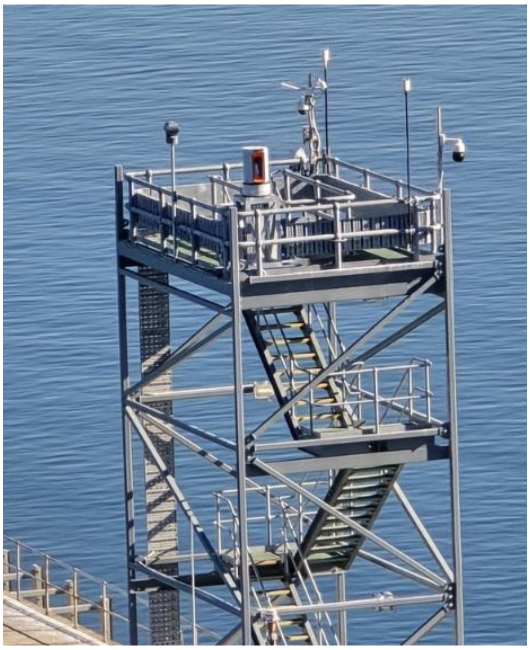

Figure 4 Photograph of Breakwater Pier tower with the LiDAR scanner shown in the foreground. (Source: Author)

Outbound vessels are scanned from South Wharf on the southern bank of the Yarra River, adjacent to the Swanson Dock central channel marker. This location provides the earliest opportunity to capture the ships in their entirety. Vessels are scanned at 150-300m from South Wharf.

LiDAR (Light Detection and Ranging) is a remote sensing method that measures distance by emitting laser pulses and detecting their reflection from objects. It produces high-resolution, three-dimensional point clouds, relative to the scanner (X, Y, Z coordinates). By surveying in the location and orientation of the scanner, these can be transformed to a geographic coordinate system, providing the latitude, longitude, and elevation of every point at its scan time.

LiDAR technology was selected to measure the vessel height. Key drivers included:

- High spatial accuracy and resolution, allowing identification of thin features like antennas.
- Consistent performance across lighting conditions, including night-time.
- Tolerance to fog and rain.

The Riegl VZ-2000i LiDAR scanner was selected for this application based on its impressive scanning capabilities (range, resolution, and speed). The VZ-2000i sensor is controllable via code, and has both 2D and 3D scanning modes, along with on-board compute capability to process point cloud data. This provides the capability to automate the scanning process and, by taking advantage of these features, to optimise the start and end times of the scan to maximise the point cloud density.

The LiDAR device is housed inside an actively cooled protective enclosure called a Syperion ArmourCase.

In addition to LiDAR technology, the system also captures AIS data to identify vessels and to prepare for a scan, as well as tide gauge data, which is used to calculate the air draft value from the height reported by the LiDAR scanner. The water level height is not determined directly from the LiDAR point cloud due to two factors:

- Vessel squat effects cause localised variations in the water level around the ship's hull.
- The water level cannot be reliably identified against the ship's hull because LiDAR can penetrate the water surface.

GPS surveys of the LiDAR device, combined with local datum information (LAT – Ellipsoid offset) are used to convert the LiDAR data to tide datum.

The process of an automated scan can be simplified as follows:

1. An appropriate vessel is identified from AIS data as approaching the scan area.
2. When the vessel is close to the scan area the system will initiate a 2D vertical scan to act as a tripwire. A 2D profile scan of a ship can be seen in Figure 5.
3. When the ship exits the 2D beam, the system has an extremely accurate understanding of the ship's position and can now initiate a full 3D scan. An example of a 3D scan is shown in Figure 6.
4. The LiDAR body rotates in the ship's direction of travel, scanning the ship from stern to bow. The duration of this scan has been optimised for the typical speeds of the vessels.
5. Once the scan is complete, the system processes the point cloud data. Several filters are applied to improve processing speed and remove data points that are not part of ship.
6. The vessel height is converted to the tide datum and then the height of the tide is subtracted to calculate the ship's air draft.
7. Results are provided to VTS within seconds, informing them if a vessel is safe to transit under the WGB or if the air draft limit has been breached and further action is required.

