APPENDIX-2　Case Studies

This collection of case studies summarizes the details of use case demonstrations utilizing spatial IDs and 4D Spatio-temporal information infrastructure being conducted by selected operators participating in demonstration projects organized by the New Energy and Industrial Technology Development Organization (NEDO).

Detailed information on the completed demonstrations is provided in the investigation reports for each demonstration*. Demonstrations i to iii are described only in the Japanese version of the case studies.

*Demonstration

iv. NEDO：Digital Infrastructure Development Project for Digital Transformation of Industries/ Research and Development on 3D Spatial Information Infrastructure (Project period: FY2022 to FY2024)[1]

v. NEDO：Digital Infrastructure Development Project for Digital Transformation of Industries/ Research and Development on Foundations Contributing to the Pilot Implementation of Digital Lifelines (Project period: FY2024)[1]

[1] < https://seika.nedo.go.jp/pmg/PMG01C/PMG01CG01> (Japanese only)

The following table shows use cases, demonstrations, and utilization spaces.

Demonstration	Use Cases	Utilization Space	Page
iv	4.1 Material Transportation Use Case	Air space	3
	4.2 Power Transmission Equipment Inspection Use Case	Air space	10
	4.3 Bridge Inspection Use Case	Air space	16
	4.4 Technical Verification of Interoperability between UTMs	Air space	25
	4.5 Technical Verification of Risk Assessment, etc. related to Non-Life Insurance	Air space	27
	4.6 Inspection, Disaster Preparedness, and Manned Aircraft Integration Use Case	Air space	32
	4.7 Technical Verification of the Usefulness of Spatial Information Infrastructure	Air space	34
	4.8 Inspection Use Case	Air space	41
	4.9 Technical Testing of Reducing Spoofing Threats Using Signal Authentication Technology	Air space	45
	4.10 Education Use Case	Aboveground	52
	4.11 Infrastructure Management Use Case	Aboveground	56
	4.12 Construction Site Application Use Case	Indoor	67
	4.13 Technical Verification of Construction Site Application	Indoor	70
	4.14 Construction Robot Use Case	Indoor	72
	4.15 Technical Verification of Construction Robots	Indoor	75
	4.16 Spatial Entertainment Use Case	Air space / Aboveground	80
	4.17 Technical Verification related to Spatial Entertainment	Air space / Aboveground	83
v	5.1 Drone Routes	Air space / Aboveground	87
	5.2 Infrastructure Management DX	Underground	93
	5.3 Autonomous Driving Service Support Road X	Aboveground	98

4. NEDO : Digital Infrastructure Development Project for Digital Transformation of Industries/ Research and Development on 3D Spatial Information Infrastructure Case Study

4.1. Materials Transportation Use Case (Hitachi, Ltd.)

i. **Demonstration overview**

In this use case, drones were flown autonomously to transport medical supplies from pharmacies. This replaces traditional manual transport with drones, which deliver medical supplies along delivery routes over rivers.

When flying drones, it is preferable to conduct visual surveys, etc. of flight routes in advance for safety reasons, but these tasks increase costs.

There is potential that using a 4D spatiotemporal information infrastructure as a digital twin may contribute to reducing the burden of onsite surveys of terrain features and other conditions.

In addition, it is necessary to consider factors such as weather risks at high altitudes during flights, and incorporating weather information into the 4D spatiotemporal information infrastructure is expected to help reduce these risks.

The appropriate voxel size to be used for this use case will also be examined.

Figure 4-1-1 shows a conceptual demonstration overview.

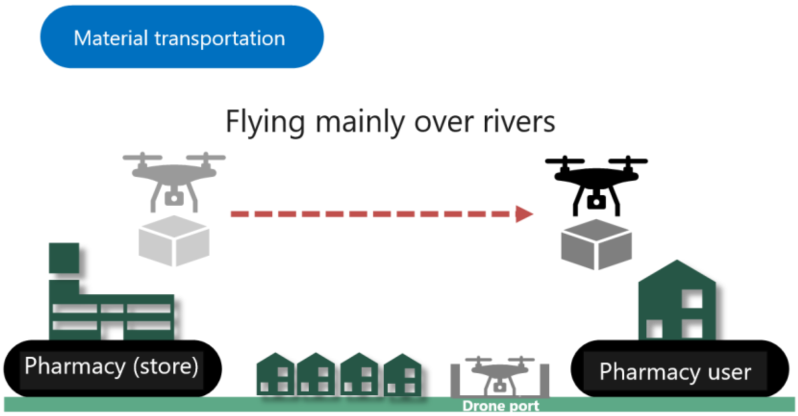


Fig. 4-1-1 Conceptual overview

ii. **Background and challenges**

The delivery of medicines from pharmacies has already begun in response to the 2019 amendment of the PMD Act, which lifted restrictions on online medical consultations and online medication guidance, enabling the delivery of medicines to patients receiving online medication guidance. In addition, with the introduction of refill prescriptions in April 2022, patients can receive prescription drugs multiple times for a certain period of time without seeing a doctor. In this context, the demand for regular delivery of prescription drugs is expected to increase further.

iii. **Outcomes**

The following outcomes are expected if this use case is implemented in society.

Table 4-1-1 Outcomes

Perspective	Outcome
Social value	Infection control (safety and security) during the delivery of pharmaceuticals, etc., and support for individuals with limited mobility such as older adults
Economic value	Revitalization of the local economy in line with improvements in the quality of local medical care

iv. **KGI & KPI**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-1-2 KGI & KPI

Perspective	KGI	KPI
Social value	Increasing drone deliveries for pharmaceuticals and other products	・ Consideration of usage scenarios (1 case) →The following two scenarios were identified ⅰ. Delivery by drone in the event of a shortage of prescription drugs ⅱ. Delivery by drone in cases where immediate delivery is required due to events such as COVID-19 ・ Presentation of flight route proposals (2 cases) →Evaluation of two flight routes: one over a river and one over the coastline ・ List of items to be checked before flight (1 case) →Flights conducted in accordance with the items to be checked as specified in the guidelines for the delivery of pharmaceuticals ・ Proposal for revising restrictions (1 case) →Identified 1 issue in the guidelines for delivering pharmaceuticals ・ Collection of opinions from pharmacies, users, landowners, etc. (20 cases, via questionnaires, etc.)

		→Conducted questionnaires during 3 demonstrations and collected a total of 24 responses
Economic value	Increase in the number of users who switched to same-day delivery	・Usage scenarios and number of deliveries →Confirmation of the number of deliveries at pharmacies in Minamisoma for the two scenarios mentioned above (ⅰ. 70 cases/month, ⅱ. 2 cases/6 months) ・Setting of income and expenditure model (costs, investable amount, cost reduction measures (subsidies, etc.) →The results of an economic feasibility study showed that it would be difficult to develop a profitable model. The number of prescription drug deliveries is currently low at 70 per month, and the cost per flight is high. Furthermore, if the cost is borne by patients, their expected cost is less than 500 yen, which is not in line with the estimated costs. It is necessary to expand demand so that multiple patients' medication packages can be transported in a single flight, and to make delivery costs covered by insurance to reduce the burden on patients.
Other (technological aspects, etc.)	Social application of mechanisms that fulfill the above social and economic values	Demonstration of linking different UTMs (1 case) →Demonstration of UTM interlinking

v. **System architecture**

The system architecture is shown in Fig. 4-1-2 below.

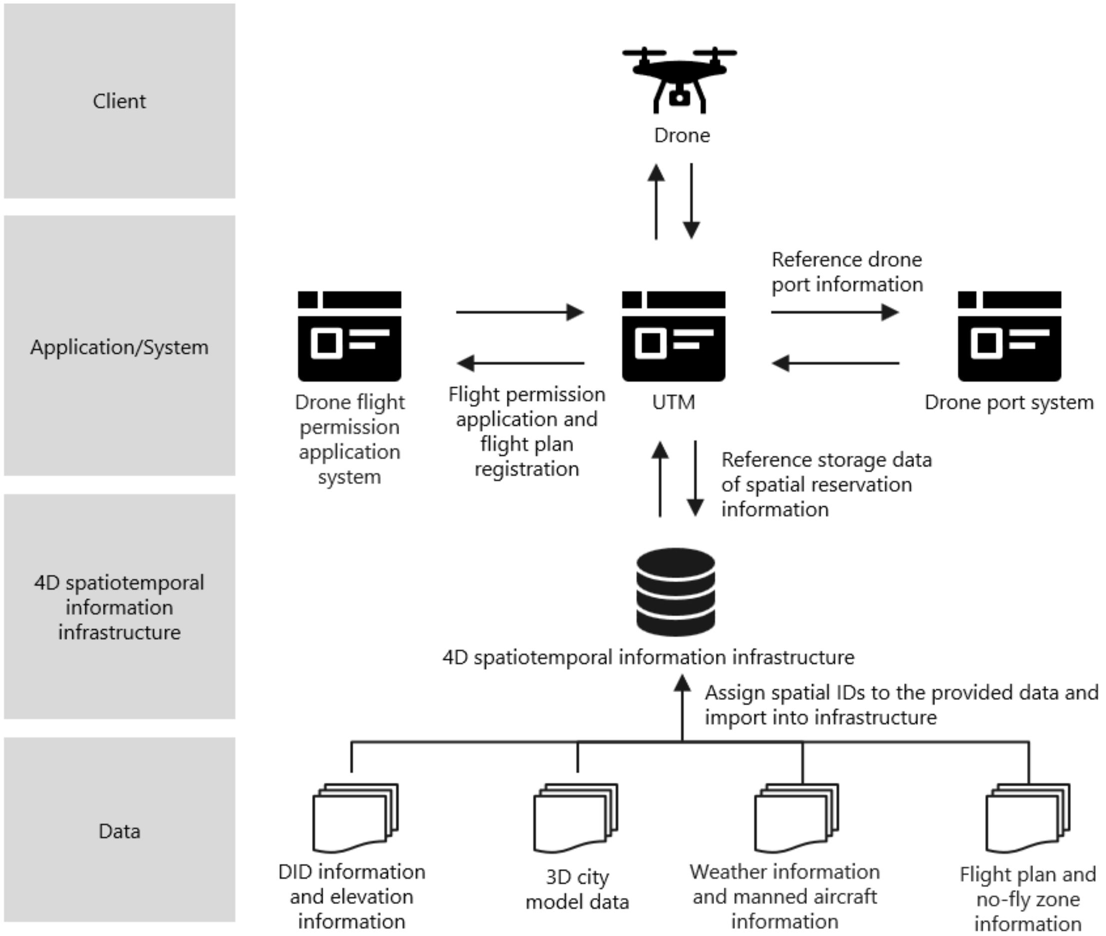


Fig. 4-1-2 System architecture

vi. **<u>Field testing details</u>**

➢ Overview

In Minamisoma, Fukushima Prefecture, delivery of pharmaceuticals using drones was conducted in residential areas. In addition, to test the effectiveness of the developed 4D spatiotemporal information infrastructure, the effectiveness of flight planning using data such as 3D city model data was tested.

➢ Field testing goal

To confirm the feasibility of drone delivery of pharmaceuticals using a 4D spatiotemporal information infrastructure.

➢ Measurement items and methods

The test items were examined from the perspectives shown in Table 4-1-3.

Table 4-1-3 Testing perspectives

No.	Perspective	Testing details
1	Effectiveness of 4D spatiotemporal	Create flight plans using the 4D spatiotemporal

	information infrastructure	information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal information infrastructure during flight. Data used: 3D city model (LOD1), weather information
2	Delivery operation scenario	Test business scenarios for same-day delivery and contactless delivery, and confirm technical feasibility.
3	Flight route	Conduct flight tests of flight routes that take safety and convenience into consideration.
4	Delivery of cargo	Test methods to ensure that packages are securely delivered to patients, due to the nature of dispensed drugs.

*In addition to the above testing, testing related to UTM interconnection and risk assessment was conducted for all use cases. Details of each test are described in Sections 4.4 and 4.5.

vii. **Field testing results**

The results for each test item are shown in Table 4-1-4.

Table 4-1-4 Testing results

No.	Testing details	Testing results
1	Create flight plans using the 4D spatiotemporal information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal information infrastructure during flight.	When planning the flight: ・The 3D city model was assumed to enable confirmation of obstacles to flight, but utility poles, vegetation, and power lines were not included in the scope of this demonstration, so it was necessary to conduct on-site surveys to confirm the safety of takeoff and landing sites as well as emergency landing sites. Based on the above, it is believed that it is not yet effective at this point in time for flight planning, and that further improvement of feature information is necessary. During flight: ・Detected sudden weather changes, enabling risk avoidance actions. ・ Identified the weather risks to the landing site at the start of long-distance flights. ・When landing, a voxel size of zoom level 22 (8 m per side) was required to confirm that there was sufficient distance from nearby buildings and power lines. However, since landing in tighter spaces is also conceivable, zoom level 22 may not always be sufficient.

		Based on the above, although there are issues with the level of detail of the voxel size, it has been found to be effective in ensuring safety during flight.
2	Test business scenarios for same-day delivery and contactless delivery, and confirm technical feasibility.	The current operations of the pharmacy operating company were reviewed and the following two current operations were identified as scenarios where drone delivery could be applied. ・If there is a shortage of prescription drugs when dispensing prescriptions, a delivery service will be used to deliver the prescription drugs. ・In cases where immediate delivery is required, such as COVID-19, prescriptions are received by fax and delivered by private vehicle. To test these scenarios, a demonstration was conducted in which patients who visited the hospital in the morning were delivered their prescription drugs by drone to a community center near their homes in the afternoon, confirming that it was possible for them to receive their prescription drugs on the same day. Based on the above, this business scenario was determined to be technically feasible.
3	Conduct flight tests of flight routes that take safety and convenience into consideration.	Demonstrations were conducted using flight routes over rivers and coastlines. The results were as follows. i . Airspace over rivers Advantages: ・Level 3.5 flight is feasible due to the low possibility of third-party intrusion. However, level 3 flight is difficult due to the presence of bridges in many parts of the river. Disadvantages: ・Since rivers are not straight, it may take a longer route to reach the destination. ・There may be third parties such as fishermen on the riverbank, requiring caution when flying. Based on the above, it is considered that relatively large, straight rivers are effective flight routes. ii . Airspace over coastlines Advantages: ・Straight flight routes can be easily created due to less obstacles. ・Since there is little possibility of third parties entering

		the area, Level 3 and Level 3.5 flights are feasible. Disadvantages: ・Due to stronger winds compared to land, aircraft with low wind resistance are not suitable. Based on the above, it is considered that the flight route is effective as long as weather conditions are favorable.
4	Test methods to ensure that packages are securely delivered to patients, due to the nature of dispensed drugs,	An operational flow was considered for delivering medicines by drone, using community centers as takeoff and landing sites. It was confirmed that prescription drugs could be delivered reliably in accordance with the "Guidelines for Delivery of Medicines by Drone." The main compliance items are as follows. ・Conduct packaging and temperature management in a manner that maintains the quality of pharmaceuticals. ・Manage drone flight status and location in real time. ・Measures to prevent unauthorized access to the package in the event that it is dropped. ・Measures to protect the privacy of patients to prevent third parties from identifying the medications. ・Pharmacies must confirm with patients that the correct medications have been received.

viii. **<u>Demonstration schedule</u>**

The demonstration schedule is shown on Table 4-1-5.

Table 4-1-5 Demonstration Schedule

Period	Demonstration item
FY2022	Coordinating delivery destinations (patients) Reviewing test items and scenarios Selecting drone models
FY2023	Confirming delivery destination (patient) Drone delivery demonstration flight (piloted flight and autonomous flight) Specifying KPIs Evaluating the effectiveness of a 4D spatiotemporal information infrastructure utilizing weather and manned aircraft data Comparative evaluation with existing delivery methods
FY2024	Drone delivery demonstration flight Reviewing KPI Comprehensive evaluation of economic efficiency and safety in the use of drones

	Comparative evaluation with existing delivery methods

ix. **Target layers and roles of players in the architecture of this demonstration**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-1-3.

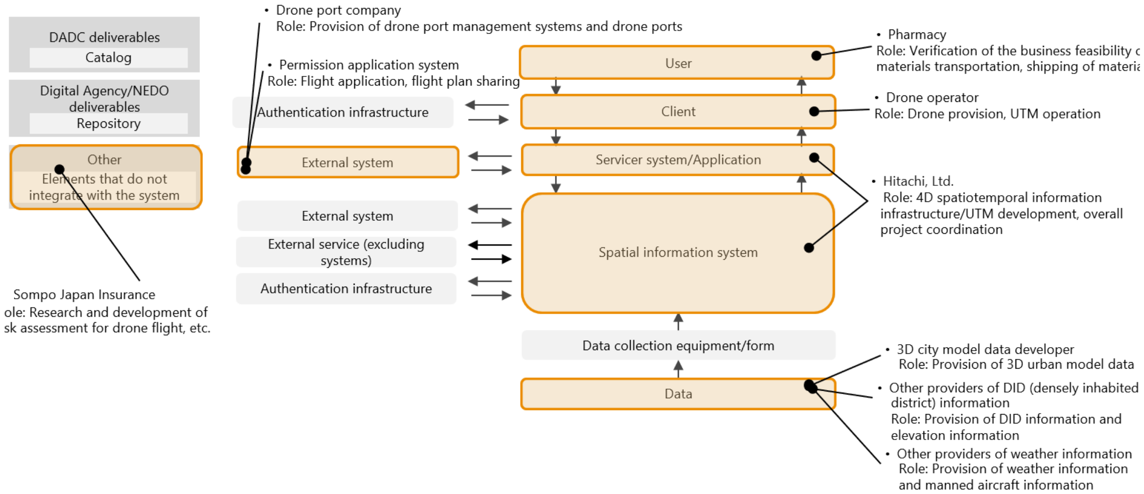


Fig. 4-1-3 Architecture map

4.2. Power Transmission Equipment Inspection Use Case（Hitachi, Ltd.）

i. **Demonstration overview**

In this use case, drones were used to inspect power lines and transmission towers. The effectiveness of utilizing a 4D spatiotemporal information infrastructure was verified during flight planning and autonomous flight. In addition, the accuracy and sufficiency of images and videos captured by drones during autonomous flight were tested to determine whether they could replace inspection work.

When flying drones, while it is preferable to conduct visual surveys, etc. of flight routes in advance for safety, such tasks increase costs.

It is expected that using a 4D spatiotemporal information infrastructure as a digital twin may contribute to reducing the burden of onsite surveys of terrain features and other features.

In addition, it is necessary to consider factors such as weather risks at high altitudes during flight, and incorporating weather information into the 4D spatiotemporal information infrastructure is expected to help reduce these risks.

Given that this use case involves inspecting narrow structures such as power lines, the study also includes an examination of appropriate voxel sizes.

A conceptual demonstration overview is shown on Fig. 4-2-1.

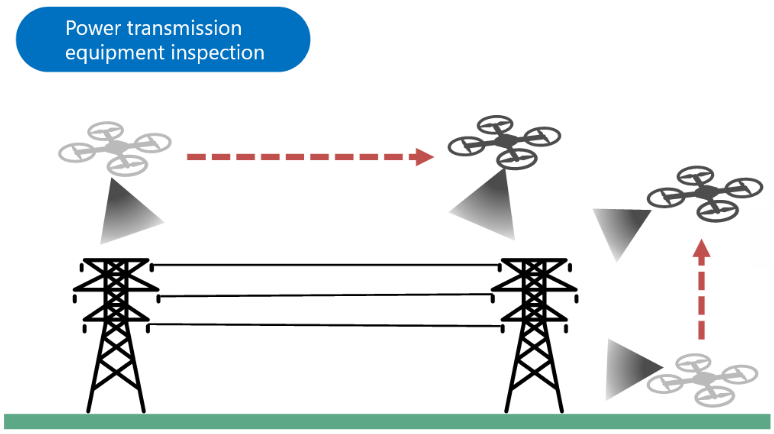


Fig. 4-2-1 Conceptual overview

ii. **Background and challenges**

Power line and transmission tower inspections are regularly conducted by workers who visually check the lines from high elevations, which is a dangerous and strenuous task. As a result, traditional manned power line inspections have become a major burden on inspection workers and have led to occupational accidents and other problems.

There is also a shortage of inspection technicians, which has resulted in a decline in inspection quality.

iii. **Outcomes**

The following outcomes are expected if this use case is implemented in society.

Table 4-2-1 Outcomes

Perspective	Outcome
Social value	Reduction in accidents during inspection
Economic value	Improvement in inspection quality and reduced costs

iv. **KGI & KPI**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-2-2 KGI & KPI

Perspective	KGI	KPI
Social value	Reduction of workplace accidents	・Consideration of work involving hazardous tasks that could be replaced by drone inspections →Although the accuracy of images captured by drones is not an issue, it was determined that it is not feasible to replace inspection work with

		drones because they cannot meet certain requirements.
Economic value	Reduction in inspection technician working hours	・Consideration of operations that can be replaced by drone inspections → As mentioned above, inspection operations cannot be replaced. ・Evaluation of time it takes drones to capture and inspect images →It is not feasible to accurately measure KPIs because certain requirements are not met. During annual inspections, drones can reduce the amount of manual work by approximately 27% within the range that images can be captured.
	Maintaining inspection quality	・Consideration of the scope of operations that can be replaced by drone inspections (30% or more of power line inspection scope) →As mentioned above, inspection operations cannot be replaced. ・Evaluation of inspection quality using images (1 power line inspection, 1 transmission tower inspection) → Inspections can be performed with the same quality as manual inspections using zoomed images.

v. **<u>System architecture</u>**

System architecture is shown on Fig. 4-2-2.

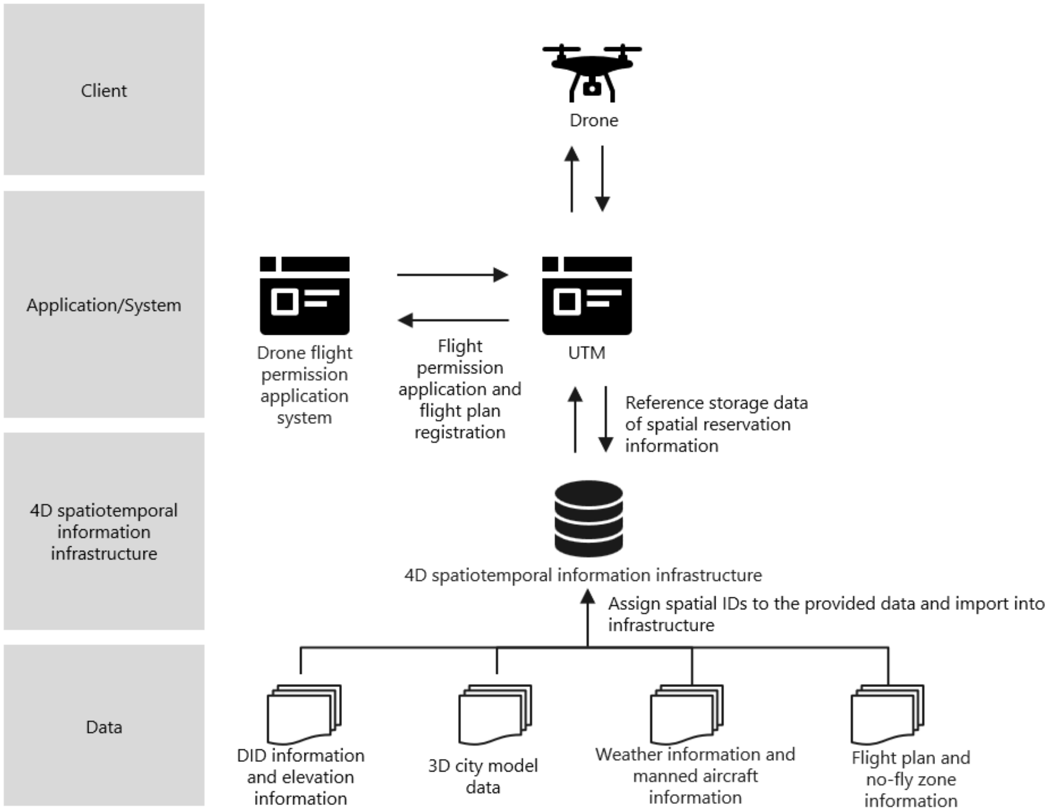


Fig. 4-2-2 System architecture

vi. **Field testing details**

➢ Overview

In Minamisoma, Fukushima Prefecture, drone-based inspection work was conducted on wind power generation-related facilities (power lines and towers).

➢ Field testing goal

To evaluate the effectiveness of a 4D spatiotemporal information infrastructure using 3D city models as input data, and assess the accuracy and sufficiency of images and videos captured by autonomous flight.

➢ Measurement items and methods

The test items were examined from the perspectives shown in Table 4-2-3.

Table 4-2-3 Testing perspectives

No.	Perspective	Testing details
1	Effectiveness of the 4D spatiotemporal information infrastructure	Create flight plans using the 4D spatiotemporal information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal information infrastructure during flight. Data used: 3D city model (LOD1), manned aircraft information, weather information
2	Imaging accuracy and	Test accuracy and sufficiency of images and videos

	sufficiency in autonomous flight	captured by drones flying autonomously, and consider the feasibility of using them to replace inspection work. Also identify issues related to capturing images with autonomous flight.

