Earthquake disaster investigation using a Compact MMS

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Abstract *On January 1, 2024, the Noto Peninsula in Ishikawa Prefecture, Japan, was struck by a magnitude 7.6 earthquake, known as "The 2024 Noto Peninsula Earthquake." This earthquake was one of the largest inland earthquakes in Japan, and caused extensive damages. Immediately after the earthquake, we conducted aerial photography and LiDAR surveys to assess the disaster. The acquired data revealed wide-spreading earthquake damages including landslides, road damages, and building collapses. However, there were limitations in identifying more detailed damages like road bumps and building tilts from the air. Therefore, in this study, a portable and easily deployable vehicle-mounted laser surveying system (MMS N-QUICK) was used to acquire high-density 3D point cloud data from the ground to grasp detailed damage conditions. As a result, the data enabled the quick identification of detailed ground damage, such as road damage and building destruction, which were difficult to assess through aerial surveys. This outcome allows us to complement the aerial survey results and achieve a comprehensive understanding of the damage.*

Keywords: Mobile Mapping System, LiDAR, 3D point cloud, Earthquake disaster

Introduction

a. Overview of the 2024 Noto Peninsula Earthquake:

The Noto Peninsula Earthquake occurred at 16:10 (Japan Standard Time) on January 1, 2024, with a magnitude of 7.6, epi-centered in the Noto Peninsula, Ishikawa Prefecture, Japan. This was an inland crustal earthquake with a magnitude of 7.6 or greater since the last one of the Nobi Earthquake (M8.0) occurred 133 years ago, in 1891. Following the earthquake, the Japan Meteorological Agency issued a "Major Tsunami Warning"—the first time since the 2011 off the Pacific coast of Tohoku Earthquake—and several locations observed tsunamis exceeding 4 meters in height within approximately five minutes of the earthquake. Additionally, significant crustal movements were confirmed, including an uplift of up to 4 meters and westward displacements of up to 3 meters centered around the Noto Peninsula. The earthquake caused extensive damages including fires, liquefaction, landslides, and the disruption of transportation networks. As of July 1, 2024, it had reported that 281 people were died, 1,326 injured, and more than 120,000 houses damaged.

b. Aerial survey:

To assess the disaster, Nakanihon Air acquired oblique aerial photographs the day after the earthquake and conducted aerial LiDAR survey four days later. The oblique photographs provide an intuitive understanding of the situation in the affected areas while the aerial LiDAR data capture the three-dimensional surface details. Through these aerial surveys, the full extent of the earthquake damages including landslides, road damages, and building collapses throughout the region became clear.

Figure 1: Oblique Photography Results

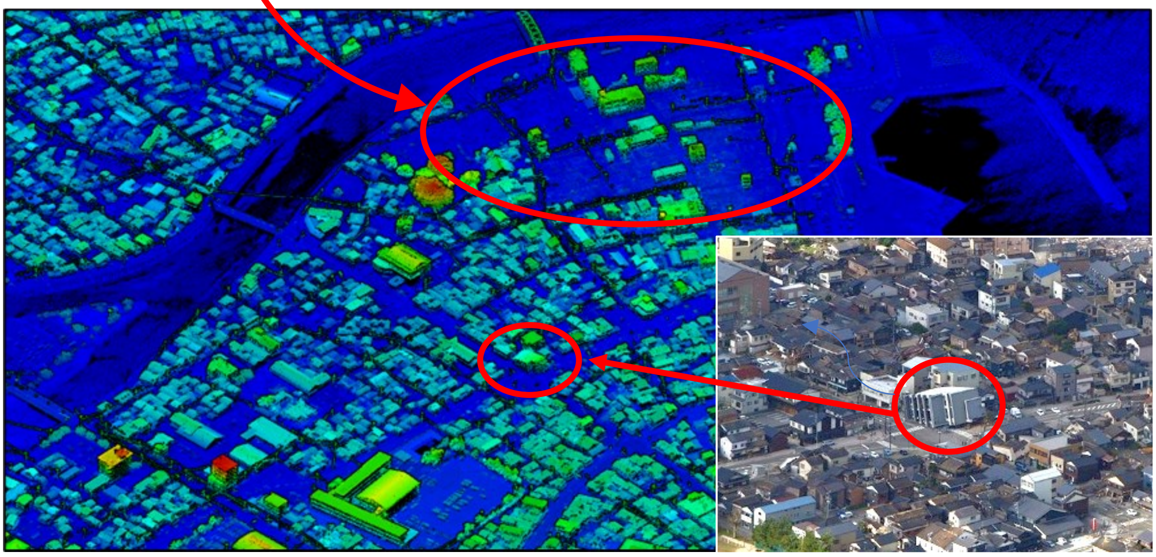

Figure 2: Aerial LiDAR data Results

c. Comparison of Aerial LiDAR Data in Two Periods:

In this study, we used open data from Ishikawa Prefecture to compare the pre-earthquake aerial LiDAR survey data obtained in 2020 with the post-earthquake aerial LiDAR survey data obtained in 2024. By comparing the data from these two periods, we were able to identify various situations caused by the earthquake, such as ground deformation, landslides, and the collapses or disappearance of buildings. These data and the information derived from them not only serve as fundamental resources for recovery and reconstruction efforts but also provide insights into understanding the mechanisms of this earthquake.

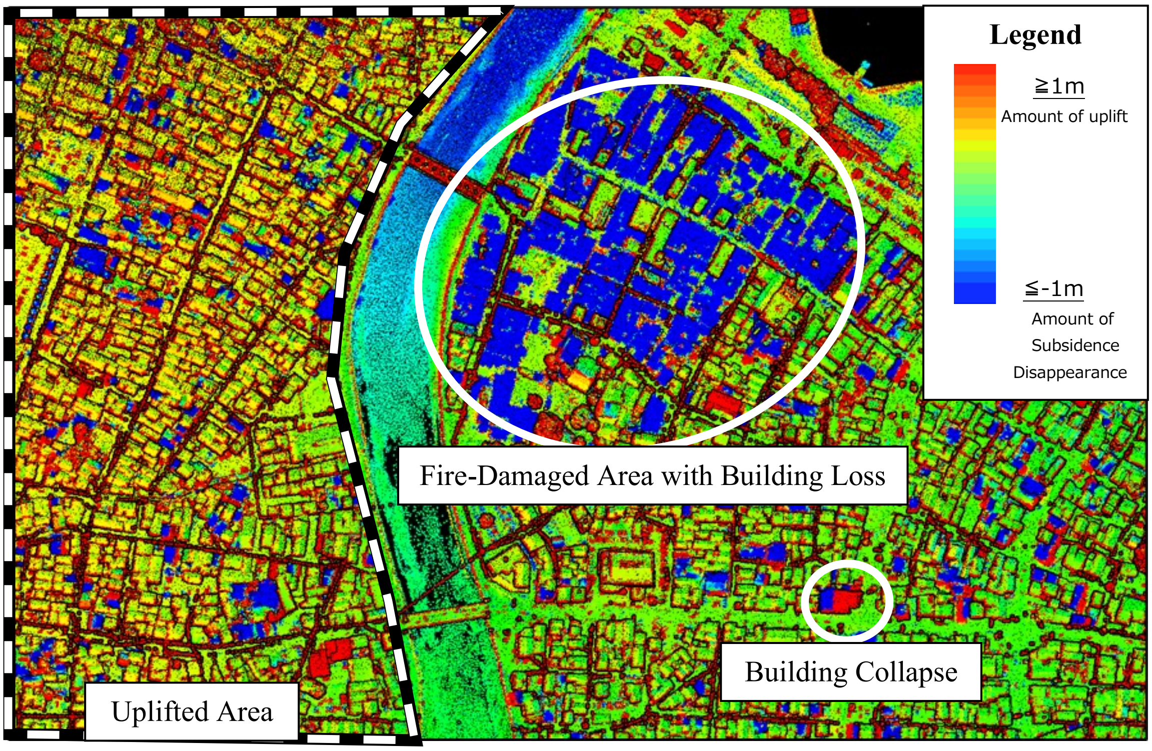

Figure 3: Example of Two-Period Change Analysis

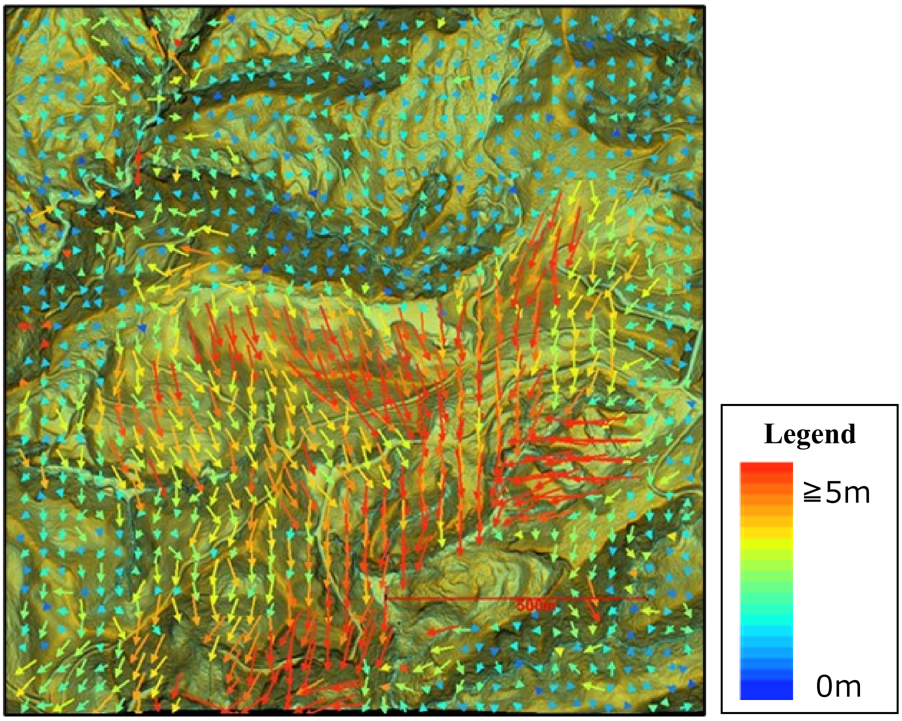

Figure 4: Example of Ground Displacement Vector Analysis

Focusing on the roofs of buildings, discrepancies in roof positions were found from comparison of the pre- and post-earthquake data. In case such discrepancies are observed between the two datasets, it is highly likely that the buildings have experienced some anomaly, such as a tilting. However, due to the significant ground deformation and movement caused by this earthquake, it was difficult to determine whether these discrepancies were the result of changes in the buildings' shapes themselves or the buildings were displaced parallel to the ground's deformation and movement.