Scan results are saved to cloud-hosted databases. Summary data (time, vessel details, air draft, etc.) are made available for quick access. Point cloud data is archived. The results are made available immediately on completion via a results API. Configured alerts are triggered. A display is made available to system users with a traffic light system of different colours highlighting the nature of the results.

Figure 5 Slice in time of a 2D profile LiDAR scan of a passing container ship. Several features of the ship are identifiable, from top to bottom: antenna, mast, bridge wing, containers, ship's hull. Coloured by point reflectance. (Source: Author)

5. Challenges

5.1 Seagulls

Seagulls are often flying in the scan areas, above and around ships. In fact, they were observed to nest on Breakwater Pier, below the tower that the LiDAR scanner is installed on. Without data filters, a seagull flying above the ship would be mistakenly identified as the highest point of the ship.

To identify and remove seagulls from the point cloud data, a cluster algorithm was used. The DBSCAN algorithm (Ester et al., 1996) was selected. Given a set of points in some space, it groups together points that are closely packed (points with many nearby neighbours), and marks as outliers points that lie alone in low-density regions (those whose nearest neighbours are too far away). It takes two input parameters:

1. ε (eps): eps represents the minimum distance between two points to be considered part of the same cluster. The value used was carefully selected based on an evaluation of many point clouds, noting distances between real features on the ship, taking into account that some features sometimes shade others, producing a gap. This need was balanced by the desire to exclude seagulls (or any other potential flying objects) from the cluster representing the ship.
2. MinPoints: This represents the minimum number of points a cluster was required to have before it was considered noise. The number of points a seagull represents in the point cloud varies based on how close it is to the scanner.