*In addition to the above testing, testing related to UTM interconnection and risk assessment was conducted for all use cases. Details of each test are described in Sections 4.4 and 4.5.

vii. **Testing results**

The results for each test item are shown in Table 4-2-4.

Table 4-2-4 Testing results

No.	Testing details	Testing results
1	Create flight plans using the 4D spatiotemporal information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal information infrastructure during flight.	When planning the flight: ・ The 3D city model was assumed to enable confirmation of obstacles to flight, but utility poles, vegetation, and power lines were not included in the scope of this demonstration, so it was necessary to conduct a site survey to confirm the safety of takeoff and landing sites as well as the flight routes. ・ Since close-range flight is necessary for inspection imaging, a zoom level of 20 (32 m per side) is too coarse for the voxel size, and a zoom level of 22 (8 m per side) or higher is recommended. Based on the above, it is believed to not yet be effective at this point in time for flight planning, and that further improvement of feature information is necessary. During flight: ・ Sudden weather changes can be detected, enabling risk avoidance actions. Based on the above, it can be said that this is effective for ensuring safety during flight.
2	Test accuracy and sufficiency of images and videos captured by drones flying autonomously, and consider the feasibility of using them to replace inspection	Due to the following reasons, although the accuracy of images is not an issue, it was determined that it is not feasible to replace power transmission equipment inspection operations because requirements are not fully met. To achieve sufficient performance, it is considered necessary to improve the performance of the cameras installed on drones and to develop technology that controls the angle and focus of the cameras during flight

	work. Also identify issues related to capturing images with autonomous flight.	using AI or other means. Transmission towers: ・Zoom imaging enabled to confirm damage to insulators and rust on bolts. ・However, although there are only a limited number of insulators, there are many bolts, so it was not possible to capture all of them. Power lines: ・Zoom imaging enabled to confirm the presence or absence of broken wires and lightning strike marks. ・However, it was not possible to fully capture all power lines with sagging while the camera was zoomed in.

viii. **Demonstration schedule**

The verification schedule is shown on Table 4-2-5.

Table 4-2-5 Demonstration schedule

Period	Demonstration item
FY2022	Pre-flight in a test environment Assessment of test items and consideration of scenarios for the next fiscal year and beyond
FY2023	Drone inspection demonstration flight Evaluation of the effectiveness of 4D spatiotemporal information infrastructure through the use of information such as 3D city models Evaluation of the accuracy and sufficiency of images and videos captured by autonomous flight
FY2024	Comprehensive evaluation of economic efficiency and safety in the use of drones

ix. **Linking with architecture map**

An overview of the architecture mapping the layers developed and used in this demonstration is shown in Fig. 4-2-3.

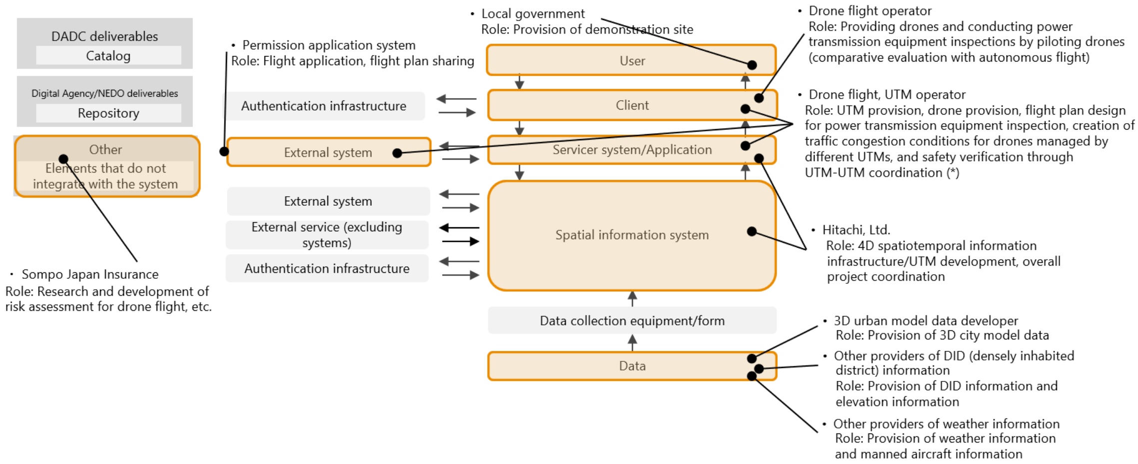


Fig. 4-2-3 Architecture map

4.3. Bridge Inspection Use Case（Hitachi, Ltd.）

i. <u>Demonstration overview</u>

In this use case, drones were used to inspect and patrol bridges, dams, and surrounding areas (such as roads, rivers, embankments, and coastlines) during regular conditions and disasters. 4D spatiotemporal information infrastructure was mainly utilized when creating flight plans to test its effectiveness.

Additionally, autonomous flights were conducted to assess the status of bridges, dams, and surrounding areas during disasters, and the effectiveness of the 4D spatiotemporal information infrastructure and its utilization methods were also tested. This testing was conducted as part of a multi-domain application utilizing the same aircraft used for infrastructure inspections (power lines and bridges).

When flying drones, while it is preferable to conduct visual surveys, etc. of flight routes in advance for safety, such inspections increase costs.

It is expected that using a 4D spatiotemporal information infrastructure as a digital twin may contribute to reducing the burden of onsite surveys of terrain features and other features.

In addition, it is necessary to consider factors such as weather risks at high altitudes during flight, and incorporating weather information into the 4D spatiotemporal information infrastructure is expected to help reduce these risks.

The study also considered the potential role and scale of a 4D spatiotemporal information infrastructure for quickly assessing damage to bridges and surrounding areas in the event of a disaster.

A conceptual demonstration overview is shown on Fig. 4-3-1.

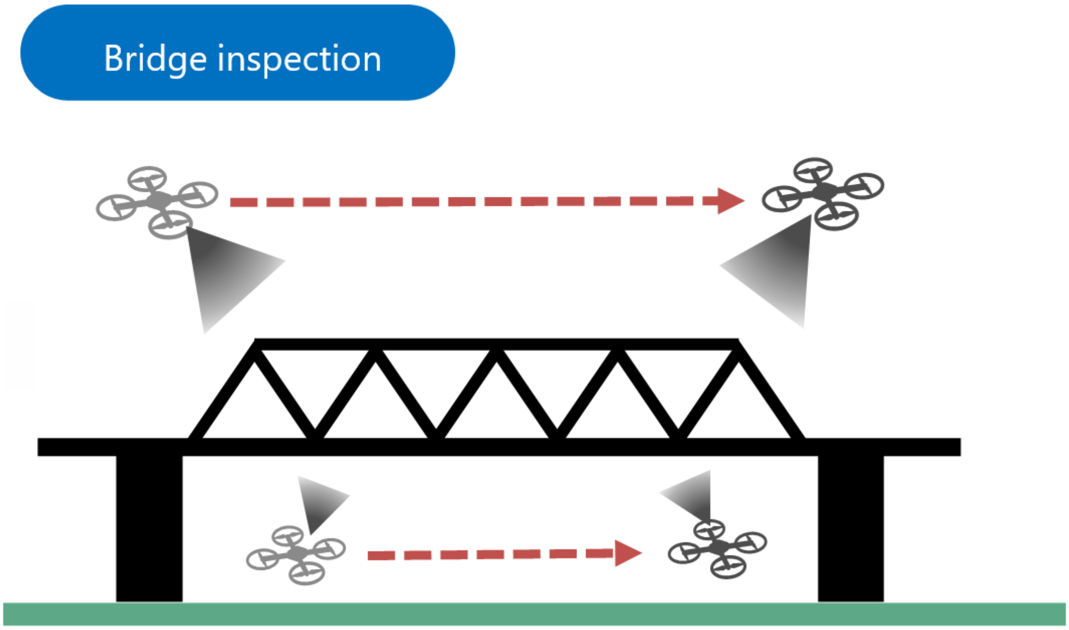


Fig. 4-3-1 Conceptual overview

ii. **Background and challenges**

Inspections of bridges by workers, similar to inspections of power transmission facilities, are dangerous and physically demanding tasks. In addition, when bridge inspection vehicles are required, traffic obstructions such as road closures and lane restrictions may occur, causing traffic congestion or other problems.

Furthermore, in the event of a disaster, bridges within the area may suffer significant damage or collapse, making it important to quickly determine whether they can still be used by people and vehicles.

iii. **Outcomes**

The following outcomes are expected if this use case is implemented in society.

Table 4-3-1 Outcomes

Perspective	Outcome
Social value	・Reduction of accidents during inspection ・Mitigation of traffic congestion caused by road closures and lane restrictions ・Rapid assessment during disasters
Economic value	Maintaining inspection quality, reducing costs

iv. **KGI & KPI**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-3-2 KGI & KPI

Perspective	KGI	KPI
Social value	Reduction of workplace accidents	Consideration of operations involving hazardous tasks that can be replaced by drone inspections →Although the accuracy of the areas that can be photographed by drones is not an issue, it was determined that it is not feasible to replace inspection work with drones because certain requirements are not fully met even with manual operation.
	Reduction of road closures and lane restrictions	Consideration operations that can be replaced by drone inspections →As mentioned above, inspection operations cannot be replaced.
	Damage assessment of bridges and surrounding areas during disasters (utilizing equipment inspection aircraft for multi-domain applications during disasters)	・Autonomous flight for capturing images of target bridges →Autonomous flight is feasible for determining damage. ・Confirmation of bridge damage using drone images → It may be possible to determine whether the bridge is safe for use. ・Confirmation of the surrounding conditions that can be assessed other than the target bridges (two areas: rivers, etc.) →The following two areas were confirmed to be able to be assessed. ⅰ. River surroundings ⅱ. Dam surroundings
	Reduction of time required to assess disaster conditions	・Comparison of damage assessment times using existing methods and drones (1 case near a bridge) → Although the work time was about the same in the post-earthquake dam inspection, the inspection quality improved.
Economic value	Reduction in inspection technician working hours	・Consideration of operations that can be replaced by drone inspections →As mentioned above, inspection operations cannot be replaced.

		・Evaluation of time spent on capturing images with drones and inspecting the images (1 bridge inspection) →KPI measurement is not feasible because certain requirements are not fully met. Within the range that images can be captured by drones, the time required for manual bridge inspections and drone inspections is approximately the same. ・Reduction in inspection report creation time through the creation of 3D models using captured images (1 bridge inspection) →Due to the time required to create 3D models, there was no contribution to reducing report creation time. However, it was beneficial in that it made it easier to visually assess the overall situation and confirm damaged areas.
	Maintaining inspection quality	・Consideration of operations that can be replaced by drone inspections (1 bridge inspection) →As mentioned above, inspection operations cannot be replaced. ・Evaluation of inspection quality using images (1 bridge inspection) → Within the range that images can be captured, level of inspection was comparable to that of manual bridge inspections.

v. **<u>System architecture</u>**

System architecture is shown on Fig. 4-3-2.

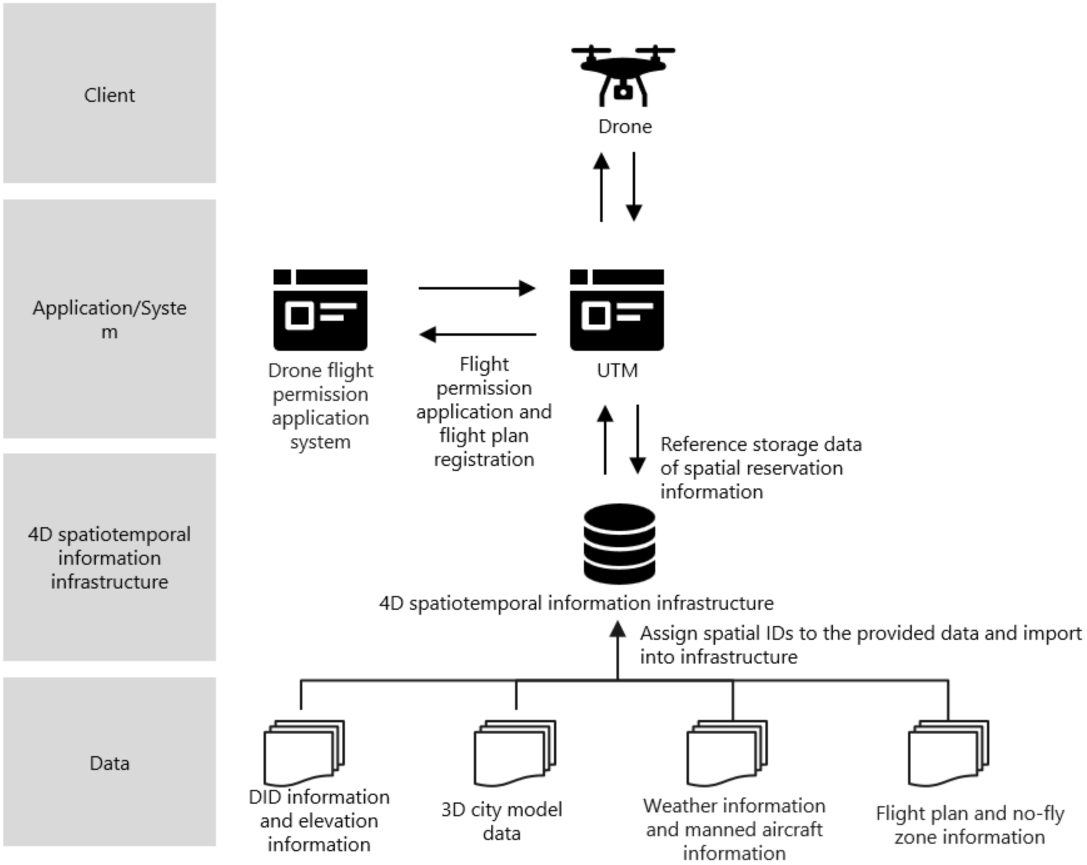


Fig. 4-3-2 System architecture

vi. **Field testing details**

- Overview

  In Minamisoma, Fukushima Prefecture, inspections and patrols of bridges, dams, and surrounding areas (roads, rivers, embankments, coastlines, etc.) was conducted using drones, assuming usage in normal and disaster situations.

- Field testing goal

  To evaluate the effectiveness of the 4D spatiotemporal information infrastructure utilizing 3D city models, etc., in the inspection and patrol of bridges, dams, and surrounding areas (roads, rivers, embankments, coastlines, etc.) during regular conditions and disasters, and evaluate the accuracy and sufficiency of images and videos captured by autonomous flight.

- Measurement items and methods

  The test items were examined from the perspectives shown in Table 4-3-3.

Table 4-3-3 Testing perspectives

No.	Perspective	Testing details
1	Effectiveness of the 4D spatiotemporal information infrastructure	Create flight plans using the 4D spatiotemporal information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal information infrastructure during flight. Data used: 3D city model (LOD1), manned aircraft information, weather information, altitude information
2	Imaging accuracy and sufficiency in autonomous flight	Test accuracy and sufficiency of images and videos captured by drones flying autonomously, and consider the feasibility of using them to replace inspection work. Also identify issues related to capturing images with autonomous flight.
3	Use of captured images in the event of a disaster	Test aimed at assessing disaster conditions following an event. Fly drones autonomously along a river to a bridge while capturing images of surrounding areas (embankments, roads) and the bridge, verifying the usefulness of the images in disaster scenarios.
4	Potential for utilizing the same aircraft (multi-domain)	Test the potential to improve asset efficiency by using a single drone platform for bridge inspections (regular conditions and disasters), and power transmission facility inspection.

*In addition to the above testing, testing related to UTM interconnection and risk assessment was conducted for all use cases. Details of each test are described in Sections 4.4 and 4.5.

vii. **Testing results**

The results for each test item are shown in Table 4-3-4.

Table 4-3-4 Testing results

No.	Testing details	Testing results
1	Create flight plans using the 4D spatiotemporal information infrastructure, and test the effectiveness of creating flight plans. Also test flight safety by using 4D spatiotemporal	When planning the flight: ・The 3D city model was assumed to enable confirmation of obstacles to flight, but utility poles, vegetation, and power lines were not included in the scope of this demonstration, so on-site surveys were necessary to confirm the safety of takeoff and landing sites as well as flight routes. Based on the above, it is believed that it is not yet effective at this point in time for flight planning, and

	information infrastructure during flight.	further improvement of feature information is necessary. During flight: ・Sudden weather changes can be detected, enabling risk avoidance actions. ・On flight routes with changes in elevation, the drone was able to fly safely by comparing altitude information with elevation information sent from the drone. Based on the above, it can be said that this is effective for ensuring safety during flight.
2	Test accuracy and sufficiency of images and videos captured by drones flying autonomously, and consider the feasibility of using them to replace inspection work. Also identify issues related to capturing images with autonomous flight.	Bridge inspection (evaluation during piloted flight): ・No issues in the accuracy of the areas where images of the bridge could be captured, but capturing close-up images of the ends of the underside of the bridge and the areas around the bearings was difficult, even with manual flight, and therefore the requirements could not be fully met. ・Therefore, it was determined that the bridge inspection work cannot be replaced by drones. River patrols: ・Significant abnormalities, such as damage to embankments, river flooding, and illegal dumping, could be confirmed from the captured images, with no issues in the accuracy and sufficiency of the patrols. ・Therefore, it was determined that river patrols can be replaced by drones. Dam inspection and patrols: ・Damage to the dam embankment, landslides on the dam lake slope, and changes in the water volume at the weir downstream of the dam could be confirmed from the captured images, with no issues in the accuracy or sufficiency. ・Therefore, it was determined that the dam inspection and patrol operations can be replaced by drones. ・However, due to the long flight distance, LTE radio waves were used for control, which presents the challenge of needing to confirm LTE signal availability in advance. Coastline patrols: ・The condition of embankments and revetments, as well as the presence of floating debris, garbage, illegal

		occupation, and dangerous behavior could be confirmed from the captured images. ・However, items that required visual and tactile confirmation, such as the strength of handrails installed on embankments, could not be confirmed from the images. ・Therefore, it was determined that coastal patrol operations can be replaced by drones, as accuracy is not an issue and requirements are met in all but a few cases. ・However, due to the long flight distance, LTE radio waves were used for control, which presents the challenge of needing to confirm LTE signal availability in advance.
3	Test aimed at assessing disaster conditions following an event. Fly drones autonomously along a river to a bridge while capturing images of surrounding areas (embankments, roads) and the bridge, verifying the usefulness of the images in disaster scenarios.	It was determined that the flight route could be sufficiently confirmed through captured images for the purpose of damage assessment. In addition, it is possible to determine bridge safety for traffic by identifying damage such as collapsed streetlights and displacement of expansion joints. Therefore, using drones is considered effective for obtaining a general overview of damage when vehicle access is restricted due to disasters. However, when vehicles can access the area, patrols by vehicles and reports from local residents are expected to be more efficient for damage assessment.
4	Test the potential to improve asset efficiency by using a single drone platform for bridge inspections (regular conditions and disasters), and power transmission facility inspection.	Demonstrations were conducted using the same aircraft across use cases including power transmission facility inspections, bridge inspections, river patrols, dam inspections and patrols, and coastline patrols. Among these, river patrol, dam inspection and patrol, and coastline patrol operations were generally found to be replaceable by images captured by drones, suggesting the feasibility of multi-domain operation.

viii. Demonstration schedule

The demonstration schedule is shown on Table 4-3-5.

Table 4-3-5 Demonstration schedule

Period	Demonstration item
FY2022	Test flight for bridge inspection using drones Economic evaluation of drone inspection compared to conventional inspection methods
FY2023	Bridges, dams, and surrounding areas (rivers, embankments) in regular conditions and during disasters Specifying KPIs Testing multi-domain models of aircraft
FY2024	Dams and surrounding areas (rivers, embankments, coastlines) in regular conditions and during disasters Reviewing KPIs Testing multi-domain models of aircraft Comprehensive evaluation of economic efficiency and safety in the use of drones

ix. Linking with architecture map

An overview of the architecture mapping the layers developed and used in this demonstration is shown in Fig. 4-3-3.

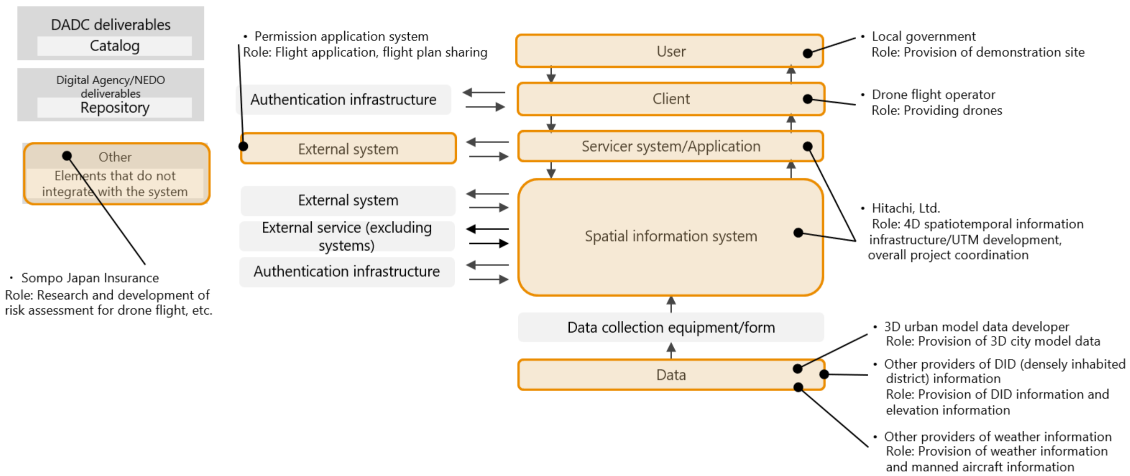


Fig. 4-3-3 Architecture map

4.4. Technical Verification of Interoperability between UTMs（Hitachi, Ltd.）

*This field testing was conducted as a technical test essential in a world where multiple drones crowd the same airspace, with the aim of extracting common issues for the social application of the material transport use case, power transmission equipment inspection use case, and bridge inspection use case described in Sections 4.1, 4.2, and 4.3.

ⅰ. Demonstration overview, ⅱ. Background and challenges, ⅲ. Outcomes, ⅳ. KGI & KPI, ⅴ. System architecture, and ⅸ. Linking with architecture map are described in the respective use case parts for material transport, power transmission equipment inspection, and bridge inspection. (Refer to Sections 4.1, 4.2, and 4.3.)

vi. **<u>Field testing details</u>**

- Overview

  Advantages and challenges to be considered in the utilization of 4-dimensional spatiotemporal information infrastructure in UTM interoperability were extracted. Specific considerations are conducted during FY2024 demonstration. For example, as a method of utilizing the 4D spatiotemporal information infrastructure, incorporating flight plan information reported to DIPS (Drone/UAS Information Platform System) 2.0, which is managed by the Civil Aviation Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, into the 4D spatiotemporal information infrastructure is under consideration, and displaying the space of registered flight plans on the 4D spatiotemporal information infrastructure. The system architecture is as shown in Fig. 4-4-1. A congested state using drones managed by different UTMs was created and the benefits of connecting UTMs linked to a 4-dimensional spatiotemporal information infrastructure were tested.

- Field testing goal

  To identify the state of UTM connectivity in congested situations, such as when drones managed by different UTMs approach each other or when flight plans conflict, and to derive the benefits and issues to be considered for a 4-dimensional spatiotemporal information infrastructure.

- Measurement items and methods

  Table 4-4-1The test items were examined from the perspectives shown in Table.

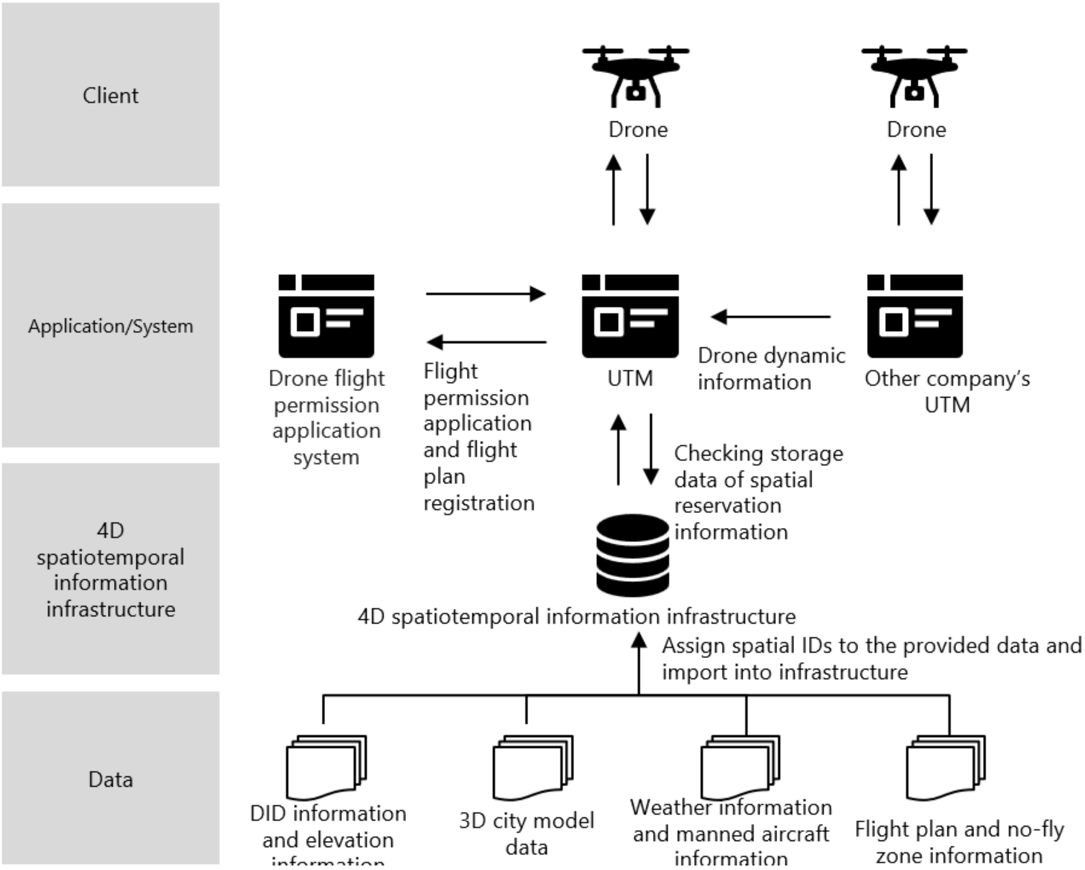


Fig. 4-4-1 System architecture（UTM interconnection）

Table 4-4-1 Testing perspectives

No.	Perspective	Testing details
1	Effectiveness of the 4D spatiotemporal information infrastructure	Create flight plans for multiple drones flying in the same airspace and test the effectiveness of risk reduction using flight area information obtained from DIPS.
2	Consideration of information to be shared between UTMs	Consider dynamic information that needs to be shared between UTMs in order to safely operate multiple drones managed by different UTMs.

vii. **<u>Testing results</u>**

The results for each test item are shown in Table 4-4-2.