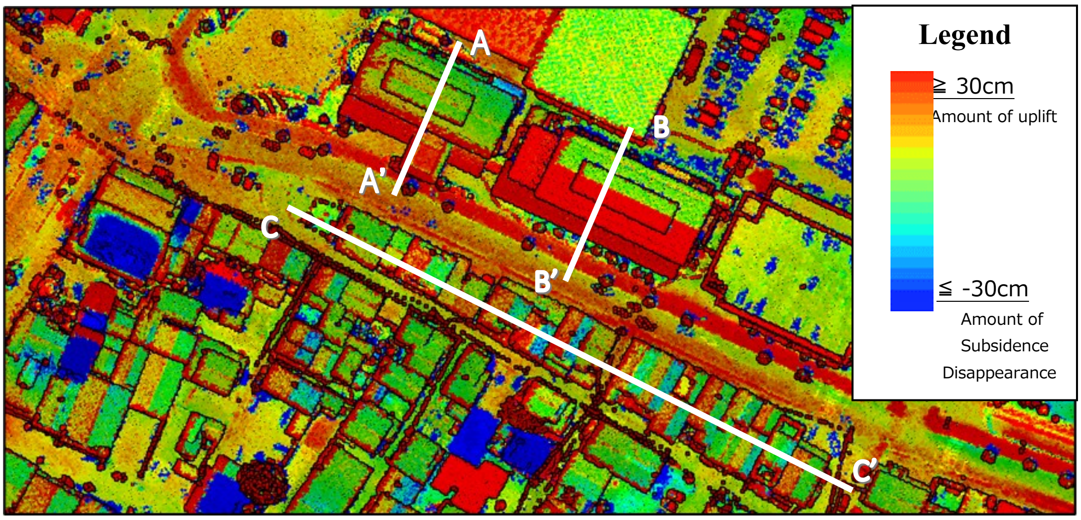

Figure 5: Example of Two-Period Change Analysis for Buildings

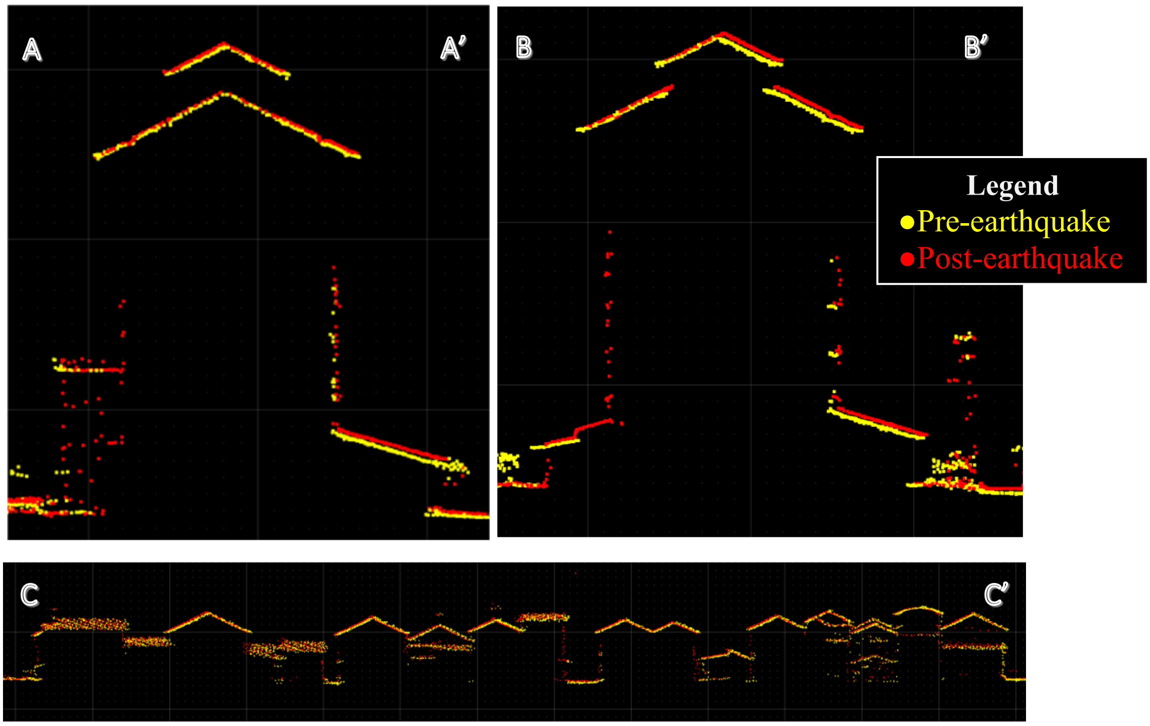

Figure 6:

Comparison of Cross-Sections of Point Clouds from Two Periods Using Aerial LiDAR Data

Surveying with a Vehicle-Mounted Laser Scanning System

a. Overview of Vehicle-Mounted Laser Scanning System:

To verify the buildings discussed in the previous chapter, a visual on-site inspection was conducted. Then, it was found that the inclination of "Building A" and "Building B," shown in Figure 1-6, are different. However, it could not be determined which the building had the anomaly. Normally, accurately assessing the inclination of a building requires entering the building and using tools like a spirit level or laser level for measurement.

Furthermore, during the site visit, many small-scale damages, which are difficult to detect from aerial surveys, were observed. However, conducting visual inspections throughout the affected area poses significant challenges in terms of resources, such as personnel and time. In addition, approaching damaged buildings can be dangerous due to the risk of collapses and secondary disasters caused by aftershocks.