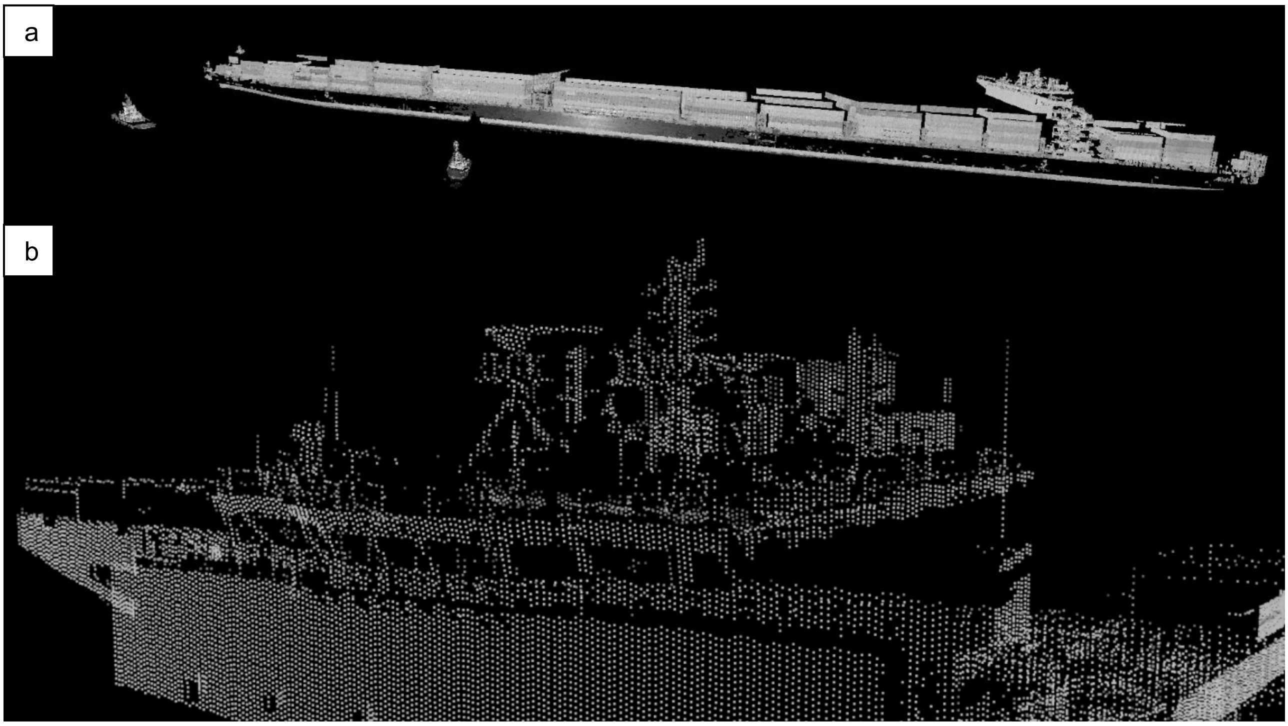

Figure 6 a – Full 3D LiDAR scan of a ship and surrounding tugs. (Source: Author)
b – Zoomed in view of the bridge. The communications tower, whip antennae, radar, and many other features are easily identifiable. (Source: Author)

Validation datasets demonstrated the filter's ability to identify seagulls, allowing them to be removed from the point cloud without erroneously reducing the reported height of the vessel. An example is shown in Figure 7.

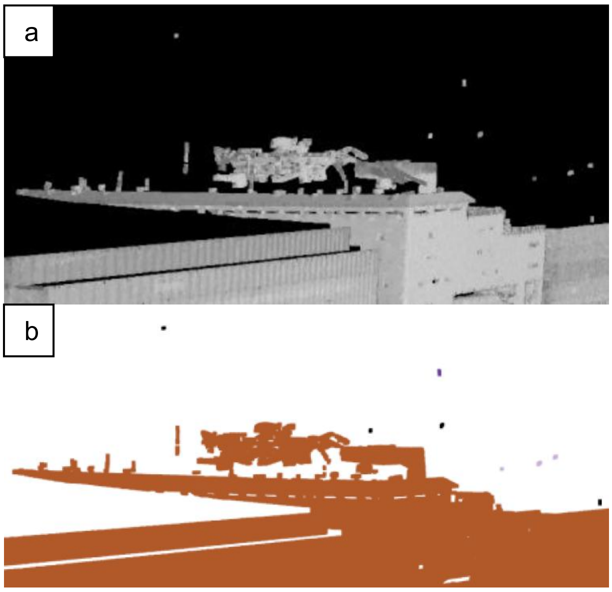

Figure 7 Example of the cluster algorithm. Several seagulls can be seen above the vessel in the point cloud in a). After applying the cluster algorithm, these have been isolated out in b), with only the vessel highlighted in brown.

5.2 Reflectivity

One of the limitations of the LiDAR technology difficulty obtaining reflections from black surfaces. This was experienced on some vessels in the validation sets that had black painted masts. Reflectivity can be improved by reducing the pulse rate of the LiDAR scanner, which is fine for static scans where time is not a factor. However, when scanning a moving ship, reducing the pulse rate will reduce the resolution of the point cloud. Managing this trade-off was important to ensure that black masts returned results, whilst thin features, such as antennas were still visible in the point cloud.

6. Performance Assessment

6.1 Validation Results

The project was broken down into three stages, to progressively prove the value of the system before unlocking the next capability. At each stage gate, the performance of the system was assessed and any issues considered.

The purpose of the validation was not to assess the positional accuracy of individual LiDAR points, which are assumed to be accurate. Rather, the key objective was to determine whether the LiDAR system successfully captured the highest physical feature of each vessel during its scan. As such, the validation was primarily qualitative: for each 3D scan, a human reviewer compared the point cloud to corresponding CCTV imagery in the visible spectrum and assessed whether the tallest part of the ship was fully represented in the scan.

The third validation dataset results showed:

- Zero false breach alerts; no ships were incorrectly reported taller than actual. This was due to the correct functioning of the cluster algorithm.
- 98% detection rate of the highest feature. Only 2% of ships were missing their highest features in the point cloud, due to low reflectivity.
- Cross-checking the results between the two measurement locations showed the South Wharf scanner returned slightly greater air draft values, which is expected and attributed to the variation in vessel squat effect caused by the different vessel speeds at each location, as well as the difference in scan range, which results in a slightly different scan resolution at each location.