Table 4-4-2 Testing results

No.	Testing details	Testing results
1	Create flight plans for multiple drones flying in the same airspace	In DIPS notifications, if the flight date, time, and flight area of a flight plan overlap, the presence of another flight plan in the same airspace can be identified. However, if neither

	and test the effectiveness of risk reduction using flight area information obtained from DIPS	the flight date, time, nor flight area overlap, this cannot be detected. To address this issue, flight area information of other aircraft obtained from DIPS was displayed on the UTM screen through the 4D spatiotemporal information infrastructure. This enables flight operators to identify the presence of aircraft flying in adjacent airspace and at similar times, which was determined to be effective in reducing flight risks such as intersection of drone flight paths in the future.
2	Consider dynamic information that needs to be shared between UTMs in order to safely operate multiple drones managed by different UTMs.	Latitude, longitude, altitude, speed, and heading direction were linked bidirectionally as dynamic information. This enables accurate understanding of the flight positions and directions of other drones when flying in the same airspace or intersecting drone flight paths, thereby confirming that there is sufficient information to determine whether to continue flight or take risk avoidance measures such as temporary suspension. Additional useful information to share are flight plans. Although heading data allows rough prediction of subsequent moves of other drones, having access to their flight plans is considered more effective for maintaining safety.

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-4-3.

Table 4-4-3 Demonstration schedule

Period	Demonstration item
FY2023	Consideration of scenarios related to UTM interconnection Preparatory flights related to UTM interconnection
FY2024	Consideration of scenarios related to UTM interconnection Demonstration flights related to UTM interconnection Evaluation and testing of effectiveness of the 4D spatiotemporal information infrastructure

4.5. Technical Verification of Risk Assessment, etc. related to Non-Life Insurance (Sompo Japan Insurance)

*This demonstration is jointly conducted for the material transport use case, power transmission equipment inspection use case, and bridge inspection use case described in Sections 4.1, 4.2, and 4.3.

i. **Demonstration overview**

This initiative aims to minimize on-site surveys prior to drone operation while quickly establishing safe flight paths. It consists of research, development, and verification testing of flight path risk assessment using spatial IDs. In addition, buildings, roads, and other features that are expected to suffer significant damage in the event of a drone crash, as well as locations suitable for emergency evacuation and landing, were selected using expertise such as non-life insurance. Methods for which drone operators utilize the information in coordination with spatial IDs were also evaluated.

ii. **Background and challenges**

Currently, detailed on-site surveys are required to evaluate planned flight paths, which are high in costs and time-consuming. Looking ahead to a future where multiple drones will be in regular operation, it is necessary to minimize the need for on-site surveys by utilizing spatial IDs, thereby resolving cost issues and enabling rapid flight path setting.

iii. **Outcomes**

The following outcomes are expected if this use case is implemented in society.

Table 4-5-1 Outcomes

Perspective	Outcome
Social value	• Minimization of accident occurrence rates and maximum estimated damage amounts through appropriate risk control • Improvement of social acceptability (ensuring psychological safety of residents) through appropriate risk control
Economic value	• Reduction of insurance costs through appropriate risk control • Reduction of costs for designing safe flight routes • Development of the drone industry through cost reduction and improved social acceptance

iv. **KGI & KPI**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-5-2 KGI & KPI

Perspective	KGI	KPI
Social value	• Improving social acceptance through	• Achieving an expected loss ratio of less than 50% for insurance means that risk reduction

	insurance products	has been achieved to a level that satisfies the risk assessment criteria. →KPI achieved. Risk reduction enables the provision of insurance products at the same premium as existing drone insurance.
Economic value	• Reduction of insurance and risk assessment costs	• Reduction in accident frequency (Achieving an expected loss ratio of less than 50% for insurance means that risk reduction has been achieved to a level that satisfies the risk assessment criteria) →KPI achieved. Even for high-risk flights such as Level 4, risk reduction makes it possible to provide coverage at the same premium as existing drone insurance. • Reduction in on-site survey workload (3 person-days ⇒ target 0.5 person-days) →KPI achieved.

v. **<u>System architecture</u>**

A system has not been established at this point.

vi. **<u>Field testing details</u>**

- Overview

Risk assessments were conducted for each drone use case in Sections 4.1, 4.2, and 4.3. By utilizing spatial IDs, the planned path set by Hitachi, Ltd was surveyed on-site. Risk assessments were then conducted based on spatial IDs and high risks were identified from the perspective of insurance companies, as well as risks that could only be confirmed through on-site surveys. Finally, the presence or absence of measures to reduce path risks were confirmed. When risk reduction measures were available, re-evaluation was conducted after taking the measures to confirm that the risks were appropriately controlled.

In addition, information on high-risk features extracted from the insurance company's perspective based on the uses and attributes of features such as buildings and roads confirmed above were linked to spatial IDs and utilized for setting safe navigation paths. (The planned flow for utilization is as shown in Fig. 4-5-1.)

- Field testing goal

To achieve an operational risk score and gain acceptance of drone operations from local residents.

- Measurement items and methods

Evaluations using a risk assessment sheet (see Fig. 4-5-2). In each category, including laws and regulations, various guidelines, flight environments, risk targets, aircraft, drone operators, and weather conditions, approximately 300 “hazard sources” that could cause damage were identified as metrics. The magnitude of risk was assessed based on factors such as the frequency and probability of damage occurring for each metric, and it was confirmed that risks were appropriately controlled within pre-set standards.

① Plotting high-risk features on a map from an insurance company's perspective

② Setting high-risk areas for shipping routes due to the above factors

③ Linking set area information to spatial IDs

④ Drone operators incorporate ③ and set flight paths in combination with spatial information

Fig. 4-5-1 Assumed flow (utilization of risk information extracted from the perspective of insurance companies)

No.	Category	Hazard source	Danger		Affected area	Risk estimate				Risk reduction measures	…
			General hazard	Specific hazard		Size	Frequency	Score	Pass/Fail (○/×)		
…	…	…	…	…	…	…	…	…	…	…	…
E001	Flight environment	Takeoff point	Route visibility measures	The flight route as seen from the pilot's position cannot be confirmed due to cliffs, hills, trees, or other obstacles.	Aircraft and operational system	Small	Sometimes	○ points	○	…	…
E002			Radio wave interference	Nearby mobile phone base stations, communication antennas, or other devices may cause radio interference.	Business execution	Small	Rare	○ points	○	…	…
E003			Magnetic interference	Nearby transmission towers, high-voltage power lines, or other structures may cause magnetic interference.	Aircraft and operational system	Small	Rare	○ points	○	…	…
E004			Measures against obstacles blocking flight direction	High-voltage power lines in the area require avoidance or detour.	Aircraft and operational system	Large	Sometimes	○ points	○	…	…
E005				Transmission towers and power lines in the area require avoidance or detour.	Aircraft and operational system	Large	Sometimes	○ points	○	…	…
E006				Trees and other obstacles in the area require careful flight and avoidance.	Aircraft and operational system	Small	Sometimes	○ points	○	…	…
E007			Appropriate placement of security guards	Flight without awareness of nearby pedestrians, observers, or traffic conditions may result in collision accidents.	Third party, etc.	Large	Frequent	○ points	○	…	…
E008		Flight route	Avoiding obstacles	Contact with, damage to, or collision with transmission towers, high-rise structures, power lines, or radio towers along the flight route, resulting in crashes.	Facilities and equipment	Large	Sometimes	○ points	○	…	…
E009				Improper fail-safe return altitude, may cause collision with obstacles and result in crashes during return.	Aircraft and operational system	Mid	Sometimes	○ points	○	…	…
E010		Signal environment such as GPS	Loss of GPS signals, etc.	Inability to fly due to insufficient reception of GPS signals or other signals necessary for aircraft control.	Business execution	Small	Sometimes	○ points	○	…	…
…				GPS signal loss in areas with high-rise buildings or valleys, resulting in instability and collision with nearby structures.	Facilities and equipment	Large	Sometimes	○ points	○	…	…
…	…	…	…	…	…	…	…	…	…	…	…
V001	Aircraft	In flight inspection	Steering and aircraft behavior confirmation	…	Aircraft and operational system	…	…	…	…	…	…
…						…	…	…	…	…	…

*Up to approximately 300 risk assessment items were evaluated. The above figure is a sample.

Fig. 4-5-2 Risk Assessment Sheet (Example)

vii. **Testing results**

The risk assessment method (including risk mitigation measures) developed using this demonstration achieved the KPIs of "achieving an expected loss ratio of less than 50% (risk mitigation to a level that satisfies the risk assessment criteria)" and "reducing the accident occurrence rate" (*).

(*) In the demonstration flights for each use case, the risks for all evaluation items in the risk assessment sheet are below the standard criteria.

As a result, even for high-risk Level 4 flights, by utilizing spatial IDs, the risks were assessed to be within the range that can be covered under the same premium as existing drone insurance. Therefore, it can be concluded that the KGI of "improving social acceptance through insurance products" and "reducing insurance costs" was achieved.

In addition, replacing the on-site surveys required for risk assessment with spatial ID-based surveys, the total workload required for risk surveys conducted during the demonstration flight is expected to be reduced from 4 to 6 person-days to 1 person-day, by utilizing information from spatial IDs to set safe flight paths and reduce the number of items to be checked during on-site surveys. The expected reduction margin of 2.5 people/day for the KPI "Reduction in local survey workload (3 person-days to 0.5 person- days)" was exceeded, and it is possible to determine that the KGI "Reduction in risk assessment costs" can be achieved.

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-5-3.

Table 4-5-3 Demonstration schedule

Period	Demonstration item
FY2022	<u>Development of risk assessment methods for non-life insurance</u> ・ Considering general assessment implementation methods (determination of target items and research methods) ・ Implementing assessments for material transportation and infrastructure inspection use cases
FY2023	<u>Review of risk assessment methods for non-life insurance and identification of areas for improvement</u> ・Reviewing assessment results (participation in demonstration experiments, testing and revision of previous year's assessment results)
FY2024	<u>Continuous improvement of risk assessment methods for non-life insurance</u> ・Reviewing assessment results (accompanying to demonstration experiments, testing and revising previous year's assessment results)

ix. **Linking with architecture map**

The material transport use case, power transmission equipment inspection use case, and bridge inspection use case are described in each use case part. (See Sections 4.1, 4.2, and 4.3.)

4.6. Inspection, Disaster Preparedness, and Manned Aircraft Integration Use Case (Trajectory, Ltd.)

i. **Demonstration overview**

This research and development project involves the development of a digital infrastructure that links real-world data necessary for the utilization of geospatial information, such as mobile devices including drones and helicopters, 3D city models, terrain data, and facility data, to spatial IDs and enables the utilization of data in a form suitable for collaborative services. The project also evaluated inter-company connectivity (UTM-GCS (Ground Control Station) connectivity).

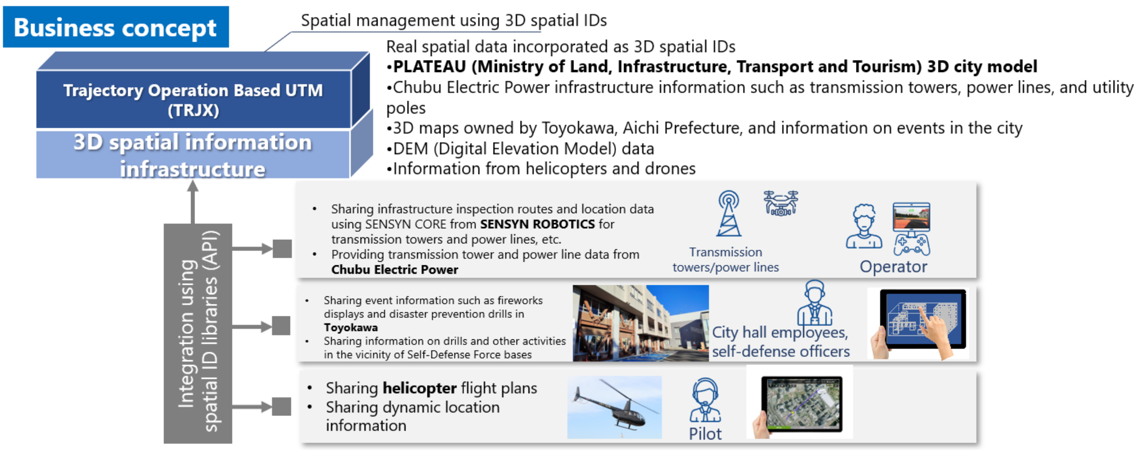


Fig. 4-6-1 Project Overview

ii. **Background and challenges**

Small and medium-sized enterprises, local governments, and residents who do not own systems face high entry barriers to spatial utilization and are being left behind in the digitalization process. In particular, spatial utilization is restricted to specific groups. The reasons for their exclusion include development costs such as interface conversion necessary for information sharing and the large amount of workload required to input information related to spatial utilization, which pose obstacles to participation. In light of these circumstances, it is necessary to establish a framework that makes spatial information more accessible in order to promote the utilization of air infrastructure. This project aims for the social application of a 4D spatiotemporal information infrastructure that enables autonomous mobile devices such as drones to recognize the enviroment while ensuring safety.

iii. **Outcomes**

The following outcomes are expected if this use case is implemented in society.

Table 4-6-1 Outcomes

Perspective	Outcome
Social value	・ Improving data quality and drone flight safety ・ Eliminating concerns regarding legal compliance ・ Eliminating information gaps in spatial utilization
Economic value	・Automation and efficiency through the use of autonomous mobile robots in multiple fields

iv. **KGI & KPI**

Since infrastructure development is the main focus, technical KPIs were established and used in the demonstration. Details are provided in Section 4.7.

v. **System architecture**

System architecture is shown on Fig. 4-6-2.

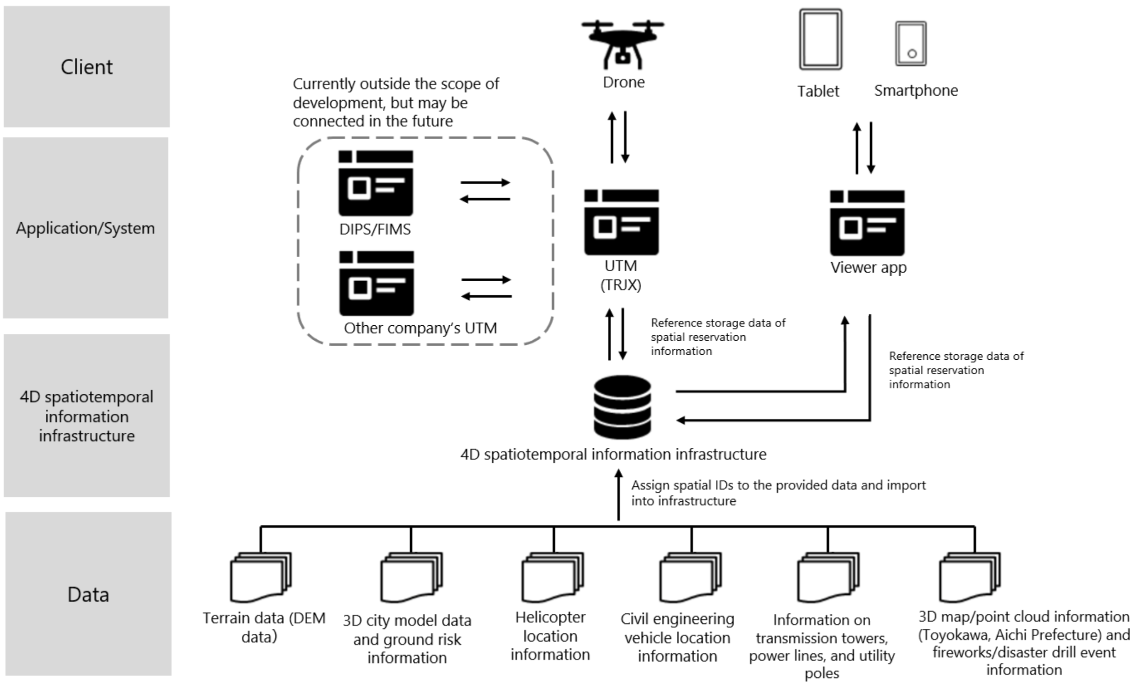


Fig. 4-6-2 System architecture

vi. **Field testing details**, vii. **Testing results**, viii. **Demonstration schedule**

Technical testing related to the infrastructure development that will be the main focus of efforts is described in Section 4.7.

ix. **<u>Target layers and roles of players in the architecture of this demonstration</u>**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-6-3.

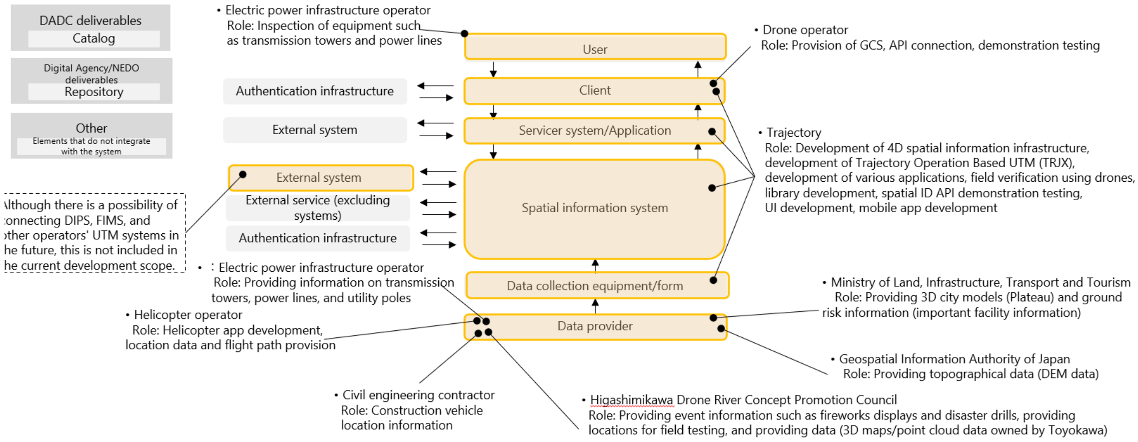


Fig. 4-6-3 Architecture map

4.7. Technical Verification of the Usefulness of Spatial Information Infrastructure (Trajectory Ltd.)

*Field testing was conducted using the inspection use case described in Section 4.6.

The details of each item in ⅰ. Demonstration overview, ⅱ. Background and challenges, ⅴ. System architecture, and ⅸ. Target layers and roles of players in the architecture of this demonstration are described in the inspection use case section (see Section 4.6).

iii. **<u>Outcomes</u>**

The following outcomes are expected if this use case is implemented in society.

Table 4-7-1 Outcomes

Perspective	Outcome
Economic value	Increase in easily usable spatial information

iv. **<u>KGI & KPI</u>**

Since infrastructure development is the main focus, technical KPIs were established and used in the demonstration. In this demonstration, achievement status of the KPI indicators shown in Table 4-7-2 were measured through field testing.

Table 4-7-2 KGI & KPI

Perspective	KGI	KPI
Economic	Drone service providers	・The extraction, registration, and update

value	can easily utilize spatial information through the use of spatial IDs.	time for spatial IDs within the demonstration area (1 km^2) for the spatial ID library: 1 minute or less for each ・The time required to convert structural information received from data providers into spatial IDs within the demonstration area (1 km^2) when registering data: 1 day or less ・The UI for spatial ID reference and registration clients must enable users to achieve their objectives smoothly. Display of spatial information within the demonstration area (1 km^2) within 1 minute * Evaluation was conducted through questionnaires to project stakeholders (Higashi Mikawa Drone River Concept Promotion Council).

vi. **Field testing details**

- Overview

Depending on the development stage, prototypes of the spatial ID general-purpose library, spatial ID reference, and registration UI, were created. Field testing of Steps 1 to 7 as shown in Fig. 4-7-1 was conducted in phases. Steps 1 to 5 involved importing various data and verifying information integration, and Step 6, involved comprehensive testing using a helicopter and multiple drones. In Step 6 testing, tests were conducted in which a helicopter approached and landed while multiple drones were conducting inspections of transmission towers and monitoring roads. In the first phase, a demonstration was conducted where relevant parties in the vicinity were notified when a helicopter approached to land surrounding drones. In the second phase, a demonstration was conducted where surrounding drones were notified of recommended avoidance routes for the helicopter when it approached, and the drones changed their flight plans to avoid the helicopter. Based on Step 6, Step 7 involved testing a business model utilizing 4D spatiotemporal information infrastructure. This included testing the cost-effectiveness of drone operators utilizing 4D spatiotemporal information infrastructure and testing the creation of new businesses utilizing 4D spatiotemporal information infrastructure by operators, assuming multiple applications.

- Field testing goal

Quantitative: One helicopter and two or more drones can fly in the same area.
Qualitative: The ability to develop safe flight plans for drones and manage airspace safety.

- Measurement items and methods

Geographical information around the flight area, infrastructure facility information, flight route information, and dynamic moving object information such as helicopters, vehicles, and people were converted into a spatial ID format. Subsequently, the following items were evaluated and tested using a drone simulator and actual flights.

(1) The spatial ID general-purpose library is sufficient and operates smoothly.

(2) Obstacles and ground risks obtained from geographic information around the flight area are avoided, and low-risk routes that do not come into contact with other aircraft are generated.

(3) Dynamic risks are detected based on the locations of helicopters, vehicles, people, and other elements, and routes are generated to avoid them.

(4) The flight routes generated above are connected via API between multiple systems (UTM-GCS) and drones to ensure safe flight.

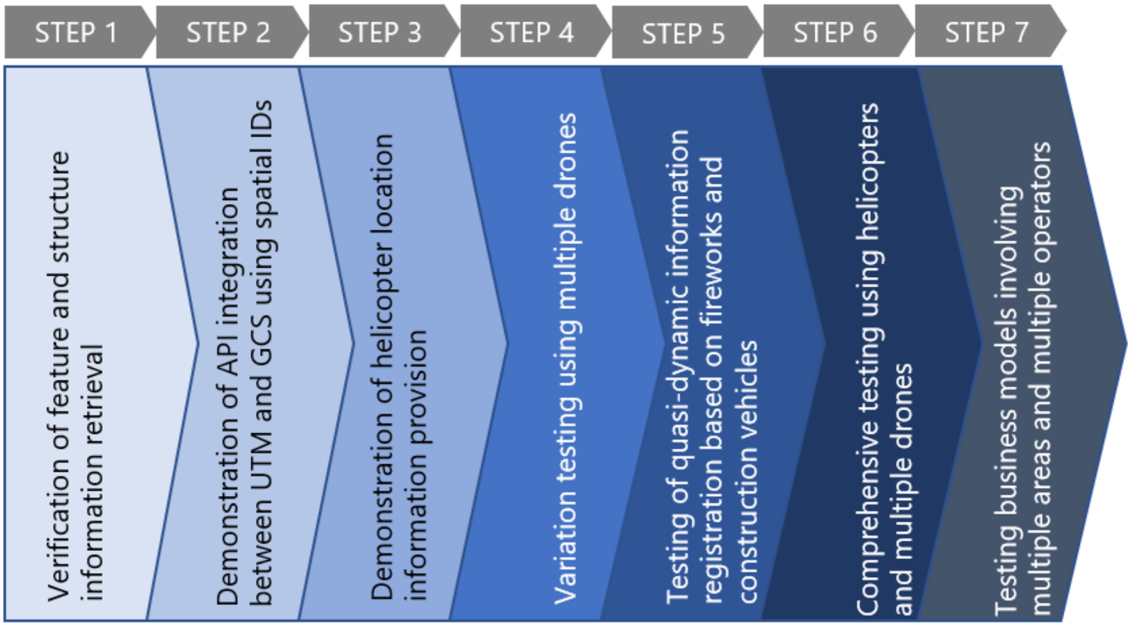


Fig. 4-7-1 Step-by-step demonstration experiment

vii. **Testing results**

The results of the field testing are shown below.