To avoid those risks, an alternative and completement way to visual on-site inspections was conducted using "MMS N-QUICK," a system developed by Nakanihon Air. "MMS N-QUICK" is a portable and compact Mobile Mapping System (MMS): "vehicle-mounted laser surveying system", that compactly integrates a "laser measurement device," "camcorder," "GNSS device," and "IMU (Inertial Measurement Unit)." This equipment can densely acquire three-dimensional point cloud data of roads and surrounding terrain and structures.

Figure 7: MMS N-QUICK developed by Nakanihon Air

	MMS N-QUICK (Compact MMS)	Conventional MMS
		
Detachment/ Transportation	Easy (due to magnetic detachment system)	Difficult (due to being fixed to the vehicle)
Vehicle Types	Almost any vehicles	Limited to specific vehicles
Measurement Accuracy	RMS: less than 0.25m	RMS: less than 0.25m
Product Price	From approx. 40,000 USD	Approx. 200,000 USD to 750,000 USD
# of Operator	One (a driver only)	Two (driver and operator)
Mounted Sensors	One laser measurement device, one camera	Multiple laser measurement devices, multiple cameras
	All-weather	Basic waterproofing

Figure 8: Comparison of MMS N-QUICK and Conventional MMS

Using "MMS N-QUICK," measurements were conducted in April 2024, after the road network was restored, and covered approximately 450 km over three days. The analysis of the data acquired by the MMS revealed various situations that were difficult to detect with aerial LiDAR data.