6.2 Air Draft Comparison

As part of the validation process, the accuracy of vessel declared air drafts was compared against the results reported by the LiDAR system. These are presented in Table 1, which shows that only 55% of vessels declared a reasonably accurate air draft value. 17% of vessels under-declared their air draft by at least 0.50m, with the largest under report observed being 5.68m (vessel declared 40.30m, the highest point on the communications tower was measured as 45.98m).

Table 1 Difference in System Measured Air Draft and Vessel Reported Air Draft. Positive difference indicates the vessel under reported their actual air draft.

Air Draft Difference	Count	Percentage
< -1.00m	35	13%
-1.00m to -0.50m	37	14%
-0.50m to 0.50m	144	55%
0.50m to 1.00m	16	6%
> 1.00m	28	11%
No declared air draft	4	2%
Total	264	100%

6.3 CCTV vs LiDAR

During the project, some research effort considered the idea of integrating LiDAR data with visible spectrum images from an adjacent CCTV camera. The concept was that if these images could be accurately overlaid with each other, a human in the loop could determine whether there was an issue with the LiDAR scan. The results from this effort concluded:

- Any camera used for this purpose should be physically attached to the LiDAR scanner to ensure that the two datasets are synchronised.
- Even high-end off-the-shelf CCTV cameras lack the zoom capability to capture the ship in sufficient detail. The lens would need to be tailored to the specific installation based on range.
- The CCTV footage would not be helpful in low light, rain or fog conditions. As shown in Figure 8, even in good lighting conditions, the LiDAR can detect features that the CCTV image and human eye find challenging.

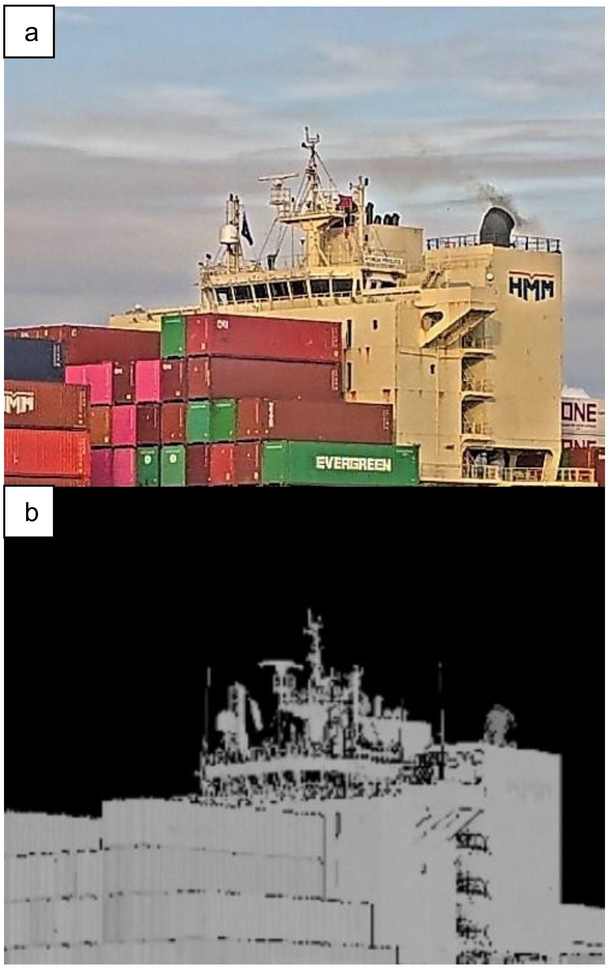

Figure 8 a) an image from the CCTV camera showing the bridge of a ship.
b) the 3D point cloud of the same vessel.
Note the ship's whip antennas are clearly visible in the LiDAR data but are not visible in the CCTV image. (Source: Author)

7. Conclusions

The system developed and deployed by OMC International for Ports Victoria successfully provides real-time, accurate measurement of vessel air draft beneath the West Gate Bridge. The integration of LiDAR scanning, AIS data, and custom clustering algorithms allows the system to detect the tallest features of vessels on 98% of occasions whilst avoiding false positive results. It enhances safety without replacing existing air draft controls and provides port operators with a higher level of confidence when managing high-clearance vessels. Additional controls such as standards around the colour, and in turn reflectivity, of ship's masts could improve the results further.

8. Acknowledgements

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9. References

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