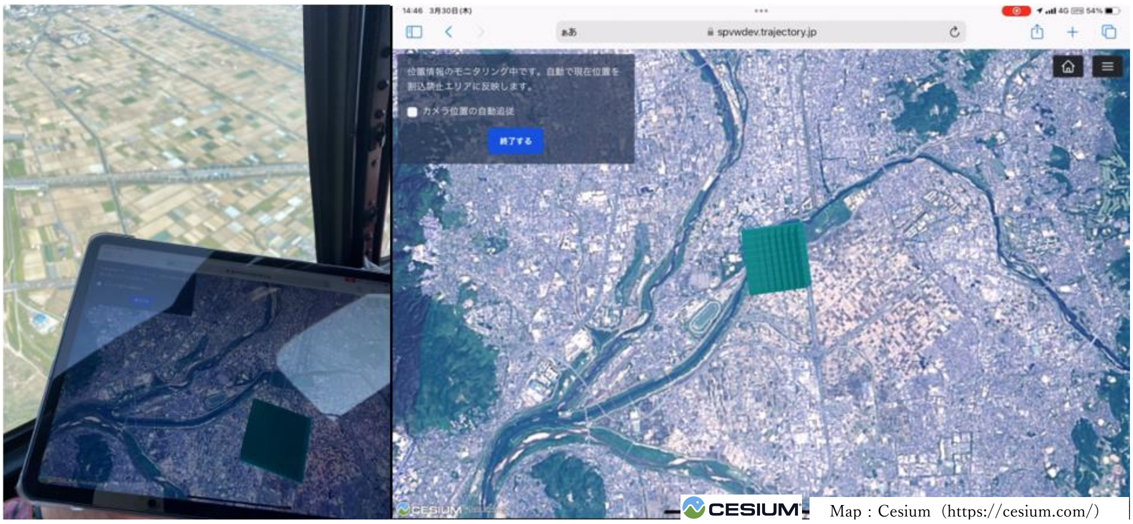
- Date: March 7, 2023
- Location: Mito-cho, Toyokawa-shi, Aichi Prefecture
- Demonstration details
  - ➢ Import 3D city models (PLATEAU, City Bureau, Ministry of Land, Infrastructure, Transport and Tourism), and link building shapes and ground risk values using spatial IDs as identifiers. Manage this data and design flight routes based on this information.
  - ➢ Share flight route information identified by spatial IDs between multiple systems

(UTM-GCS) to design collision-free flight paths.

- Actual flight demonstration simulating power transmission equipment inspection

- Demonstration results
  - Confirmed that 3D city models are registered as spatial IDs on SDSP, UTM, and GCS
  - UTM/GCS API integration using spatial IDs enabled the sharing of drone location information and the design of safe flight routes

- Date: March 30, 2023
- Location: Fushimi-ku, Kyoto-shi, Kyoto Prefecture
- Demonstration details
  - Fly helicopter with an iPad equipped with the no-fly zone function of the spatial ID viewer, and proximity detection messages notified on the screen of the ground drone navigation application (TRJX Transponder-A)
  - Test operational limits and operational stability of proximity detection notifications
- Demonstration results
  - Confirmed that location information can be shared using the iPad app installed on the helicopter
  - Confirmed operational limitations based on conditions such as location information update intervals and helicopter speed



Map : Cesium（https://cesium.com/）

- Date: October 12, 2023
- Location: Tojo-cho, Toyokawa-shi, Aichi Prefecture
- Demonstration details
  - Confirm inter-system (UTM-GCS) integration using multiple aircraft
  - Incorporate spatial information reflecting spatial occupancy due to differences in separation between aircraft, and design flight paths between multiple aircraft
  - Register ground risk information, such as residences, roads, riverbeds, and power transmission towers, owned by local governments and private companies
  - Test hazard avoidance by notifying surrounding stakeholders of helicopter proximity in an environment with a helicopter and multiple drones (used for inspection, logistics, and aerial photography), prompting drones to land or reroute accordingly,
- Demonstration results
  - Confirmed flight paths can be designed to avoid other aircraft, using a system that connects multiple aircraft (UTM-GCS),
  - Confirmed that ground risk information owned by local governments can be registered as spatial IDs without problems
  - Confirmed that helicopter approach information can be notified to drones from SDSP, making it possible to avoid danger

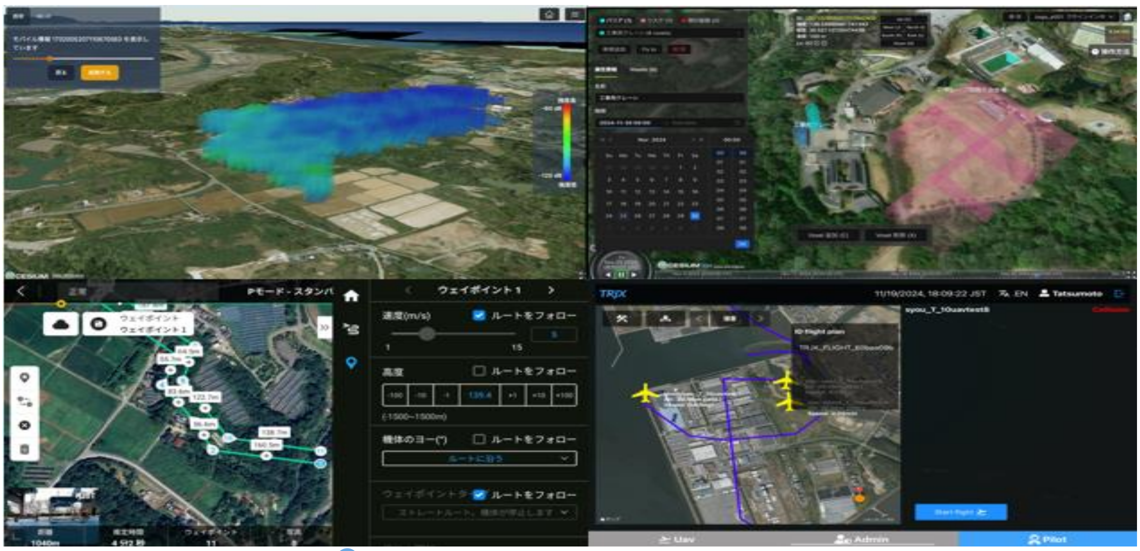
- Date: March 26, 2024
- Location: Tenryu-ku, Hamamatsu-shi, Shizuoka Prefecture
- Demonstration details
  - Develop and conduct test flights along routes over a river, assuming multiple use cases including river patrol, bridge inspection, and power line inspection
  - Acquire information such as ground surface and structure data owned by local governments, dynamic ground risks captured by ground cameras, and confirm their incorporation into spatial IDs
  - Detect people and vehicles using ground cameras, notify drone operators, and test drone retreat behavior
- Demonstration results
  - Confirmed that flight is possible in multiple use cases by utilizing spatial IDs
  - Acquired structural information and dynamic ground risk information owned by local governments and confirmed that it is incorporated in spatial IDs

CESIUM Map : Cesium（https://cesium.com/）

- Date: November 28, 2024
- Location: Yamada-machi, Kaga-shi, Ishikawa Prefecture
- Demonstration details

- ➢ Equip drones with equipment to measure LTE communication quality and set spatial risks based on regional communication quality and communication strength
- ➢ Register ground risks by local governments (field managers)
- ➢ Create and test interactive routes based on spatial risk information
- ➢ Share location information of manned aircraft using ADS-B
- ➢ Share location information between multiple organizations using Remote ID and DJI cloud API
- ➢ Safe and efficient port management considering spatial size
- ➢ Function test of collision detection and route deviation detection for multiple aircraft using spatial IDs
- ➢ Confirm video storage function utilizing DJI cloud API
- ➢ Test business model, including cost-effectiveness and ease of entry, for drone business utilizing 3D spatial information infrastructure

- Demonstration results
  - ➢ Communication strength and quality observed were registered as spatial risks
  - ➢ Ground risk information provided by local governments was confirmed to have been registered without problems
  - ➢ Created interactive routes taking into account recorded risks
  - ➢ Confirmed that it is possible to obtain the location information of manned aircraft using ADS-B
  - ➢ Confirmed that the connection process with UTM-GCS can be significantly reduced by using Remote ID and DJI cloud API
  - ➢ Confirmed that it is possible to ensure safety while efficiently utilizing space by reducing the separation at takeoff and landing points compared to during flight.
  - ➢ Confirmed that collision detection and route deviation detection during flight are possible by utilizing spatial IDs
  - ➢ Confirmed that image data is stored in the cloud and linked to maps using DJI Cloud API
  - ➢ Confirmed that the use of 3D information infrastructure lowers the barriers to entry into the drone business



CESIUM Map : Cesium（https://cesium.com/）、Apple Map（https://www.apple.com/jp/maps/）

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-7-3.

Table 4-7-3 Demonstration schedule

Period	Demonstration item
FY2022	STEP 1: Testing the acquisition of terrain and structure information STEP 2: Demonstration of API integration between UTM and GCS using spatial IDs STEP 3: Demonstration of helicopter location information provision
FY2023	STEP 4: Variation testing using multiple drones STEP 5: Testing of quasi-dynamic information registration simulating fireworks STEP 6: Comprehensive testing using helicopters and multiple drones
FY2024	STEP 7: Testing business models involving multiple areas and multiple operators

*The results obtained from each stage of the demonstration experiment conducted using the prototype spatial ID generic library, spatial ID reference and registration UI were incorporated into research and development, and a rapid PDCA cycle was implemented to improve performance and quality.

4.8. Inspection Use Case（Space Service Innovation Laboratory, Zenrin Co., Ltd., LocationMind Inc., Intelligent Style, Swift Xi Inc.）

i. **Demonstration overview**

In current drone operations, flight routes are designed based on the experience and intuition of operators, with final flight plans determined after on-site surveys to check for obstacles and surrounding traffic. This process, from design to plan determination to actual flight commencement, takes several days to several weeks. With the enforcement of the revised Civil Aeronautics Act in December 2022, restrictions on flights beyond visual line of sight (Level 4 flights) were lifted in urban areas, and the number of drones flying over third parties is expected to increase dramatically in the future. In drone logistics and other operations requiring immediacy and urgency, such as transporting supplies during disasters, it is important to quickly design safe flight routes. In addition, when operating multiple drones simultaneously, creating flight paths manually requires significant effort.

Using the 4D spatiotemporal information infrastructure developed in this demonstration, a system was developed that integrates dynamic and static spatial information of various types, such as moving objects (drones, autonomous mobile robots, etc.) and infrastructure in the three-dimensional space of the air, ground, and underground, which are relevant to the safe flight of drones, by linking it with spatial IDs, and quantitatively evaluated the safety of planned flight routes. The evaluation results can be provided to various map platforms via API with assigned spatial IDs. In addition, safety assessments referenced JARUS "SORA

(Specific Operation Risk Assessment)," which is a guideline for risk assessment related to drone operations, and by combining geographic spatial information such as the concentration of people and vehicles on the ground, the number and width of lanes, and the presence or absence of sidewalks, in order to evaluate ground and air risks more quantitatively. The safety evaluation results can be provided to various map platforms via API by assigning spatial IDs. Technology was developed and tested to enhance the accuracy of the evaluation system's calculation results using human flow big data. Flight tests were conducted in both urban and rural areas to evaluate flight route safety and the practical utility of spatial IDs.

ii. **<u>Background and challenges</u>**

Currently, drone flight routes rely on human judgment and experience to consider various factors such as terrain, features, weather conditions, and the flight paths of other drones, which makes it difficult to create multiple routes of consistent quality manually. Therefore, a system is needed that can automatically calculate routes for multiple drones by incorporating various information. Since height information is important, if flight altitude can be calculated based on spatial voxel features (such as transmission towers, power lines, antennas, trees, etc.), directionality becomes apparent. In addition, a mechanism is needed to quantitatively evaluate the safety of the created route.

iii. **<u>Outcomes</u>**

The following outcomes are expected if this use case is implemented in society.

Table 4-8-1 Outcomes

Perspective	Outcome
Social value	• Efficient and safe drone operations • Expansion of drone operation areas/routes and high-frequency operations
Economic value	• Reduced costs of drone utilization • Expansion of the range of operations to which drones can be applied

iv. **<u>KGI & KPI</u>**

This verification measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-8-2 KGI & KPI

Perspective	KGI	KPI
Social value	• Formulation of safe flight plans based on height information for	• Collection of data related to safe operation

	features in spatial voxels (transmission towers, power lines, antennas, trees, etc.) • Early collection of damage information over a wide area, linking it to spatial IDs, and confirmation of the appropriateness of risk management systems that contribute to securing entry and evacuation routes, followed by feedback • Further collection and accumulation of flight log information	a) Selection and collection of key flight log information b) Identification of risks, concerns and other problems from the results of demonstration flight data, and analysis of risk factors
Economic value	• Reduction in inspection workload (time) • Reduction in total costs through the use of drones	• Construction of a spatial information infrastructure targeting specific demonstration sites • Implementing an online operational risk assessment system and data provision API • Experimental drone flights and provision of data through spatial ID integration with other map platforms, followed by evaluation

v. **<u>System architecture</u>**

The system architecture for this use case is shown in Fig. 4-8-1.

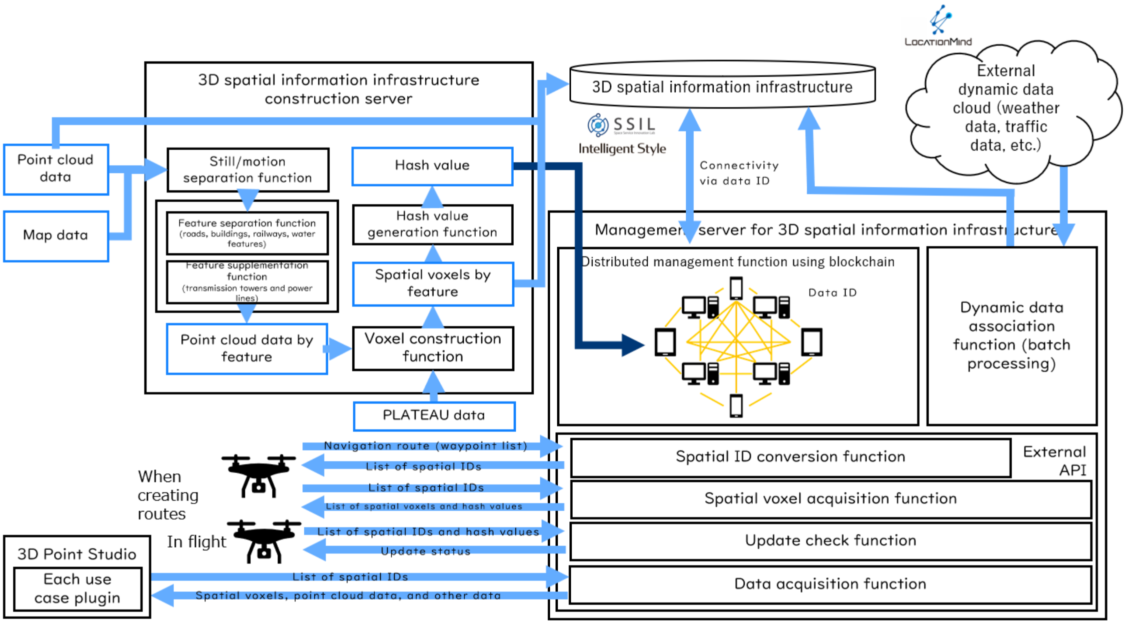


Fig. 4-8-1 Overview of the 4D Spatiotemporal Information Infrastructure

vi. **Field testing details**

On November 23, 2024, a demonstration experiment was conducted in Kawanehon-cho, Shizuoka Prefecture, to test the usefulness of spatial IDs for drone flights using a risk assessment system integrated with a 4D spatiotemporal information infrastructure. The test aimed to determine whether utilizing spatial IDs could reduce the time required to confirm safe flight routes for drones and make it easier to collect data useful for initial response in the event of a disaster.

vii. **Testing results**

By utilizing a risk assessment system that links spatial IDs from a 4D spatiotemporal information infrastructure, risks associated with terrain and the height of features along flight routes were quickly identified. Compared to conventional manual planning, safe routes were established in a shorter time, confirming the usefulness of spatial IDs. In addition, spatial ID integration enables the identification of collision risks with features that were not visible in existing data due to compression, enabling the establishment of safer flight routes.

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-8-3.

Table 4-8-3 Demonstration schedule

Period	Demonstration item
FY2022	Determine the evaluation methods and scenarios for demonstration

	flights assuming API integration with online operations risk evaluation systems, coordinate with candidate sites and regulatory agencies, and finalize feasible demonstration flight plans.
FY2023	Conduct analysis and testing utilizing flight routes obtained from a prototype online operational risk evaluation system and expertise of rotary aircraft operations. The goal is to collect a large amount of data for each aircraft type.
FY2024	Analyze demonstration flight test data and identify risks and concerns for social application.

ix. **<u>Target layers and roles of players in the architecture of this demonstration</u>**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-8-2.

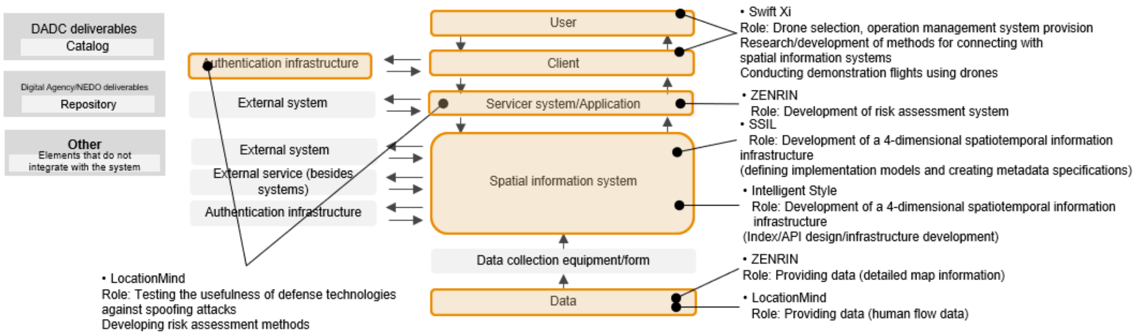


Fig. 4-8-2 Architecture map

4.9. Technical Testing of Reducing Spoofing Threats Using Signal Authentication Technology（LocationMind Inc.）

*This field testing is based on the testing described in the inspection use case in Section 4.8.

i. **<u>Demonstration overview</u>**

In this demonstration, signal authentication technology was developed and tested to counter spoofing threats such as spoofing during flight and tampering with flight history.

ii. **<u>Background and challenges</u>**

In utilizing spatial IDs, it is considered valuable to store not only physically visible elements such as transmission towers, power lines, antennas, and trees, but also “invisible information” such as radio waves. For example, areas where interference waves are generated may be dangerous for drone flight. Therefore, by expressing this information in voxels, it is expected that safer flight plans can be devised.

There are many invisible risk factors, but one that has been particularly problematic in recent years is location spoofing. Spoofing is a technique that falsifies or alters location information to make it appear as if a device is in a different location than its actual location.

In recent years, widespread spoofing has been confirmed in areas such as conflict zones around the world. This has caused the location information of unprotected devices to become inaccurate, resulting in cases where drones and aircraft have been unable to navigate properly.

Spoofing risks occur at unpredictable times and locations, and are constantly changing. Therefore, it is essential to be able to quickly update and search for the latest information in order to counter these risks. In addition, a system that can dynamically manage information is required in order to respond to changing risks. From this perspective, the compatibility with the spatial ID infrastructure is high. As shown in the figure below, areas where spoofing risks exist are represented as voxels.

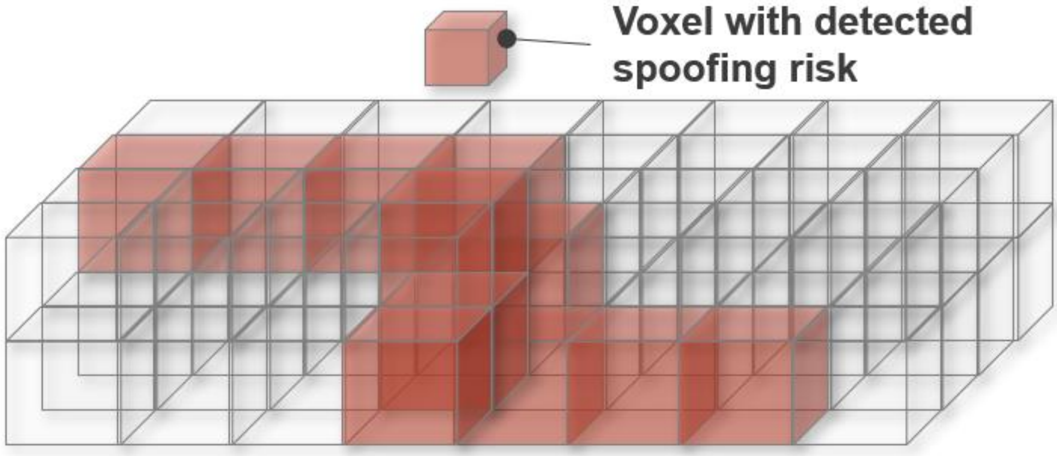


Fig. 4-9-1 Conceptual image of visualizing spoofing risks

Meanwhile, spoofing signals are invisible, and since spoofing itself is carried out covertly, it is difficult to detect the existence of risk, and there is no established detection technology. Therefore, this demonstration tested the effectiveness of a spoofing risk detection method using signal authentication technology. Specifically, a drone equipped with signal authentication technology was developed to test whether it could detect spoofing risks and function as a sensor for detecting spoofing. This provided insights for considering future integration with a 4D spatiotemporal information infrastructure.

iii. **<u>Outcomes</u>**

The following outcomes are expected if this use case is implemented in society.

Table 4-9-1 Outcomes

Perspective	Outcome
Social value	• Improved drone flight safety due to countermeasures

	against spoofing attacks • Ensuring the reliability of actual flight routes based on location information records

iv. **KGI & KPI**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-9-2 KGI & KPI

Perspective	KGI	KPI
Social value	• Reducing the accident rate of drone flights caused by spoofing attacks	• Success rate of satellite signal authentication in a positionable environment ➢ [Number of GNSS satellites successfully authenticated] ÷ [Number of GNSS satellites supporting signal authentication and capable of receiving navigation messages] • Detection rate of spoofing signals corresponding to signal-authenticated satellites Signal authentication success rate in an environment where spoofing signals exist

v. **System architecture**

The system architecture for this use case is shown in Fig. 4-9-1.

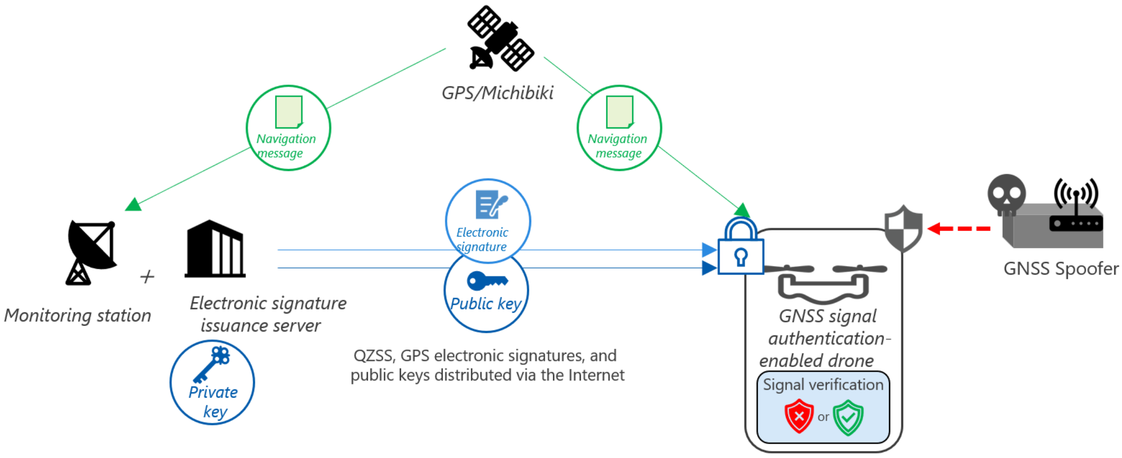


Fig. 4-9-2 System architecture

vi. **Field testing details**

➢ Overview

To reduce the threat of spoofing against drones, the usefulness of signal authentication as a fundamental countermeasure was tested. Specifically, spoofing (transmitting false GNSS signals) was conducted during the drone ground and flight experiments mentioned above and demonstrated that LocationMind's signal authentication technology could detect spoofing. If the test broadcast of the Quasi-Zenith Satellite System is ready in time, experiments can be conducted to use authentication signals from the Quasi-Zenith Satellite System. This demonstrates that authentication technology can be applied to improve the safe flight of drones and social acceptance in Japan and its surrounding areas.

➢ Field testing goal

To confirm that spoofing can falsify drone location information, and to quantify the spoofing detection success rate, which is an indicator of anti-spoofing performance, through spoofing experiments using drones equipped with signal authentication.