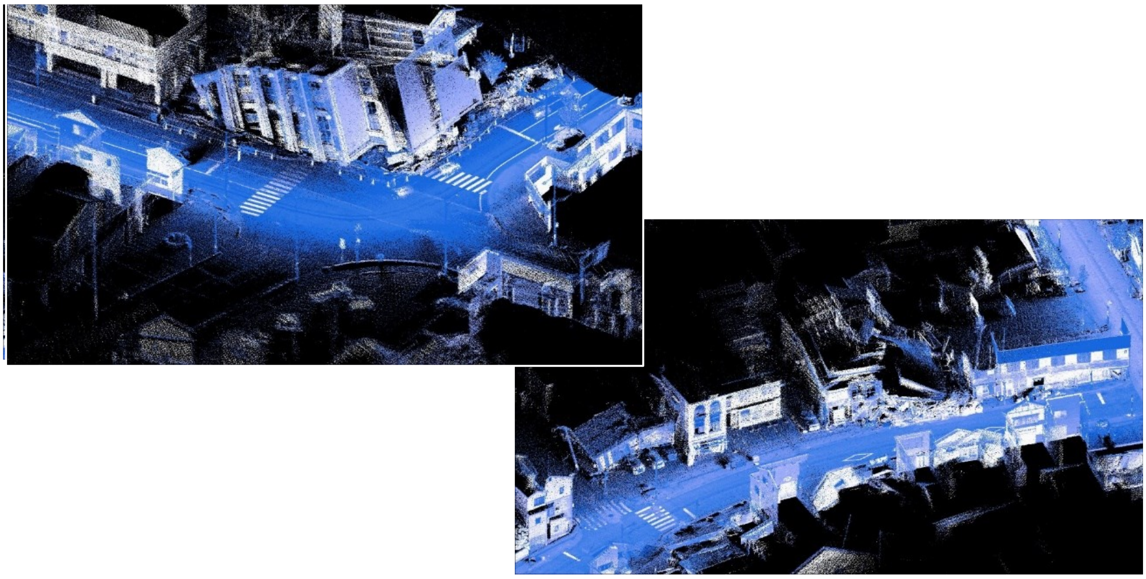

Figure 9: 3D Point Cloud Data Acquired by MMS N-QUICK

Analysis of Data Acquired by the Compact MMS

a. Verification of Building Tilt:

Upon examining the sides of "Building A" and "Building B" in Figure 1-6 using LiDAR data acquired from the Compact MMS, it was found that "Building A" was tilted by approximately 0.8 degrees, while "Building B" was found to be normal. In the cross-sectional comparison of the two periods of the aerial LiDAR data, the roof shape of "Building A" was almost identical in both periods, whereas a significant discrepancy was observed in "Building B," and they lead to the prediction of some anomaly. However, it is now believed that the roof displacement of "Building B" was likely due to the movement of the ground throughout the entire area. The Compact MMS is capable of acquiring dense 3D point cloud data of building sides, which are difficult to capture with aerial LiDAR surveying, and allowing for the detection of subtle tilts without stepping into the building. On the other hand, no abnormalities were detected in the LiDAR data derived from the Compact MMS for the group of buildings labeled "C." It is possible that the data from the Compact MMS may struggle to detect subtle tilts in low-rise residential buildings with one to two stories.