➢ Measurement items and methods

i. Laboratory and desktop testing

- Overview:

  Conduct risk assessment by evaluating spoofing risks and the effectiveness of signal authentication as a defense measure, as well as the utilization of these measures, in a laboratory setting and in a desktop environment.

- Details:

  Perform actual spoofing on GNSS receivers and inertial navigation devices that can be installed on drones to test the feasibility of spoofing and to identify risk scenarios that could occur if spoofing actually occurred during flight. Furthermore, test whether spoofing could actually be detected by implementing signal authentication technology. Also evaluate the risk of spoofing during actual flight based on the risk scenarios listed above.

ii. Outdoor drone testing

- Overview:

  At an outdoor flight test site, conduct spoofing and signal authentication tests on actual flying drones to test their anti-spoofing performance and consider flight risk management scenarios.

- Details:

  Based on spoofing risk scenarios, conduct demonstration of spoofing and signal authentication, and examine measures to prevent spoofing and respond to incidents.

In addition, the above demonstration testing mainly used the online signal authentication system shown in Fig. 4-9-1 System architecture, and also tested the usefulness of signal authentication using the Quasi-Zenith Satellite System, which began implementation in FY2024.

vii. **Testing results**

Multiple spoofing attempts and signal authentication were tested while varying the signal strength, the signal authentication success rate was quantified, and the feasibility of spoofing detection using signal authentication technology was verified.

In general, when affected by spoofing, the receiver measures incorrect position information based on the spoofed signal. This occurs when the strength of the spoofing signal is sufficiently greater than the strength of the correct positioning signal (signal transmitted from the GNSS satellite). Meanwhile, signal authentication is successful when the correct positioning signal is received, so if the influence of spoofing signals becomes strong, signal authentication will fail. Therefore, whether spoofing signals could be detected were verified by carrying out tests involving gradually changing the strength of spoofing signals and checking the success rate of signal authentication.

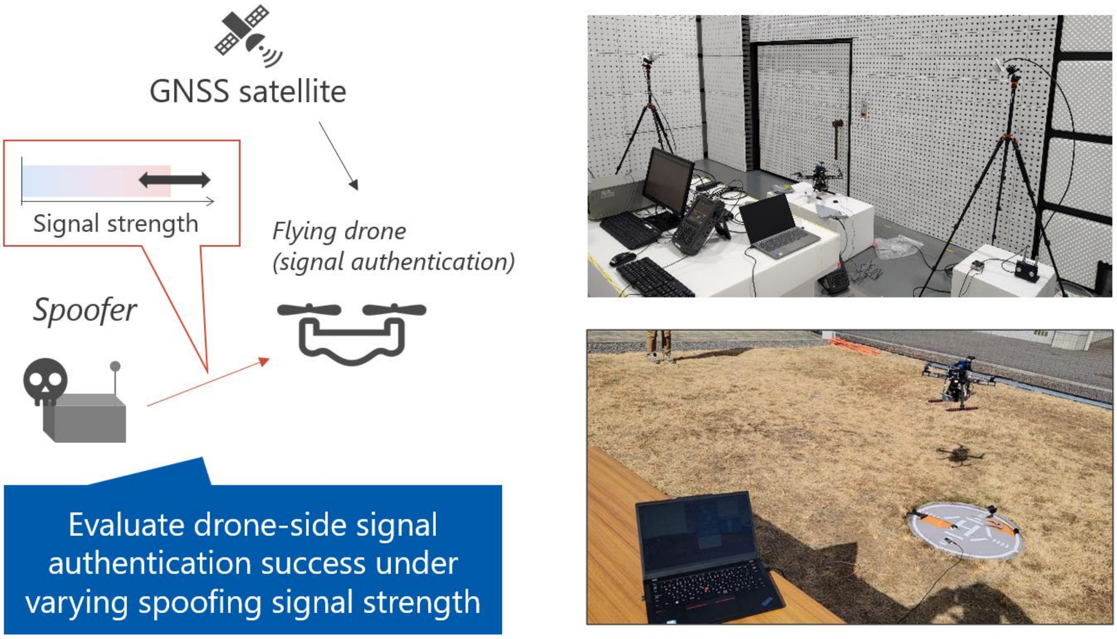


Fig. 4-9-3 Overview of demonstration experiment

The results of the experiment showed that the signal authentication success rate in a positioning environment averaged 95%, which is sufficiently high even when considering factors such as noise. Furthermore, it was confirmed that when the strength of spoofing signals exceeded a certain threshold, the signal authentication success rate fell to around 10% in terms of the detection rate of spoofing signals corresponding to signal-authenticated satellites. In this experimental environment, the signal authentication success rate dropped significantly when the difference in signal strength between the spoofing signal and the correct positioning signal (signal transmitted from the GNSS satellite) reached around 15 dB. Generally, signal strengths of 30 dB or higher are considered to increase the likelihood of location spoofing. The results of this experiment suggest that it is possible to detect the presence of spoofing before effects occur. These results are indicative values obtained in the experimental environment and may vary depending on factors such as the surrounding environment, accumulation period, and signal strength of the transmitted radio waves.

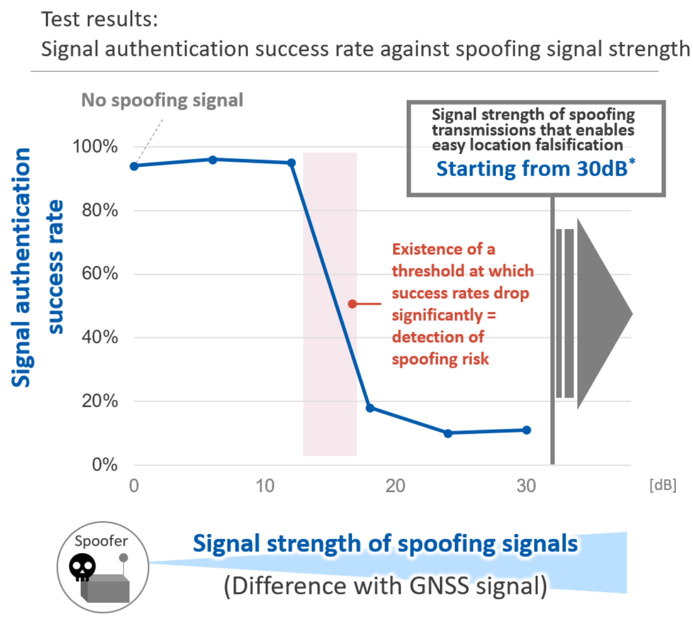


Fig. 4-9-4 Experimental results: Signal authentication success rate relative to spoofing signal strength

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-9-3.

Table 4-9-3 Demonstration schedule

Period	Demonstration item
FY2022	Conduct spoofing attacks on commercially available GNSS receivers and inertial navigation devices to evaluate the risks.
FY2023	Experimentally evaluate the feasibility of defense using signal authentication technology through ground experiments on GNSS receivers. At the same time, incorporate the flight risks of unprotected drones into risk management methods.
FY2024	Evaluate spoofing attack risks through experimental drone flights and implement spoofing risk assessment in risk management methods. Also test the usefulness of signal authentication using the Quasi-Zenith Satellite System.

4.10. Education Use Case（Space Service Innovation Laboratory, Zenrin Co., Ltd., Intelligent Style）

i. Demonstration overview

In collaboration with Hosei University's "Data Scientist Training Program for Urban Research and Analysis Using Digital Twins," a training system for PLATEAU, a 3D city model, was developed which enables the superimposition, spatial analysis, and visualization of point cloud data and human flow big data based on spatial IDs. The developed teaching materials system was also introduced into courses related to urban data science at the Faculty of Engineering and Design at Hosei University.

ii. Background and challenges

In the current field of education, there is a strong push to develop highly specialized human resources who can lead industrial digital transformation. In order to expand the various applications of spatial IDs by utilizing an environment where large amounts of data can be linked in real time, it is necessary to develop human resources together with university education programs.

iii. Outcomes

The following outcomes are expected if this use case is implemented in society.

Table 4-10-1 Outcomes

Perspective	Outcome
Economic value	—
Social value	Increase in highly specialized human resources leading industrial digital transformation

iv. KGI & KPI

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-10-2 KGI & KPI

Perspective	KGI	KPI
Economic value	—	—
Social value	Increase in highly specialized human resources leading industrial digital transformation	Number of introductory courses
		Number of students enrolled in introductory courses

v. **System architecture**

The system architecture has been omitted at the request of the operator.

vi. **Field testing details**

➢ Overview

Data science exercise materials were created centered on Hosei University's Ichigaya Campus and were tested in a course offered by the Department of Civil and Environmental Engineering, Faculty of Engineering and Design at Hosei University. After trial implementation, the system is planned to be introduced on a full-scale basis. Following its introduction and based on feedback and requests from students, the teaching materials and will be continuously refined and the 4D spatiotemporal information platform will be updated with the aim of further enhancing the educational environment.

➢ Field testing goal

To introduce at least one data science course and set a goal of 50 or more students.

➢ Measurement items and methods

Counting the number of introductory courses offered by the Department of Civil and Environmental Engineering, Faculty of Engineering and Design at Hosei University, and counting the number of students enrolled in those courses at the time of final grading.

vii. **Demonstration schedule**

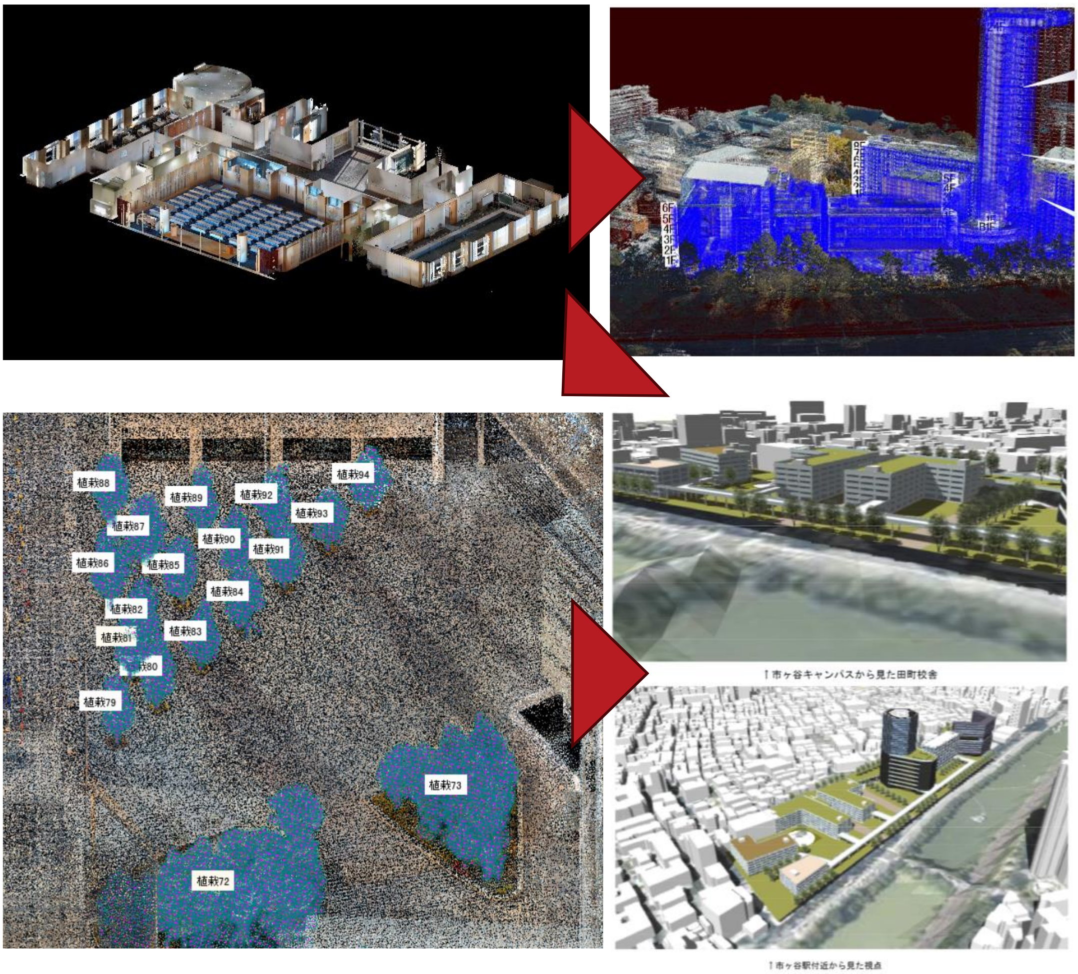
The verification schedule is shown on Table 4-10-3.

Table 4-10-3 Demonstration schedule

Period	Demonstration item
FY2022	No demonstration items (demonstration to begin in FY2023)
FY2023	Trial implementation in courses offered by the Department of Civil and Environmental Engineering, Faculty of Engineering and Design at Hosei University
FY2024	Full-scale implementation in courses offered by the Department of Civil and Environmental Engineering, Faculty of Engineering and Design at Hosei University

viii. **Testing results**

In FY2023, as shown in Fig. 4-10-1, point cloud data was measured indoors and outdoors at Hosei University's Ichigaya Campus during a surveying practical course (approximately 90 participants) offered by the Department of Civil and Environmental Engineering, Faculty of Engineering and Design. Spatial IDs were assigned to each point cloud data based on features. In addition, landscape design utilizing point cloud data was implemented on a trial basis in a CAD practical course.



All 3D terrain models are created by processing
the 3D terrain data from the 'GSI Maps'.

Fig. 4-10-1 Course content

In FY2024, as shown in Fig. 4-10-2, educational materials utilizing a 4D spatiotemporal information infrastructure were introduced on a full-scale basis in the 13th class of Surveying Exercise X and Y (held on January 20, 2nd period) at the Department of Civil and Environmental Engineering, Faculty of Engineering and Design, Hosei University. 26 students were given a map and photos that showed only the approximate locations, and they were tasked with estimating where the inspection photos had been taken in 3D space. They after confirmed the locations of those items in a digital twin environment organized using spatial IDs within the Hosei University campus and experienced how easy it was to understand the space using spatial IDs. Figure 4-10-3 shows an example of students linking inspection photos to spatial IDs in the digital twin environment.

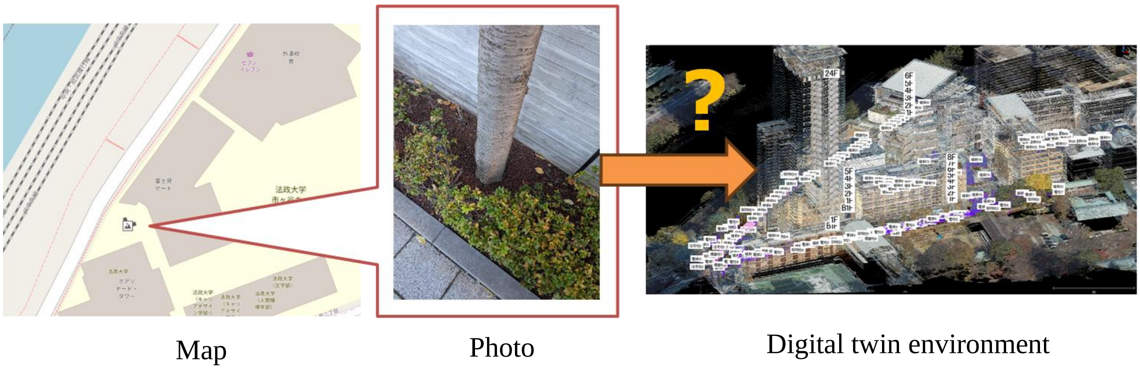


Fig. 4-10-2 Course content

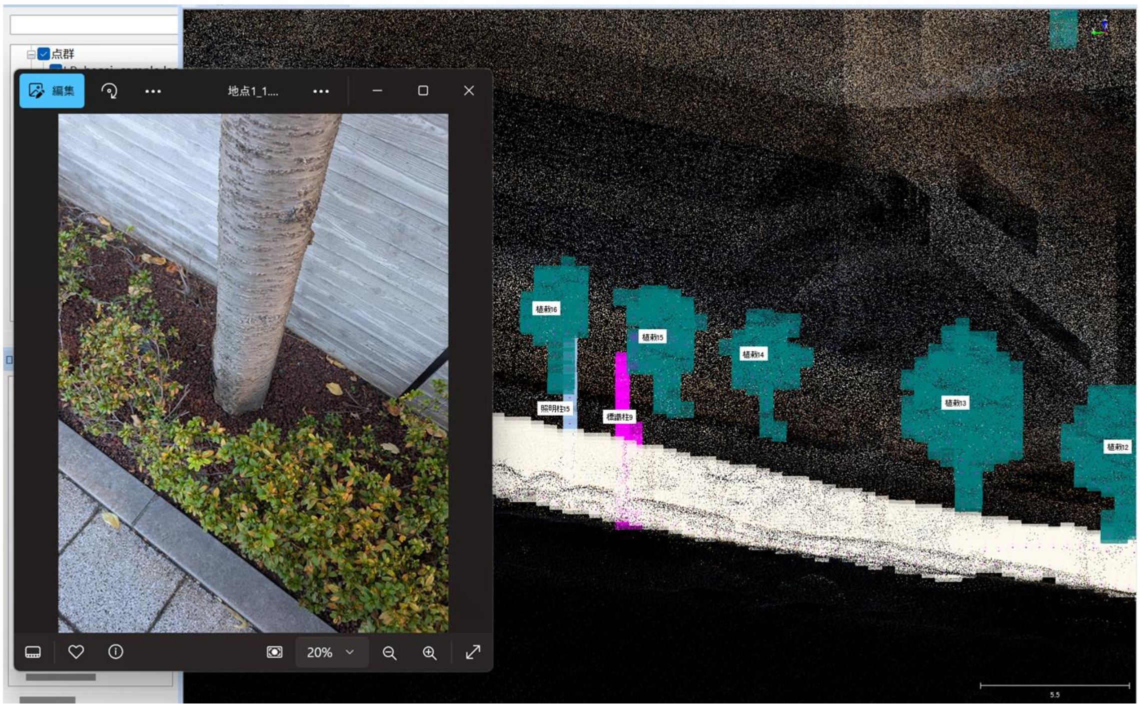
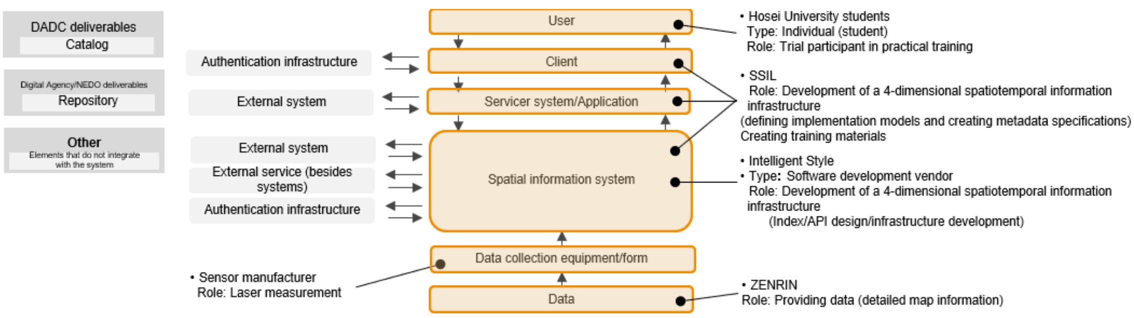


Fig. 4-10-3 Examples of students' assignments

ix. **Linking with architecture map**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-10-4.



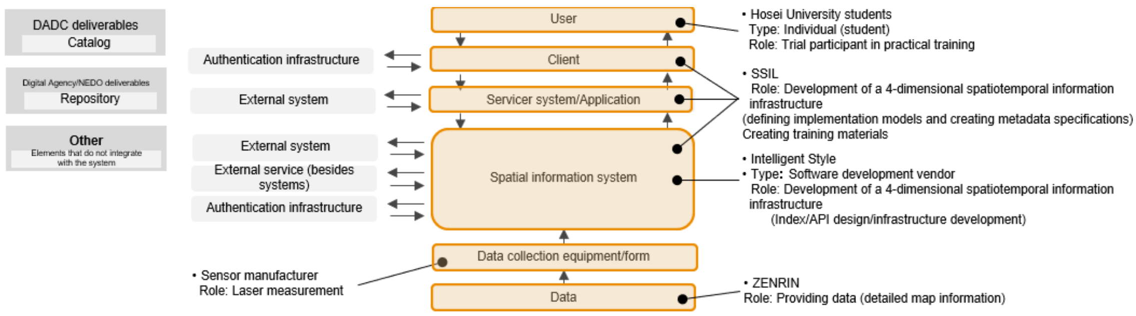


Fig. 4-10-4 Architecture map

4.11. Infrastructure Management Use Case（Space Service Innovation Laboratory, Zenrin Co., Ltd., Intelligent Style）

i. Demonstration overview

A digital twin was constructed by assigning spatial IDs to point cloud data in Shizuoka Prefecture, and the safety of data management and the accuracy of feature identification were verified. Then, the on-site survey app and 3D Point Studio were enhanced as infrastructure management systems compatible with spatial IDs. Furthermore, demonstration experiments were conducted in normal and disaster situations to test the usefulness of the system. In particular, during normal situations, infrastructure monitoring was attempted by incorporating point cloud data measured during inspections into digital twins and analyzing changes.

ii. Background and challenges

Point cloud data measured by lasers mounted on aircraft and vehicles is being utilized to improve the management of public structures such as roads and rivers. As a specific example, Shizuoka Prefecture is conducting aerial laser surveys covering the entire prefecture and constructing a digital twin environment based on point cloud data. Currently, measures are being considered for utilizing digital twins in normal situations (infrastructure monitoring) and emergency situations (disaster assessment, etc.). By applying spatial IDs to these digital twins, it is expected that, in addition to the various measures, data management can be streamlined in accordance with the point cloud data update cycle.

iii. Outcomes

The following outcomes are expected if this use case is implemented in society.

Table 4-11-1 Outcomes

Perspective	Outcome
Social value	• Construction of a digital twin environment based on spatial ID

	● Construction of tools that enable the use of digital twin environments for infrastructure management
Economic value	● Realization of a secure data management system based on blockchain ● Realization of linking inspection results to any space and high-speed spatial searches

iv. **<u>KGI & KPI</u>**

This demonstration measures the achievement of KPI indicators through field testing with the aim of achieving the KGI shown below.

Table 4-11-2 KGI & KPI

Perspective	KGI	KPI
Social value	・Construction of a digital twin environment based on spatial IDs ・Construction of a spatial ID-compatible field survey app	・Number of spatial IDs that identified features ・Time required to construct a digital twin environment
Economic value	・Linking inspection results to arbitrary spaces and features, secure management of such data, and high-speed spatial search ・Realization of a spatial ID-compatible inspection results database	・Infrastructure inspection data search time ・Compatibility with field survey app

v. **<u>System architecture</u>**

The system architecture for this use case is shown in Fig. 4-11-1.

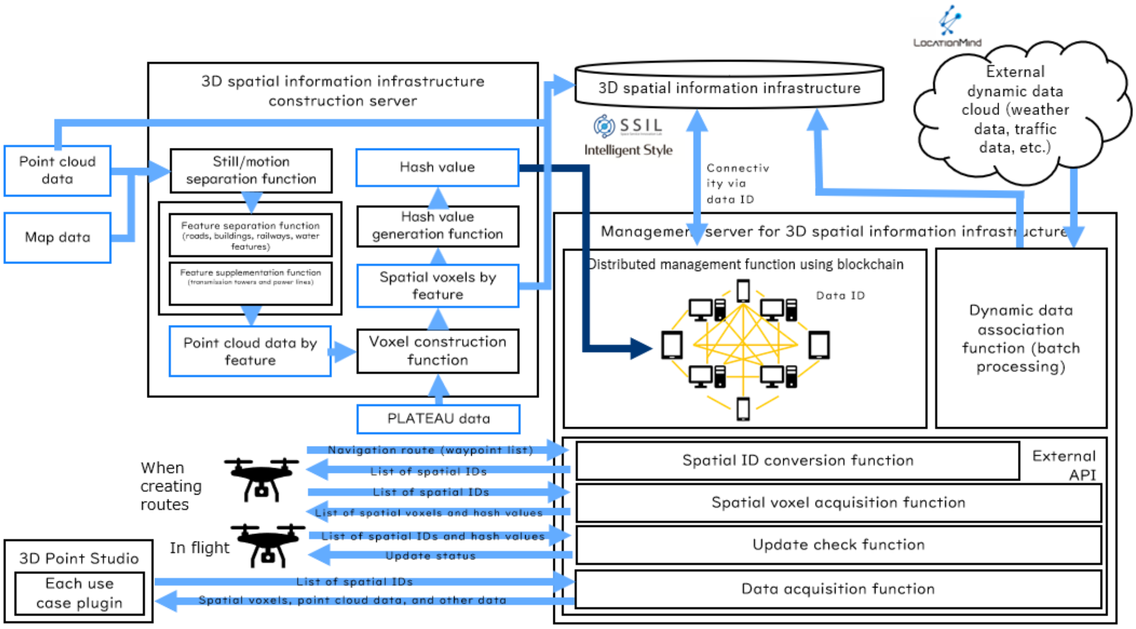


Fig. 4-11-1 Overview of the 4D Spatiotemporal Information Infrastructure

vi. **Field testing details**

Evaluation of authenticity assurance and secure traceability of spatial information

- Overview

In this evaluation, in order to confirm that data accumulated on a 4-dimensional spatiotemporal information infrastructure can be securely managed using blockchain, testing was conducted to determine whether the authenticity of the data on the infrastructure has been lost in data circulating externally by using hash values (original IDs) generated from point cloud data divided by spatial IDs. At this point, the original ID is linked to the spatial ID and managed on a distributed collaborative ledger using blockchain technology, making it impossible to tamper with from outside.

- Field testing goal

The goal is to ensure authenticity by comparing the original IDs generated from the original point cloud data, the point cloud data identical to the original, and the point cloud data modified from the original in the digital twin environment with spatial IDs assigned in Shizuoka Prefecture.

- Measurement items and methods

In this evaluation, authenticity was confirmed based on the specifications under considerations by the Subcommittee on Specification of Point Cloud attribute data for Road (hereinafter referred to as the Subcommittee on Specification of Point Cloud attribute data for Road), established by the Infrastructure Information Standardization Committee of the Japan Construction Information Center. When generating hash values, as shown in the figure below, the spatial ID voxels surrounding the entire point cloud data are divided into eight sections, and the presence or absence of points within each voxel is checked. At this point, voxels containing points are further divided into eight sections, while voxels not containing points are not subdivided any further. This process is repeated until the specified zoom level of the spatial ID is reached. Then, the presence or absence of points within the voxels is converted into a character string for each zoom level. Finally, the original ID is generated from this character string using a hash algorithm. At this time, the hash algorithm used is SHA256, which is referenced from the CRYPTREC Ciphers List published by CRYPTREC, and the zoom level for comparing the original ID is set to 28. If the original ID is the same between point cloud data, the data is determined to be the original data, and if it is different, the data is determined to have lost its originality.

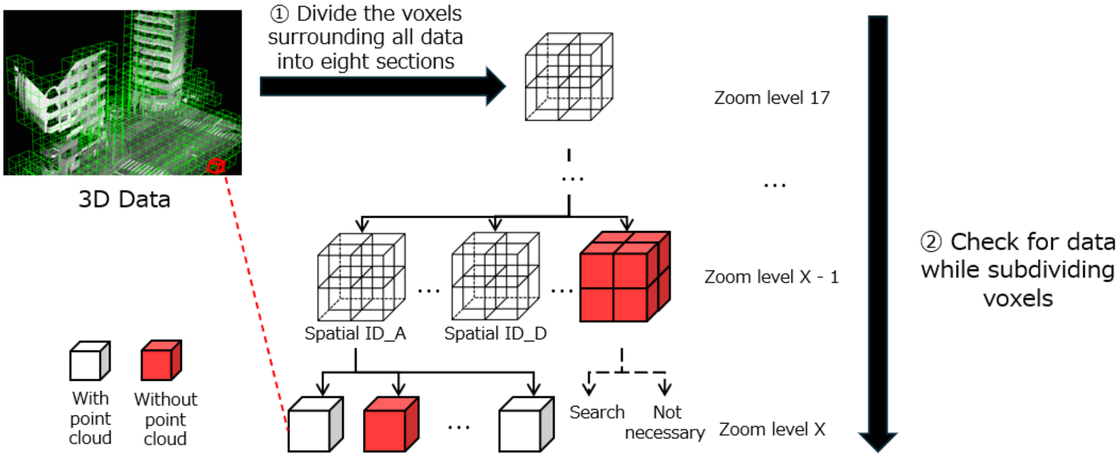


Fig. 4-11-2 Method for generating hash values (original IDs) from point cloud data

Evaluation of accuracy of feature recognition in 4-dimensional spatiotemporal information infrastructure

- Overview

The 4D spatiotemporal information infrastructure identifies features based on point cloud data, Zenrin maps, and AI, and is constructed using spatial voxels created for each feature. In this project, technology was developed to identify features by superimposing point cloud data and Zenrin maps, as well as technology to identify features based solely on point cloud data with AI. By training AI using high-precision point cloud data for each feature constructed using the technology using point cloud data and Zenrin maps, it is possible to build general-purpose identification technology that does not depend on Zenrin maps.

Therefore, in this evaluation, the accuracy of feature recognition results was confirmed based on Zenrin maps, which form the foundation of the 4-dimensional spatiotemporal information infrastructure.

- Field testing goal

The goal is to build a digital twin environment for Shizuoka Prefecture with assigned spatial IDs.

➢ Measurement items and methods

In constructing a digital twin environment, the number of spatial IDs in the digital twin obtained through automatic feature recognition and the time required for construction are counted. In addition, the accuracy of feature recognition in randomly sampled map frames is compared with manual results to evaluate the conformity rate, reproduction rate, and F-value.

Evaluation of infrastructure management system utilizing 4D spatiotemporal information infrastructure

➢ Overview

In this evaluation, infrastructure monitoring is tested by integrating point cloud data acquired during inspections into the digital twin and analyzing structural changes. In this project, a spatial ID-compatible version of 3D Point Studio was developed to visualize spatial voxels for each feature stored in 4D spatiotemporal information. Furthermore, an on-site survey app compatible with spatial IDs was constructed. By using the field survey app, it is now possible to seamlessly access spatial IDs on site, link inspection results to them, and view them in the spatial ID-compatible version of 3D Point Studio.

➢ Field testing goal

The goal is to realize an infrastructure management system using the spatial ID-compatible 3D Point Studio and field survey app that integrate with it, and to improve the efficiency of inspection operations.

➢ Measurement items and methods

In Shizuoka Prefecture, actual slope inspections were conducted using an infrastructure management system and the usefulness of this system was evaluated through interviews with infrastructure inspection personnel.

vii. **<u>Demonstration schedule</u>**

The demonstration schedule is shown on Table 4-11-3.

Table 4-11-3 Demonstration schedule

Period	Demonstration item
FY2022	No demonstration items (demonstration to begin in FY2023)
FY2023	Construction of a digital twin with spatial IDs assigned to point cloud data in Shizuoka Prefecture
FY2024	Demonstration experiments on usage scenarios during regular conditions and disasters to test usefulness

viii. **<u>Testing results</u>**

Evaluation of authenticity assurance and secure traceability of spatial information

This figure shows the results of evaluating three types of data: original data, data from which fine noise has been removed or uniformly thinned, resulting in a loss of originality, and data with the same phase but saved in different software and with different point sequence saving orders which retains its originality.

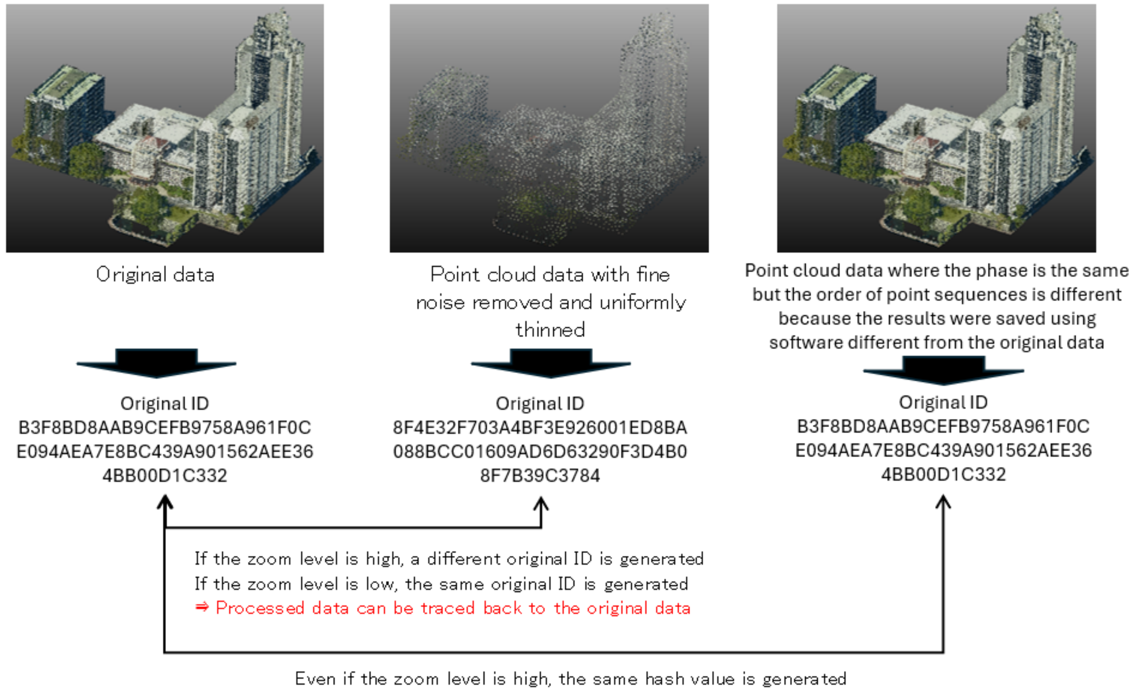


Fig. 4-11-3 Confirmation of authenticity using hash values

As shown in the figure, point cloud data that has lost its originality generates different original IDs, while point cloud data with different storage sequences but the same phase generates the same original ID. This original ID is linked to a spatial ID and managed on a blockchain, making it impossible to tamper with. Therefore, by using this original ID for comparison when determining whether infrastructure data on the 4D spatial information infrastructure needs to be updated or when confirming the reliability of infrastructure data originating from the infrastructure that is circulating externally, it is possible to guarantee authenticity. It has been confirmed that authenticity can be guaranteed based on the specifications being considered by the Subcommittee on Specification of Point Cloud Attribute Data for Roads. Based on the above, the introduction of blockchain and original ID mechanisms enables secure management of infrastructure data on this platform.

Evaluation of accuracy of feature recognition in 4D spatiotemporal information infrastructure

A feature recognition technology was developed based on Zenrin maps and, as shown in Figure 4-11-4, and established spatial IDs for six types of features (buildings, railways, water bodies, transmission towers, power lines, and roads) for approximately 2,000 spaces (equivalent to approximately 3,000 times the size of the Tokyo Dome) at spatial ID level 17 in

Shizuoka City, Shizuoka Prefecture, in about four days. This enables an environment in which data can be linked and searched quickly for any feature space, as shown in Figure 4-11-5.

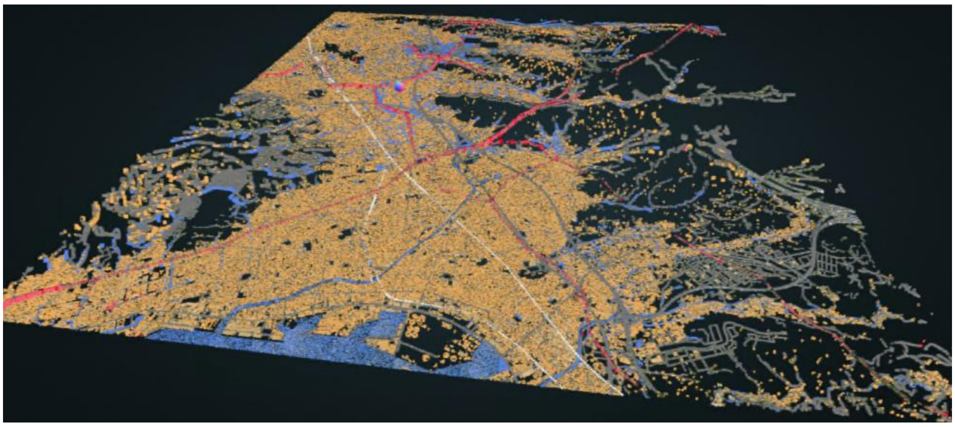


Fig. 4-11-4 Digital twin environment in Shizuoka Prefecture

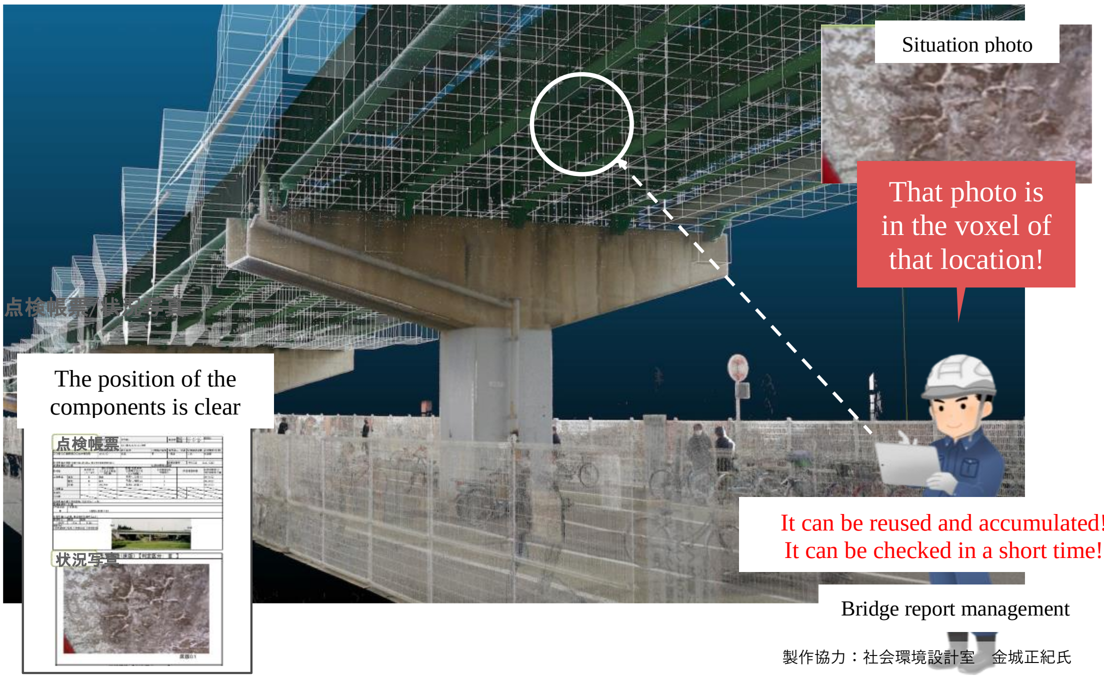


Fig. 4-11-5 Conceptual image of data search during inspection using a digital twin environment

When confirming the accuracy of feature recognition in randomly sampled map frames, it was found that roads, water bodies, transmission towers, and power lines could be extracted reliably. However, although buildings could be extracted with a high accuracy of F value 0.99, there were several extraction omissions, resulting in a slightly lower reproduction rate of 0.98. Upon confirming the cause, it was found that this was due to the fact that the buildings were not included in the map, as shown in Fig. 4-11-6. This made it clear that if the map data is accurate, it is possible to extract features with certainty.

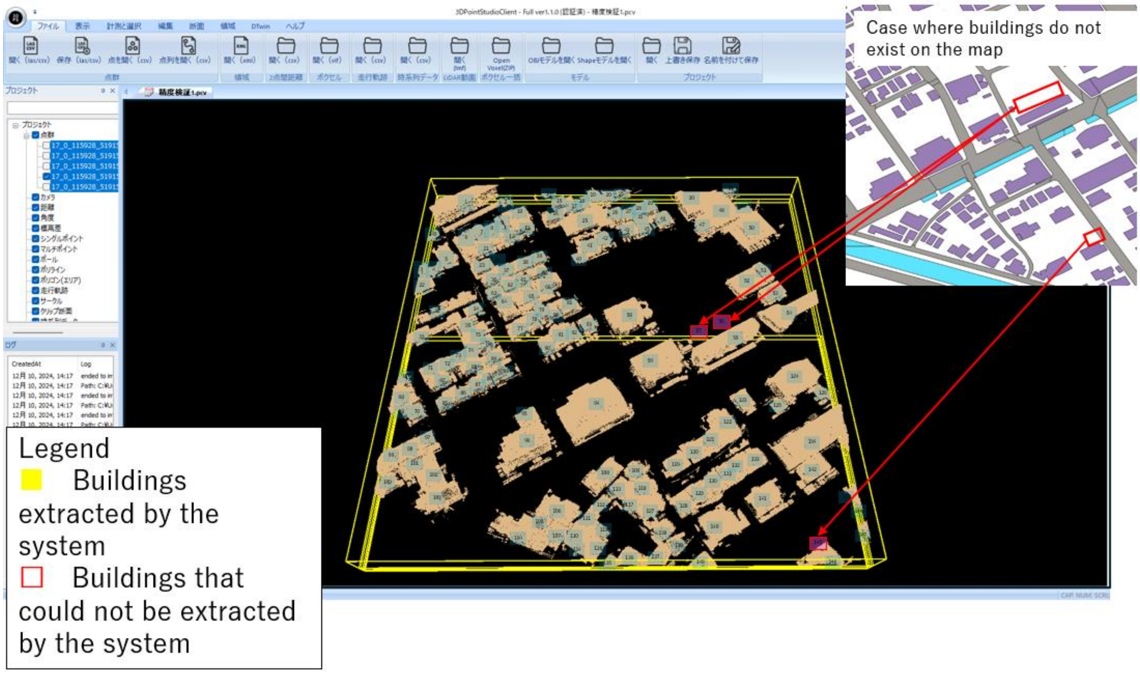


Fig. 4-11-6 Scope of construction of 4D spatiotemporal information infrastructure

Evaluation of infrastructure management system utilizing 4D spatiotemporal information infrastructure

The results of developing the spatial ID-compatible version of 3D Point Studio are shown in Fig. 4-11-7. This system can import and visualize not only point cloud data but also spatial voxels of arbitrary areas via a network from a 4D spatiotemporal information infrastructure. In addition, files can be associated with arbitrary spatial voxels, and associated files can be viewed. Fig. 4-11-7 shows the viewing results of the digital twin environment of Yaguchi Bridge in Shizuoka Prefecture.

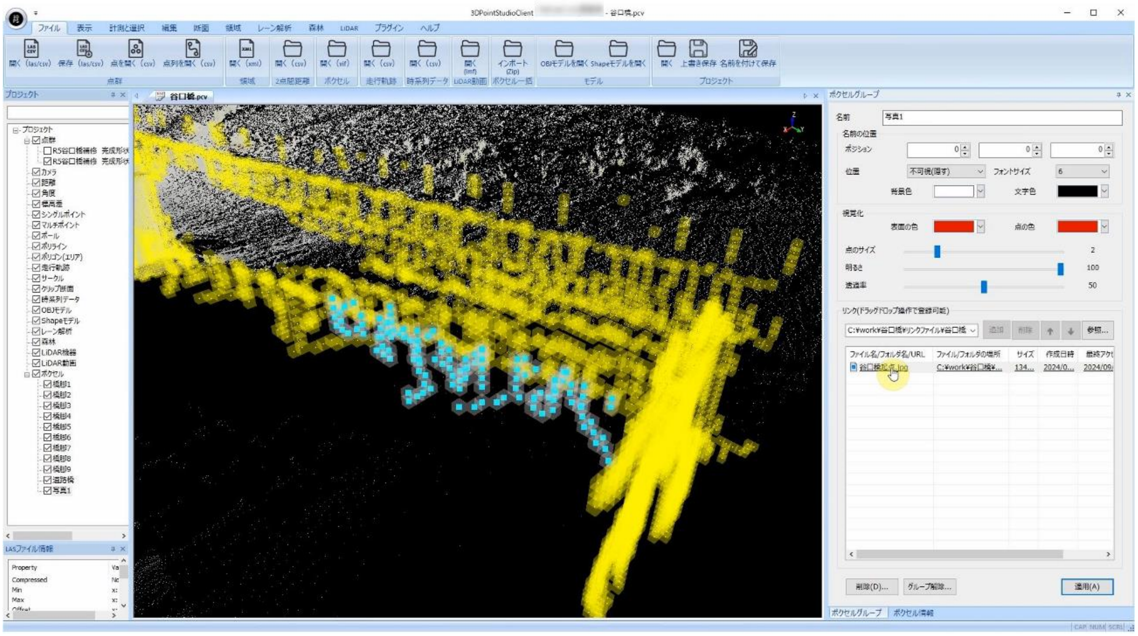


Fig. 4-11-7 Scope of construction of 4D spatiotemporal information infrastructure

The results of improvements to the spatial survey app are shown in Fig. 4-11-8. This system enables simple inspections using a tablet, and the results can be seamlessly linked to spatial IDs. The inspection results of this system can be viewed in the spatial ID-compatible version of 3D Point Studio using spatial IDs as the axis.

Fig. 4-11-8 On-site survey app

In this evaluation, field trials were conducted in Shizuoka Prefecture as shown in Fig. 4-11-9. The following opinions were obtained from those who conducted the inspections, demonstrating the usefulness of the infrastructure management system.

- Convenient for measuring the size of cracks, etc.
- During patrols, inspection items can be quickly confirmed using images, and point clouds, which is ideal for on-site use, can be measured for more detailed information.
- In disaster recovery projects, if the amount of sediment can be obtained from point clouds, surveying work can be eliminated.
- When using iPhone/iPad LiDAR outdoors, there were times when the 5-10m ranging distance did not reach the target area as expected.

Fig. 4-11-9 Field testing

The usefulness of spatial ID utilization in digital twins

Based on the above field tests, the usefulness of spatial ID utilization in digital twins was evaluated. The results of organizing the characteristics of point cloud data, original voxels, and spatial IDs as data for forming digital twins are shown in Table 4-11-4. In addition, Table 4-11-5 shows the results of organizing the characteristics of spatial IDs as a location reference method from the perspective of establishing a digital twin environment that integrates and provides diverse data.

Table 4-11-4 Point cloud data, original voxels, and spatial ID characteristics

Item	Point cloud data	Original voxel	Spatial ID voxel
Acquisition/ generation method	Acquired by laser scanner, generated from images using SfM/MVS	Cuboids defined based on points	Cuboids defined based on latitude, longitude, and zoom level
Data size	△ Bulky	○ Compact and can be adjusted as needed	
Position accuracy	△ Depends on the accuracy of measuring instruments	△ Depends on voxel size/zoom level	
Position accuracy	△ Random	○ In sequence	
Shape representation	○ Reproducible including edges	× Impossible to express edges	
Deviation	△ There is meaning in the deviation of points	○ There is no meaning to the deviation of points (uniform)	
Definition criteria	△ Latitude, longitude, elevation, and XYZ	△ No standard (depends on how it is made)	◎ Standards exist
Hierarchical structure	× None	○ Hierarchical structure exists (Depends on the point cloud to be analyzed)	◎ Hierarchical structure exists (has a relationship of inclusion)

Table 4-11-5 Address, latitude/longitude, elevation, and spatial ID characteristics

Item	Geographical identifier (address, etc.)	Latitude, longitude, elevation	Spatial ID
Position reference accuracy	× Grid-based location referencing	○ Point-based location referencing	△ Voxel-based location referencing
Data association	◎ Easy due to the granularity of the grid	△ Difficult due to measurement errors	○ Easy with large voxel width
Interoperability with existing systems	○ Already adopted by many systems, no conversion required		× Since this is a new concept, conversion from latitude and longitude is necessary from time to time
Data analysis (extracting differences over time, etc.)	× It is difficult to apply uniformly because the size varies depending on the section	△ Random distribution requires high-load analysis processing such as searching for corresponding points	○ High-speed analysis is possible because the data is aligned
Data conversion to arbitrary precision	○ Convertible to prefectures, cities, towns, and villages	△ Data conversion not supported	○ Conversion while maintaining inclusion relationships is possible
Accuracy settings for information disclosure (location of underground structures, etc.)	○ Can be converted to any precision for disclosure, taking security into consideration	× Disclosure of coordinate values exactly as they are	○ Can be converted to any precision for disclosure, taking security into consideration

ix. **<u>Target layers and roles of players in the architecture of this demonstration</u>**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-11-10.

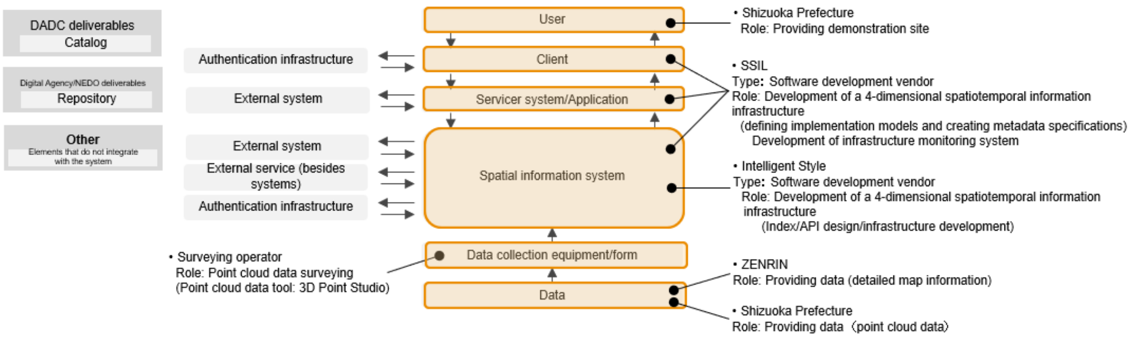


Fig. 4-11-10 Architecture map

4.12. Construction Site Application Use Case （Takenaka Corporation, NTT Communications Corporation）

i. Demonstration overview

A field app was introduced to support spatial adjustment work at construction sites and a system was built to enable the acquisition of spatial usage data linked to spatial IDs. The effectiveness of this system was demonstrated from three perspectives: the value of the field app itself, the value of using spatial IDs, and the value of distributing spatial IDs. The results quantitatively showed that each of these elements contribute to the improvement of site operations. A conceptual demonstration overview is shown on Fig. 4-12-1.