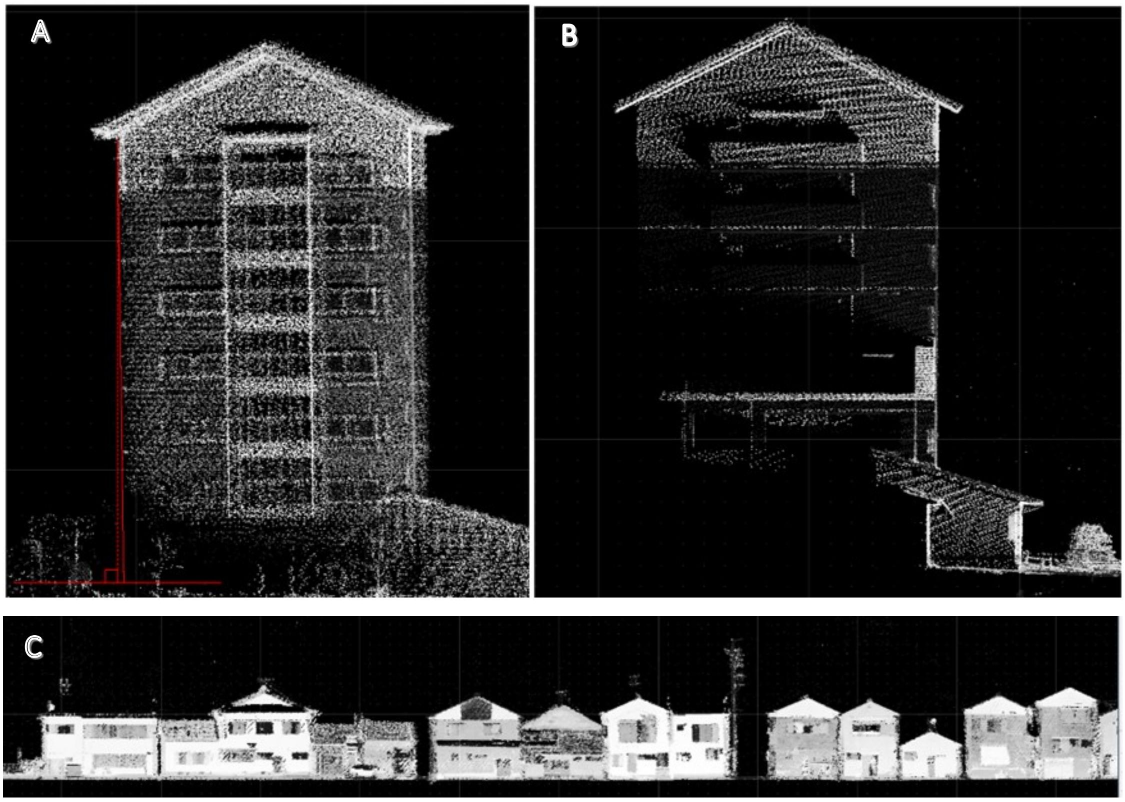

Figure 10: Cross-Section of Point Cloud Data from the Compact MMS

b. Verification of Road Damage:

In the post-earthquake aerial LiDAR data, the point density of the 3D point cloud was not dense enough to detect specific road damages. Additionally, even if the differential data from the two periods of pre- and post-earthquake were used, significant ground deformations and movements in this region made it challenging to identify specific road damages.

On the other hand, the single period LiDAR data from the compact MMS could detect manhole protrusions and spotting subsidence on the roads (Figure 3-2). While such road damages may be less noticeable compared to large-scale disasters like landslides, they have a significant impact on daily life and recovery efforts. The combination of rapid measurement over a wide area by aerial survey and high-density data acquisition by the compact MMS reveals various possibilities that were not visible before.