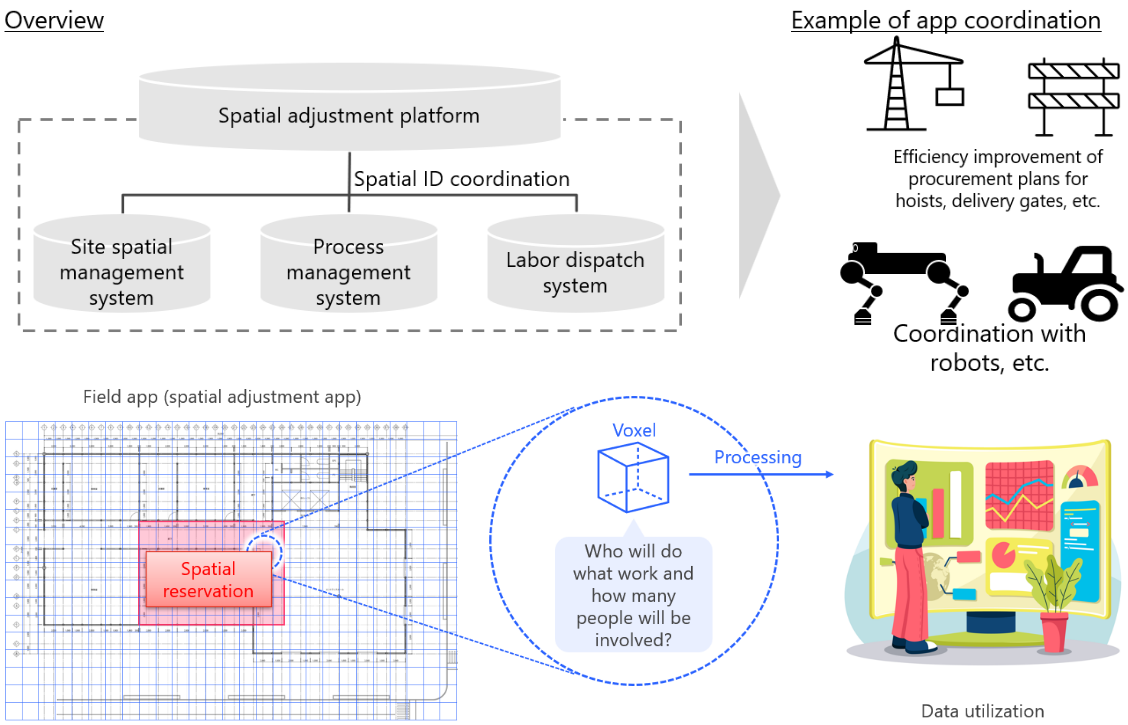


Fig. 4-12-1 Conceptual overview

ii. **Background and challenges**

Construction management is carried out comprehensively from various perspectives (QCDSE), including quality, cost, delivery, safety, and environment. However, current construction management has not been digitized, and heavily relies on individual experience and intuition. This has become a factor in hindering the efficiency and consistency of construction management. Due to the delayed introduction of digital technology, information sharing and analysis are insufficient, and decision-making on site may become ambiguous.

Furthermore, the construction industry as a whole is facing a severe labor shortage, with a particular difficulty in securing experienced personnel. The lack of experienced engineers is making it difficult to pass down expertise and know-how in the field, raising issues in construction quality. Although there is an urgent need to train younger engineers and enable them to quickly gain experience in the field, the current environment for doing so is not yet fully in place.

iii. **Outcomes, KGI & KPI**

The outcomes, KGI, and KPI created when this use case is implemented in society are defined in Table 4-12-1.

Table 4-12-1 Outcomes

	Outcome	KGI	KPI
Efficiency improvements through tool introduction and digitization (tateras value)	• Efficiency improvement in onsite work coordination and planning (economic value and improvement of existing businesses)	• Reduction in personnel expenses/labor costs	• Work coordination and preparation hours/reduction rate at the workplace
	• Reduction of rework in the field (economic value and improvement of existing businesses)	• Reduction of additional man-hours	• Rework hours/reduction rate at the workplace
Efficiency improvement through integration of field data (value of spatial ID)	• Improved operational efficiency through integrated field data (economic value and new value)	• Reduction in personnel expenses/labor costs	• Work coordination and preparation hours/reduction rate at the workplace
	• Visualization and improvement of production efficiency through spatial efficiency evaluation (economic value and new value)	• Visualization of spatial efficiency	• Number of new production efficiency indicators introduced
	• Improving operational efficiency by visualizing resource utilization efficiency (economic value and new value)	• Visualization of resource utilization efficiency	• Number of new operational efficiency indicators introduced
	• Improving construction quality and safety at work sites through the integration of spatial information and on-site data (social value)	• Improvement of construction quality and safety	• Accuracy of AI-generated feedback on site inspection photos
Realization of a spatial adjustment platform for construction sites (spatial ID distribution value)	• High value-added construction site data through data aggregation and integrated management of diverse applications (Other (technical aspects, etc.))	• Increase in the types of data that can be cross-tabulated among the various types of data handled at the site (examples of data types: spatial reservations, work plans, safety management)	• Number of external app integrations (increasing the number of integrations contributes to an increase in the types of data that can be handled)
	• Contribution to the spatial ID value penetration cycle (Social value)	• Increase in data linked to spatial IDs circulating in society	• Number of measures to promote the registration and utilization of spatial ID data

*For outcomes from the perspective of external integration, refer to Table 4-14-1. (Outcomes assuming robots as integration targets are listed.)

iv. **System architecture**

System architecture is shown on Fig. 4-12-2.

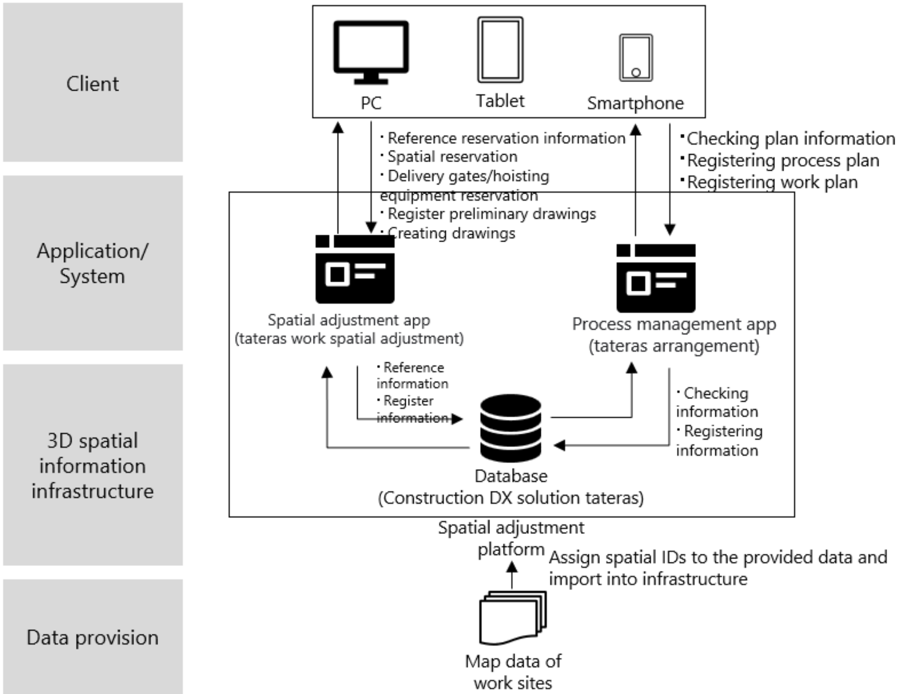


Fig. 4-12-2 System architecture

v. **Field testing details**, ⅶ. **Testing results**, ⅷ. **Demonstration schedule**

For details, refer to Section 4.13.

ⅸ. **Target layers and roles of players in the architecture of this demonstration**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-12-3.

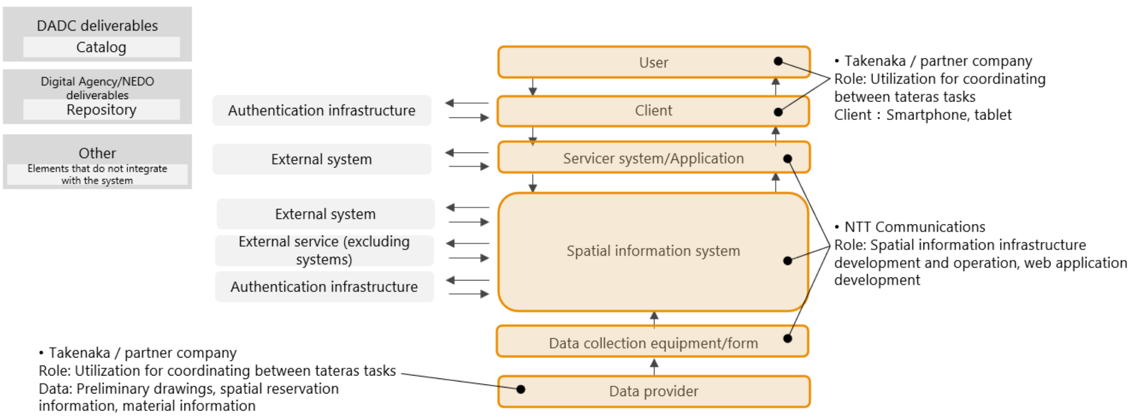


Fig. 4-12-3 Architecture map

4.13. Technical Verification of Construction Site Application （Takenaka Corporation, NTT Communications Corporation）

*This field testing was conducted using the construction site app use case described in Section 4.12.

ⅰ. Demonstration overview, ⅱ. Background and challenges, ⅲ. Outcomes, ⅳ. KGI & KPI, ⅴ. System architecture, and ⅸ. Target layers and roles of players in the architecture of this demonstration are described in the Construction Site App Use Case section (see Section 4.12).

vi. **Field testing details**

- Overview

  The spatial adjustment platform developed in this demonstration was introduced at an actual construction site. In the field testing, the effectiveness was measured by conducting interviews and questionnaires with site managers and foremen.
- Demonstration period

  February 2025
- Demonstration location

  Construction sites managed by Takenaka Corporation (23 sites)
- Measurement items and methods

  In the field testing, the spatial adjustment platform developed in this demonstration project was introduced, interviews and questionnaires were conducted with users (110 people), and the degree of achievement of KPIs was measured.

vii. **Testing results**

In Demonstration ⅵ. conducted in February 2025, KPIs were measured. The test subjects were 110 users at 23 sites where the system had been introduced. The results are shown in Table 4-13-1.

Table 4-13-1 KPI Measurement Results

Perspective	KPI	Measurement results
Economic value (Improvement of existing businesses)	• On-site work coordination and preparation hours/reduction rate • Rework hours/reduction rate on-site	• 13% reduction in time spent on afternoon meetings • 22% reduction in time spent preparing morning meeting materials • Approximately 30% of respondents experienced a reduction in missed adjustments at least once a month

Economic value （New value）	• On-site work coordination and preparation hours/reduction rate • Number of new production efficiency indicators introduced • Number of new operational efficiency indicators introduced	• No clear reduction in workload confirmed through interviews • 4 new production efficiency indicators introduced • 1 new operating efficiency indicator introduced
Social value	• Accuracy of AI-generated feedback on-site inspection photos • Number of measures to promote the registration and utilization of spatial ID data	• 64% correct answer rate • 6 promotion measures
Technical aspects	• Number of external app integrations (increasing the number of integrations contributes to an increase in the types of data that can be handled)	• 1 external app integration

Value of using tateras

The value of tateras highlights the importance and high demand for spatial management at construction sites. A questionnaire to 110 users showed that the set KPIs were achieved. These results confirm the importance of digitization and centralized management in industries where construction site conditions are constantly changing and many workers come and go. As the amount of spatial information increases in the future, the importance of spatial IDs is expected to grow further.

Value of using spatial IDs

Spatial information accumulated in tateras was aggregated and visualized using spatial IDs as keys, and five production efficiency indicators were introduced. Although practical value was not confirmed at this stage, it has contributed to increasing opportunities for change toward a more data-driven way of working. In addition, by assigning background information to photos taken on site using spatial IDs as keys, the accuracy of photo identification by generative AI was improved. This suggests a new way to use spatial IDs in the era of generative AI.

Value of distributing spatial IDs

A value penetration cycle for spatial IDs was proposed and measures were implemented to increase data volume. As a result, it was confirmed that this contributed to value penetration. Going forward, it is expected that services compatible with spatial IDs will implement measures based on the value penetration cycle, thereby forming a foundation for the circulation of abundant spatial ID data within Japan. In the construction robot use case, tateras spatial ID data was linked to a robot navigation system to enable spatial ID distribution between different apps. In the future, spatial ID distribution between systems developed by different entities is expected to further enhance spatial ID distribution in Japan.

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-13-2.

Table 4-13-2 Demonstration schedule

Period	Demonstration item
FY2022	UI design, interviews UI improvement, development
FY2023	UI improvement, development Demonstration ⅰ. (development using prototype) Demonstration ⅱ. (development using improved system)
FY2024	Demonstration ⅲ. (demonstration using improved system) Demonstration ⅳ. (integrated development and demonstration)

4.14. Construction Robot Use Case（Takenaka Corporation）

i. **Demonstration overview**

In this use case, the aim is to increase the feasibility of replacing human tasks with robots by enabling autonomous mobile control of construction robots in conjunction with construction management, both indoors and outdoors, and in a three-dimensional direction through implementing unified spatial management between construction management and robot operation management using spatial IDs.

Robots can capture images at their destinations, enabling site staff and construction managers to manage construction, which is expected to reduce labor costs, alleviate labor shortages, and improve safety. In addition, the use of spatial IDs is expected to improve route design accuracy and reduce system maintenance costs. A conceptual demonstration overview is shown on Fig. 4-14-1.

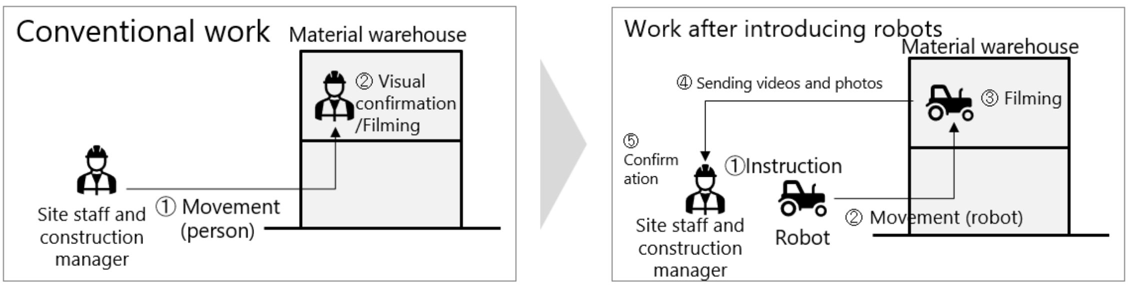


Fig. 4-14-1 Conceptual overview

ii. **Background and challenges**

In the construction industry, a shortage of construction site personnel is expected in the future. In addition, people entering and exiting construction sites pose a high risk of accidents, making safety the utmost priority. Against this backdrop, robots are increasingly being used for human tasks that can be replaced by machines. Challenges in utilizing robots include the difficulty of autonomous movement between indoor and outdoor areas due to the lack of a coordinate system that unifies indoor and outdoor spaces, and the difficulty of specifying coordinates for height, which is important in construction sites. In addition, autonomous movement requires the acquisition of a detailed map of the entire building in advance, which is costly to maintain.

iii. **<u>Outcomes</u>**

The following outcomes are expected if this use case is implemented in society.

Table 4-14-1 Outcomes

			Outcome
Robot demonstration value	Value of using robots	Automation	• Improved productivity through the use of robots (economic)
			• Remote operation and task execution by workers unable to perform onsite work (social) - Alleviating labor shortages caused by population decline - Improving safety at construction sites
		Safety improvement	• Reduced risk of construction delays due to accidents, etc. (economic)
	Value of using spatial IDs	Route design	• Efficient 3D movement and indoor/outdoor movement (economic)
			• Enables the use of not only specific high-quality robots but also a wide variety of robot devices (social)
		Development efficiency	• Efficiency improvement in construction work using spatial information (economic)
			• Efficiency improvement of external system integration (social)

iv. **<u>KGI & KPI</u>**

The following KGI & KPI have been set for the outcomes.

Table 4-14-2 Value of using robots

	Outcome	KGI (Indicators for evaluating outcome achievement)	KPI (Verification of effectiveness during demonstration:★) (Directly measured indicators)
Automation	• Improved productivity through the use of robots (economic)	• Increased productivity • Reduction in personnel expenses/labor costs	• Man-hours per unit period for workers★ • Man-hours per unit time for robots★ • Number of personnel required
	• Remote operation and task execution by workers unable to perform onsite work (social) - Alleviating labor shortages caused by population decline - Improving safety at construction sites	• Reduction of human labor at work sites	• Workers' time spent/distance traveled onsite ★ • Number of personnel required
Safety improvement		• Replacement of tasks by robots	• Robots' time spent/distance traveled onsite ★
	• Reduced risk of construction delays due to accidents, etc. (economic)	• Reduction of risks caused by human error	• Results of questionnaire on the safety of onsite workers

Table 4-14-3 Value of using spatial IDs

	Outcome	KGI (Indicators for evaluating outcome achievement)	KPI (Verification of effectiveness during demonstration:★) (Directly measured indicators)
Route design	• Efficient 3D movement and indoor/outdoor movement (economic)	• Efficient robot operation using spatial IDs	• Man-hours required for route design work using spatial IDs (work man-hours and training man-hours)★ *Compared to using robots alone
	• Enables the use of not only specific high-quality robots but also a wide variety of robot devices (social)	• Replacement of tasks by robots	• Number of types of tasks replaced by robots★ • Number of robot types compatible with spatial IDs★
System efficiency	• Efficiency improvement in construction work using spatial information (economic)	• Increased scope of application for spatial information	• Man-hours (business man-hours and training man-hours) for tasks related to the use of spatial information such as map creation and site photo management★ *Compared to cases where spatial IDs are not used
	• Efficiency improvement of external system integration (social)	• Increased data integration using spatial IDs as keys	• Number of data items to be linked to external systems • Number of systems to be linked to external systems • Omission of processing flow when linking to external systems (compared to when not using spatial IDs)

v. **System architecture**

System architecture is shown on Fig. 4-14-2.

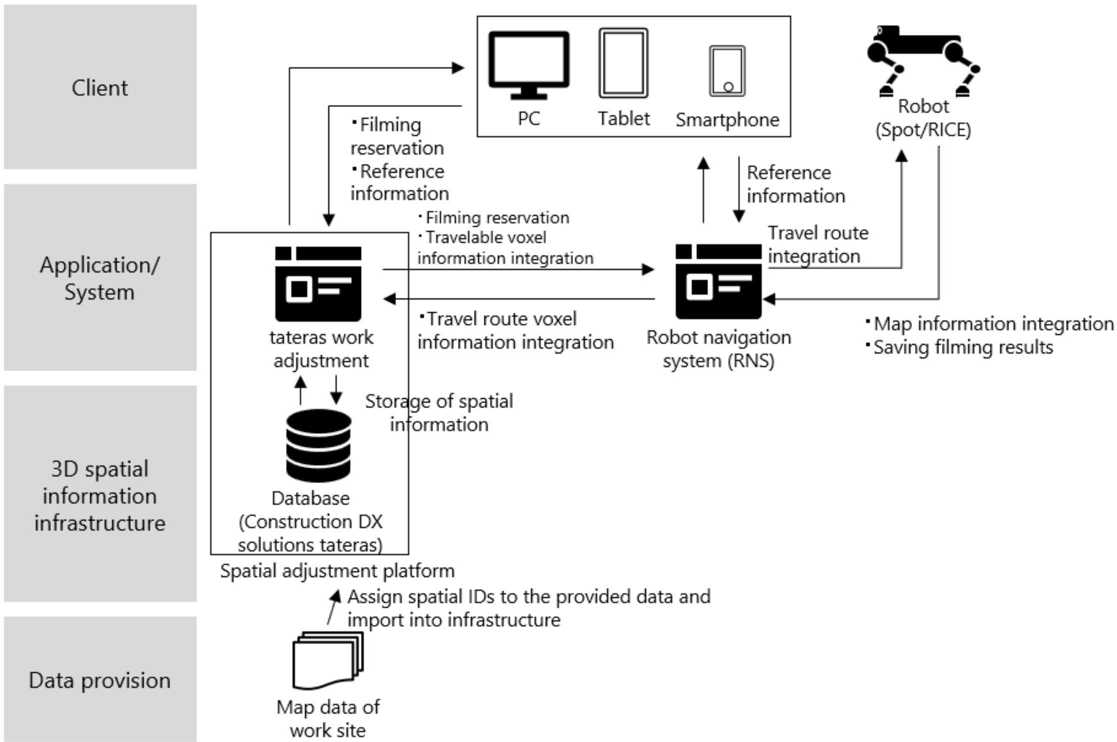


Fig. 4-14-2 System architecture

vi. **Field testing details**, ⅶ. **Testing results**, ⅷ. **Demonstration schedule**

See Section 4.15 for details.

ix. **Target layers and roles of players in the architecture of this demonstration**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-14-3.

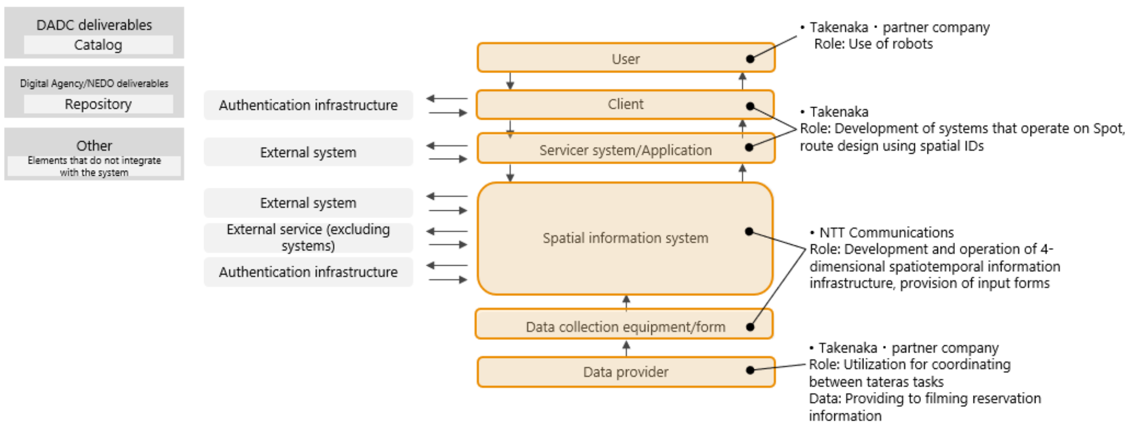


Fig. 4-14-3 Architecture map

4.15. Technical Verification of Construction Robots (Takenaka Corporation, NTT Communications Corporation)

*This field testing was conducted using the construction robot use case described in Section 4.14.

ⅰ. Demonstration overview, ⅱ. Background and challenges, ⅲ. Outcomes, ⅳ. KGI & KPI, ⅴ. System architecture, ⅸ. Target layers and roles of players in the architecture of this demonstration are described in the Construction Robot Use Case section (see Section 4.14).

vi. **<u>Field testing details</u>**

➢ Overview

The developed system was introduced at a construction site and tested that it functions properly. The aim was to identify any operational or business issues. The robot management system developed in this demonstration was trialed at a construction site managed by Takenaka Corporation, and feedback was gathered on the user experience.

➢ Demonstration period

December 2024

➢ Demonstration location

・Testing of indoor and outdoor movement: Factory buildings and surrounding areas owned by partner companies

・Testing of integration with site spatial management app: Construction sites managed by Takenaka Corporation

➢ Measurement items and methods

In field testing, construction demonstration robots were deployed at sites managed by Takenaka Corporation to test their functionality and their ability to replace work processes. Testing of indoor and outdoor movement and testing of integration with the site space management app was conducted at separate sites. Testing was conducted based on the perspectives shown in Table 4-15-1. Based on the testing results, which focused on technical testing points, demonstrations were considered from social and economic perspectives.

Table 4-15-1 Testing perspectives

Perspective	Testing details	Details
Technical aspects (route design)	Route design in robot navigation systems	Test whether it is possible to design routes in a format that can be handled by Spot, as well as the data format, logic, and practicality.
	Conversion from global spatial ID to robot coordinate system	Test whether it is possible to convert global spatial IDs based on latitude, longitude, and altitude into a robot coordinate system, and test the conversion accuracy.
Technical aspects (indoor/outdoor movement)	Indoor movement	Test whether the robot can move along a specified route in an indoor space under the following conditions. Also test the appropriateness of the zoom level. Conditions for movement •The robot must travel along the specified route. •The robot must not enter areas outside the designated travel route.
	Outdoor movement	Test whether the robot can move along a specified route in an outdoor space under the following conditions. Also test the appropriateness of the zoom level. Conditions for movement •The robot must travel along the specified route. •The robot must not enter areas outside the designated travel route.
Technical verification points (photography)	Capturing images of construction work using Spot	Test whether images can be captured at a level that could be used for construction management.

vii. **Testing results**

Demonstration was conducted based on the following testing points and obtained results were generally as expected.