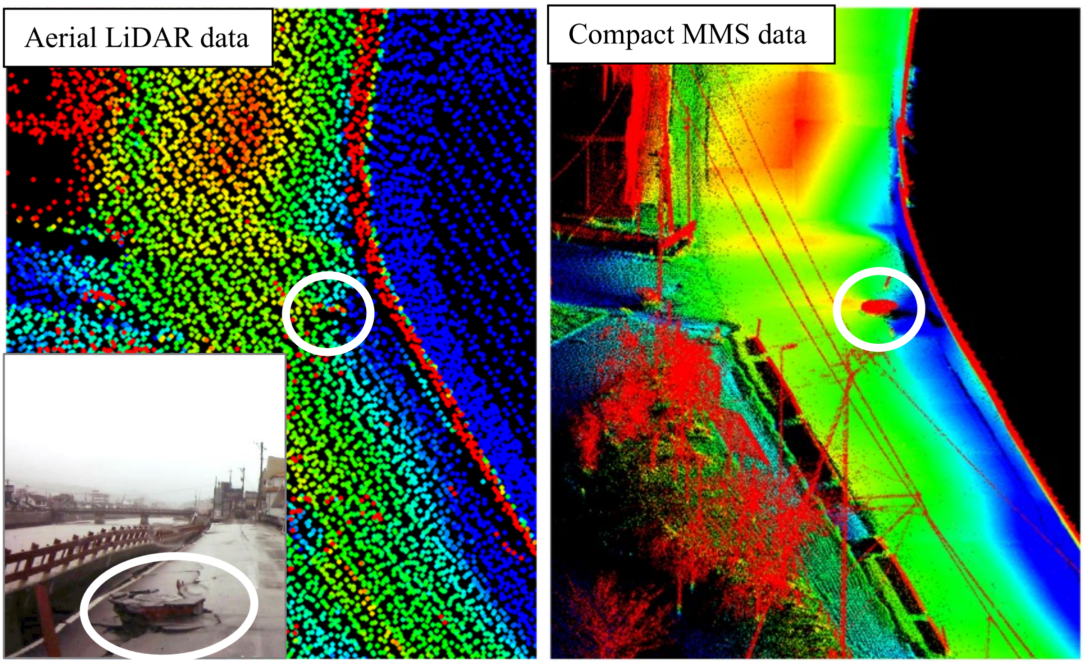

Figure 11: Bird's-Eye View of the Point Cloud

Conclusion

Nakanihon Air deployed aircraft the day after the earthquake to assess the damage of earthquake. The data acquired from the aerial surveys were highly valuable for recovery planning and situation assessment. However, damage conditions such as building tilts and minor road damages, which were difficult to confirm through aerial measurements, were effectively supplemented by the 3D point cloud data acquired from the compact MMS.

Aerial surveying is an indispensable method for understanding the full extent of earthquake damages, as it allows for rapid measurement of large areas without being affected by ground conditions. However, aerial surveying is heavily dependent on weather conditions, and due to the measurement from the high altitude, such investigations required very details like the sides of buildings are challenging because the acquired data are not dense enough.

On the other hand, surveying with the compact MMS, which uses vehicles, is more susceptible to road conditions, and the survey area is limited to roads and their surroundings. Nonetheless, it provides a cost-effective way to quickly assess detailed ground damages, such as road conditions and buildings. It serves as an optimal method to complement aerial surveys effectively.

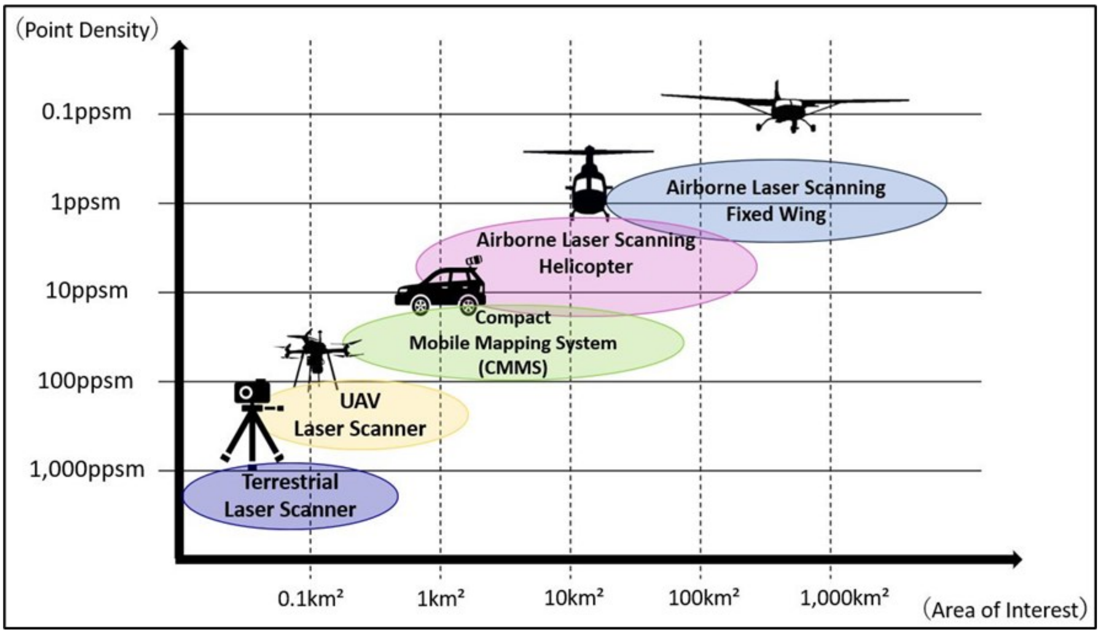

Figure 12: Comparison of LiDAR Measurement Methods

Acknowledgments

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