Table 4-15-2 Testing results

Testing points	Demonstration item	Results
Integrated map creation	Manage an integrated map on the robot navigation system by linking site drawings and geographic coordinate data from “tateras,” located on the 4D spatiotemporal information platform.	Created and managed the integrated map by linking site drawings and geographic coordinates from “tateras” with environment maps generated by the robot using SLAM.
Route design based on information sharing using spatial IDs	Manage robot route planning on the robot navigation system by linking spatial reservation information registered in “tateras” to spatial IDs and integrating it into the system. (This fiscal year, routes were manually created by operators, not automated.)	Designed routes on the robot navigation system based on spatial reservation information linked to spatial IDs from “tateras,” as well as information from the integrated map.
Autonomous movement	Enable autonomous movement at the construction site based on the created route, including level changes and indoor/outdoor movement.	Navigated the designated route as expected.

In addition, KPIs were evaluated as follows.

As the first step in the evaluation, the robot moved autonomously within the construction site to analyze patterns of interruption. A route of a large box-shaped area was set, taking 12 minutes to complete one lap. As a result, the following patterns of interruption were found.

A. The route is completely blocked by materials, autonomous movement is suspended, and all subsequent movement is performed manually.
B. Work using an aerial work platform is being performed on the route, so autonomous movement is suspended, the work area is avoided via manual operation, and autonomous movement is resumed.
C. Work using an aerial work platform is being performed on the route, and autonomous movement is suspended in a situation where avoidance is impossible even after switching to manual operation. All subsequent movements are performed manually.

Pattern A can be avoided if the configuration information is registered in tateras, but patterns B and C are not registered in tateras in detail, making avoidance difficult even if integrated with tateras.

Through multiple autonomous movements, it was found that pattern B occurred on average once per autonomous movement, with a 15-second interruption, and pattern C occurred with a probability of 40%. In order to calculate the occurrence probability of pattern A by linking tateras, the following evaluation was conducted.

(a) The location of equipment and materials at the demonstration site was visually confirmed at intervals of approximately two hours and the information was registered in tateras. This was conducted because the location of materials and equipment deployed at work locations changes at intervals of approximately two hours. This was conducted for several days and 10 configuration patterns were prepared.

(b) A simulated route was created for patrolling the demonstration site. To accommodate the placement of equipment and materials, the route was designed with branching points that allowed it to split into two paths at several locations. In this demonstration, four branches were created, with each pair of paths merging again before reaching the next branching point. Due to the limited size of the test site, it was difficult to design routes with multiple consecutive branches that remained separated, therefore the setup was simplified to facilitate evaluation. With two branches at four points, a total of $2^4=16$ possible route patterns were generated.

(c) Analysis was conducted for the number of routes blocked by equipment and materials and interrupted from among the 16 routes set in (b) for the 10 equipment configurations registered in (a).

The results showed that, out of the 16 possible routes for each of the 10 patterns, the percentages of routes interrupted was 100%, 87.5%, 93.75%, 93.75%, 75%, 93.75%, 87.5%, 87.5%, 75%, and 75%, with an average of 86.875%. Since one lap takes 12 minutes, it was estimated that the time from the first branch to the merge is 3 minutes, from the second branch to the merge is 3 minutes, from the third branch to the merge is 3 minutes, and from the fourth branch to the merge is 3 minutes. Where branch interruption occurred was analyzed and the duration of the 12-minute lap that would require manual operation was calculated. It was found that an average of 6.3 minutes of manual operation time was required.

In the case of pattern A mentioned above without tateras integration, 6.3 minutes of manual operation is required. Additionally, in pattern B, each attempt takes 15 seconds, which amounts to 0.25 minutes of manual operation. Furthermore, since pattern C occurs 40% of the time, an average of 2.4 minutes of manual operation is required. By adding these together, the percentage of manual intervention required when there is no tateras integration was calculated. Furthermore, when tateras integration is used, it is considered that all A patterns can be avoided, and the manual operation time for B and C patterns was calculated. As a result, without tateras integration, manual intervention took 6.55 minutes, while with tateras integration, manual intervention took 2.65 minutes. The manual intervention ratio was 0.55% and 0.22%, respectively. The autonomous movement ratio, which is calculated by subtracting the manual intervention ratio from 1, can be considered the automation rate. This shows that tateras integration improved the automation rate by approximately 32%.

This automation rate was used to calculate the reduction in working hours. The calculation conditions are shown below.

1. Three site workers conducted three 60-minute patrols per day
2. Robots were used to conduct two of the three patrols
3. Each of the three workers spent 10 minutes reviewing images instead of conducting patrols

The reduction in working hours for on-site staff was calculated based on the automation rate. Assuming 20 working days per month, the reduction in working hours per month would be 136 minutes without tateras integration and 233 minutes with tateras integration.

Value of using robots

The introduction of robots alone has reduced the current 360-minute patrol time by 136 minutes, or approximately one-third. Furthermore, assuming that there is a certain risk of injury during on-site movement, reducing the number of visits to the site from three to one would, by simple calculation, reduce the risk by one-third.

Value of using spatial IDs

By utilizing spatial IDs and creating robot routes using tateras information, it appears that approximately 100 minutes of work time can be reduced in addition to the effects of simply introducing robots, resulting in a total reduction of approximately two-thirds of the patrol work time. In addition, safety and peace of mind can be improved by ensuring that on-site workers are aware of the robots' movement patterns and by eliminating the possibility of robots entering the work area.

Furthermore, by using spatial IDs as a common language for inter-system communication, it becomes possible to link robots other than those used in this verification to tateras, enabling the standardization of robot navigation systems. In this project, integration was conducted not only with Spot, a four-legged walking robot, with tateras, but also RICE, a wheeled delivery robot. When integrating RICE alone, it would have been necessary to develop the part that imports tateras information separately. However, by using spatial IDs and sharing the development part used for Spot, the development workload was reduced by 28%.

viii. **<u>Demonstration schedule</u>**

The demonstration schedule is shown on Table 4-15-3.

Table 4-15-3 Demonstration schedule

Period	Demonstration item
FY2022	Requirement definition Robot selection
FY2023	Demonstration ⅰ.: Development, implementation, and demonstration of

	a system for setting robot routes using spatial IDs, as well as integration and demonstration using a field spatial management app and robot spatial IDs
FY2024	Demonstration ⅱ. : Integration and demonstration using a site spatial management app and robot spatial IDs, as well as control using spatial IDs for multiple robots of different types

4.16. Spatial Entertainment Use Case（Takenaka Corporation, Keisuke Toyoda's Laboratory, Institute of Industrial Science, The University of Tokyo）

i. **Demonstration overview**

This use case explored the potential for creating new experiences in the entertainment field by linking global spatial IDs and local spatial IDs, while indicating technical considerations. A game was developed in which users in different locations could battle common enemies in real time, demonstrating the value of coexistence of the two by using global spatial IDs and local spatial IDs according to their respective characteristics. Human-scale VR content was also developed, with technical challenges identified, such as errors in self-position estimation using VR devices.

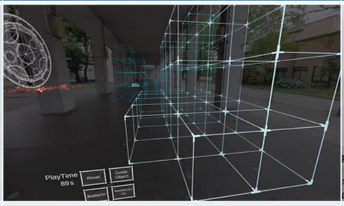
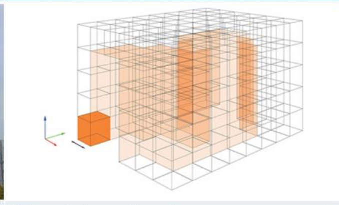
	2023 Prototype Content	2024 Demonstration Content ①	2024 Demonstration Content ②
			
Content overview	An AR RPG played in real space. Players collect bullets in the exploration phase, battle monsters in the battle phase, and view VR art in the reward phase.	Engage in combat against flying objects defined on the G spatial IDs from two L spatial IDs. The position of the G flying objects and the HP are stored on the G spatial IDs and synchronized between the two L spatial IDs.	This content passes through passageways composed of L spatial ID voxels without hitting walls. Collision detection in the content is compared with collision detection using data obtained from motion capture to verify the L spatial ID specifications.
Goal	To explore the potential of spatial IDs in entertainment and to place a grid modeled after voxels within content and explore ways to utilize it.	To create a prototype of content linked with G spatial IDs and L spatial IDs, to search for content using spatial IDs (simulation), and to acquire external information using spatial IDs (simulation).	To verify the optimal size of L spatial ID voxels taking into account the alignment errors contained in current HMDs and content.

Fig. 4-16-1 Demonstration content

ii. **Background and challenges**

In the entertainment field, there are no platforms or unified standards for linking external information or sharing information between different types of content, which have resulted in hindering system integration and data integration. In recent years, content that can be experienced in physical spaces using AR and VR technologies, as well as games that utilize vast digital spaces, have emerged, but few reflect actual spatial information in the content.

Spatial IDs are infrastructure that handles spatial information linked to actual locations across the entire globe, and acquiring information not previously utilized in existing entertainment content and to link content together becomes easier, opening up the possibility of implementing new entertainment content that utilizes actual spatial conditions and information linked to specific locations.

iii. Outcomes

The following outcomes are expected if this use case is implemented in society.

Table 4-16-1 Outcomes

		Expected effects (outcomes)
Value of spatial entertainment	Enhancing the appeal of AR entertainment content linked to physical spaces	• Prototype of synchronized multiplayer AR content linked to real space
		• Prototype of multiplayer AR content with players in remote locations
	Utilizing physical spaces	• Creating a lively atmosphere
Value of using spatial IDs	Coordination with real space	• Easier linkage between real space and entertainment content
	Spatial information management and integration	• Management of information based on voxels
		• Incorporating external information in content
		• Content management and search
Technical verification	Consideration of specifications for local spatial IDs that can be used for entertainment	• Consideration of the relationship between global and local
		• Consideration of local spatial ID specifications

iv. KGI & KPI

The following KGI & KPI have been set for the outcomes.

Table 4-16-2 KGI & KPI

Expected effects (outcomes)	KGI (Indicators for evaluating outcome achievement)	KPI (Verification of effectiveness during demonstration: ★) (Directly measured indicators)
• Prototype of synchronized multiplayer AR content linked to real space	• Confirmation that multiple users can have the same experience at the same time and place	• 3 or more people can have the same experience • Comments from users
	• Consideration of challenges and possibilities for improving user experience through coordination with features and spatial characteristics	• Extracting three or more from each focus group of experts and engineers involved in spatial entertainment
• Prototype of multiplayer AR content with players in remote locations	• Identification of steps and processes that can be eliminated in the implementation process when sharing content remotely	• Comparison of implementation methods and man-hours required when implementing content to be shared remotely
• Creating a lively atmosphere	• Demonstrating effectiveness for future commercialization and expansion	• Consideration of scenarios for spreading to three or more areas
• Easier linkage between real space and entertainment content	• Confirmation of spatial perception using voxels	• Implementing to content
	• Identification of tasks that can be made more efficient using spatial IDs	• Comparing with existing methods
• Management of information based on voxels	• Presenting the potential of voxel-based data management	• Comments from users
• Incorporating external information in content	• Presenting examples of content utilizing external information	• Simulated implementation in content
• Content management and search	• Examples of content management and search	• Simulated implementation of scenarios
• Consideration of the relationship between global and local	• Consideration of usable voxel sizes	• Deviation from the specified position of the AR-displayed voxel
	• Need for definitions that match features	• Number of voxels required for each spatial ID with different swing angles
• Consideration of local spatial ID specifications	• Organization of pros and cons based on differences in definitions	• Extracting from focus groups
	• Presenting specifications	• Consideration of specifications for items in accordance with spatial ID specifications

v. System architecture

System architecture is shown on Fig. 4-16-2.

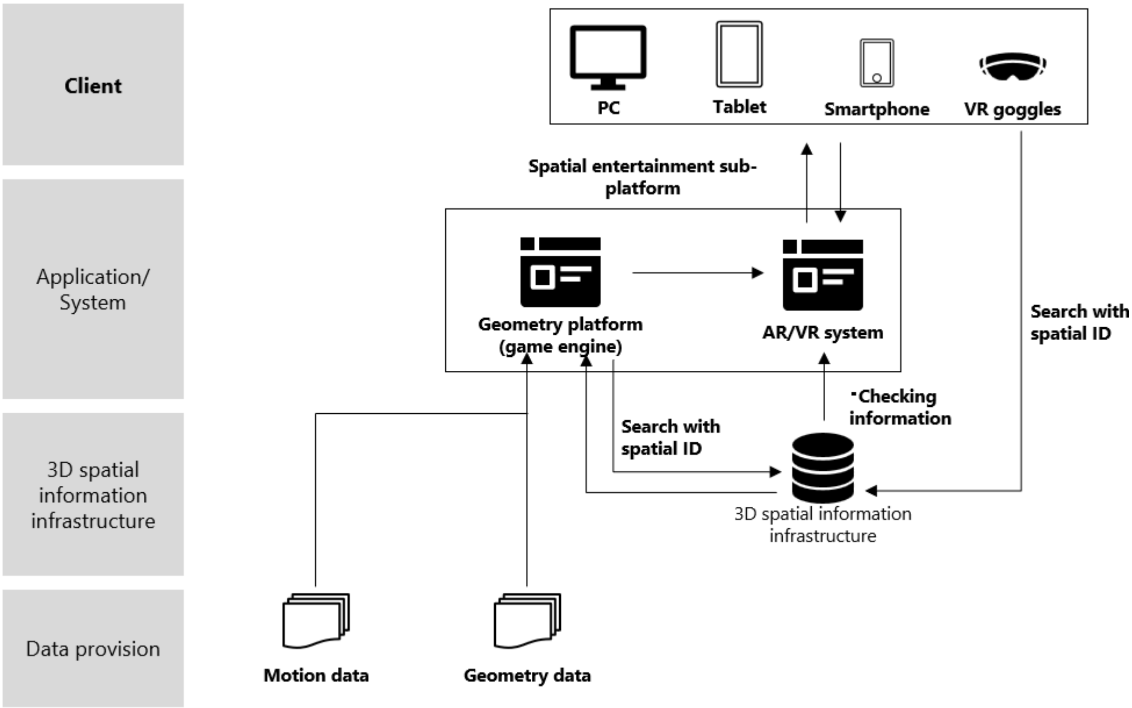


Fig. 4-16-2 System architecture

vi. **Field testing details**, ⅶ**. Testing results**, ⅷ**. Demonstration schedule**

Technical testing, which was the main initiative in the first year, is described in Section 4.17.

ix. **Target layers and roles of players in the architecture of this demonstration**

The architecture map showing the mapping of the layers subject to this demonstration and related players is shown in Fig. 4-16-3.

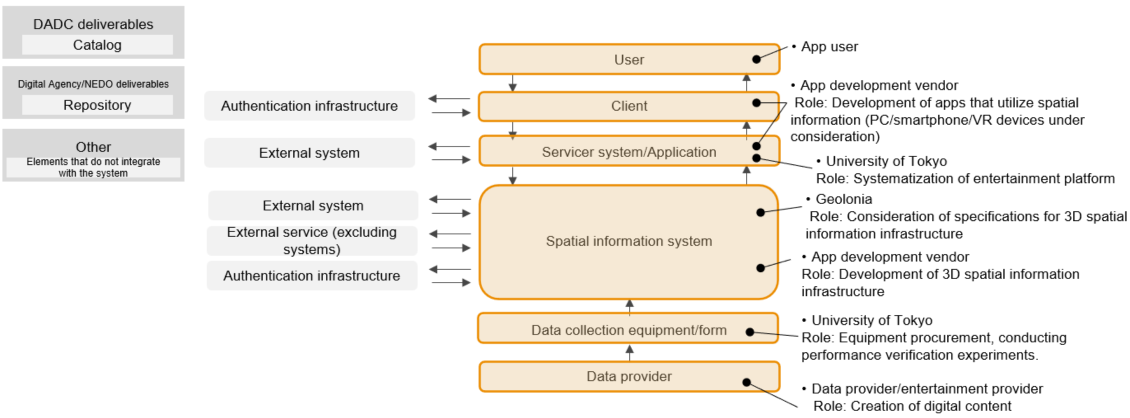


Fig. 4-16-3 Architecture map

4.17. Technical Verification related to Spatial Entertainment （Takenaka Corporation, Keisuke Toyoda's Laboratory, Institute of Industrial Science, The University of Tokyo）

Items ⅰ. Demonstration overview, ⅱ. Background and challenges, ⅲ. Outcomes, ⅳ. KGI & KPI, ⅴ. System architecture, and ⅸ. Target layers and roles of players in the architecture of this demonstration are described in the Spatial Entertainment Use Case section (see Section 4.16).

vii. <u>**Field testing details**</u>

FY2023 Prototype Content ⅰ., FY2024 Demonstration Content ⅰ.

- Overview

  The prototype content was created with the aim of examining the potential applications of spatial IDs in the entertainment field. First, voxels were placed locally to examine how spatial IDs can be used and the challenges that arise when it is used. As spatial IDs are a standard for handling physical spaces, the content used in the prototype was AR content linked to physical spaces.

  The aim of this demonstration content was to examine the integration and differentiation between global spatial IDs and local spatial IDs. Local spaces were set up in two remote locations, and object data stored on a server intended for global spatial IDs was projected in each local space, enabling the same content to be experienced in both remote locations.
- Demonstration period

  Prototype content: January to March 2024, Demonstration content: January to March 2025
- Demonstration location

  Yoyogi Park, Institute of Industrial Science, The University of Tokyo
- Measurement items and methods

  ・Current coordinates of the base ship: The coordinates of the base ship defined by geographic coordinates were converted to the coordinates of each local space, projected using AR, and confirmed on mobile devices.

  ・Hit points and damage of the base ship: Confirmed damage from attacks by multiple users to be correctly reflected on the server managing the hit points of the base ship.

  ・Time synchronization: Based on the time of the experience device, content starts every 15 minutes, and the server confirms that the trajectory of the base ship is projected at the same position for all participants.

  ・Weather expression: By referring to pseudo weather data stored in each voxel of the local spatial ID, when moving to a voxel that stores rain information, confirm whether the screen becomes dim and rain particles are displayed.

FY2024 Demonstration content ⅱ

- Overview

The aim of this verification is to examine the voxel size that can be used for AR content created with current HMDs and content creation software that requires high-precision alignment.

Content was developed that records the contact between the user's head, hands, and voxels placed in the space. The records obtained using HMD during the experience were compared with the records obtained by software using the actual movements of the users captured by high-precision motion capture, and the usable voxel size were examined by testing the differences.

- Demonstration period
  January to March 2025
- Demonstration location
  Institute of Industrial Science, The University of Tokyo
- Measurement items
  The positional deviation contained in the voxels actually projected in AR due to various inaccuracies, such as initial position calibration, HMD self-position estimation, hand tracking, and differences in display methods (optical or video), relative to the position of the voxels defined with the origin set at the center of the physical space.
- Measurement methods
  ・HMD-based content: A maze constructed from voxels was projected in AR, and users wearing HMDs navigate through the maze without touching the walls.
  ・Contact log recording: Record contact between the user's head and hands and the walls as a log.
  ・High-precision marker-based motion capture: Markers are attached to an HMD and fixtures held in both hands by the user to capture the user's movements.
  ・Collision detection in Unity: Collision detection with the maze performed in Unity using data captured by motion capture.
  ・Comparison of contact frequency: Compare the contact logs from the HMD and motion capture to evaluate the impact of errors.

vii. **<u>Testing results</u>**

FY2023 Prototype Content, FY2024 Demonstration Content ⅰ

・Establishment of position synchronization and time synchronization

In verifications conducted in FY2023 and FY2024, position synchronization (multi-view display) and time synchronization were confirmed for AR content. Synchronization with three people was conducted in FY2023, and in FY2024, synchronization with five or more people was conducted, using different methods each year. Multi-perspective AR content has high technical barriers and is not widely available to the general public, but this was achieved using STYLY and Unity in this demonstration.

・Challenges and possibilities of content linked to physical space

Content linked to physical spaces can create a sense of immersion and realism by linking to geographic information and spatial structures. Multi-perspectives enable users to share experiences, promoting communication and collaboration. Issues such as occlusion and self-position estimation accuracy remain, but this project showed that these can be resolved with appropriate settings and ingenuity.

・**Extracting procedures for reducing remote content and identifying issues**

The possibility of linking local spatial IDs and global spatial IDs when experiencing the same content linked to physical spaces at remote locations was tested. Rather than defining the geographical coordinates of moving objects in detail, it was defined using waypoints, showing that global spatial IDs can serve as waypoints.

・**Alignment with physical spaces that can be streamlined using spatial IDs**

Accurate positioning in relation to physical spaces is important in AR content, and in this demonstration, a method of setting HMDs and markers at the initial position was adopted. With this method, it is necessary to know where the initial position is in physical spaces. While VPS enables high-precision alignment, creating digital maps requires technical expertise. Therefore, a system in which the provider stores the alignment locations and maps in spatial IDs and users refer to them is ideal. In addition, alignment at multiple locations was found to be necessary for content covering a wide area.

・**Possibility of utilizing external information**

In FY2024 content, weather information was simulated and utilized. The scope of application of the information was set using spatial IDs, and this was achieved by assigning weather conditions as attribute information to each voxel.

FY2024 Demonstration Content ⅱ

This testing examined the size of voxels that can be used for AR content. When using local spatial IDs for small voxels, there are limitations to the positioning accuracy, and therefore restrictions on the voxel size that can actually be used. For example, even if 10 cm voxels are used, if the alignment of the device used for the AR content experience is mismatched by more than 10 cm, the ID calculated from the position information will differ from the actual voxel ID.

In the testing, a maze composed of voxels using an HMD was projected in AR and the contact with the walls as a log was recorded when the user wore the HMD and passed through the maze (ⅰ). In addition, marker-based motion capture was used to capture the user's movements and collision detection was performed in Unity (ⅱ). ⅰ includes errors in initial position alignment, errors in HMD self-position estimation, errors in hand tracking, and errors due to differences in display methods. ⅱ uses high-precision motion capture data, enabling measurement of user contact data for voxels at set positions.

In the case of 500 mm voxels, there was no significant difference in the number of contacts between ⅰ and ⅱ. Therefore, the impact of errors is considered to be minimal, making it usable. In the case of 250 mm and 125 mm voxels, there was a difference in the number of contacts, so additional testing was conducted to compare the coordinates of the contact points. The coordinate deviation averaged 125 mm or more, making it difficult to utilize 125 mm voxels. Furthermore, as the experience time increased, the deviation of the contact points tended to increase, indicating that the error could become even larger with longer content.

viii. **Demonstration schedule**

The demonstration schedule is shown on Table 4-17-1.

Table 4-17-1 Demonstration schedule

Period	Demonstration item
FY2022	・Testing of requirements for a 4D spatiotemporal information infrastructure system ・Selection of equipment ・Formulation of implementation plan
FY2023	・Planning, creation, and demonstration of prototype content i
FY2024	・Planning, creation, and demonstration of demonstration content i ・Planning, creation, and demonstration of demonstration content ii

5. NEDO: Digital Infrastructure Development Project for Digital Transformation of Industries/ Research and Development on Foundations Contributing to the Pilot Implementation of Digital Lifelines

In the "Digital Lifeline National Comprehensive Development Plan," which was formulated with the aim of solving social issues and developing industries, demonstration projects are being promoted in the three priority areas of the early harvest project: drone routes, autonomous driving service support roads, and infrastructure management DX as support measures for advanced social implementation.
The development of digital lifelines aims to build infrastructure from three aspects: hardware, software, and rules, and in the development of soft infrastructure, "spatial ID" is adopted as an identifier for handling spatial information, and the practicality and effectiveness of spatial ID are being verified and evaluated in each area of early harvest.

This chapter describes the outline of the demonstration project in the early harvest project, as well as the results of verification and evaluation related to spatial ID and the disclosure of the demonstration results.

5.1. Drone routes (Grid Sky Way. LLP, Trajectory, Ltd., The University of Tokyo, Fujiyama Corporation, NEC Corporation, Japan Electric Co., Ltd., KDDI SmartDrone Inc., Intent Exchange, Inc., Space Service Innovation Laboratory)

i. Demonstration Overview

Based on constraints such as risks on the ground and in the air, we will develop a drone route system that integrates information distribution and safety management support necessary for safe and convenient operation within the route, and a system for distributing drone-related data.

In addition, in order to realize safe and efficient operation within drone routes, we will conduct research and research on management methods and rules related to drone routes. In Chichibu and Hamamatsu, which are the first implementation areas, we will conduct power grid management and multi-use demonstrations over rivers to confirm the effectiveness of drone routes. An image of the use case in the Chichibu and Hamamatsu areas is shown in Figure 5-1-1.

- Formulation of drone route specifications and operation methods
    - Specifications and operation methods were designed as a result of drone route development and service implementation.
- Formulation of Mobility Hub Specifications and Operation Methods
    - Design of management systems and operation methods such as reservations for airfields linked to routes
- Formulation of specifications related to data linkage
    - Designing a specification to link data related to drone routes with spatial ID as a common identifier
- Formulation of guidelines for nationwide expansion
    - Draft guidelines for the construction and utilization of drone routes for operators and operators

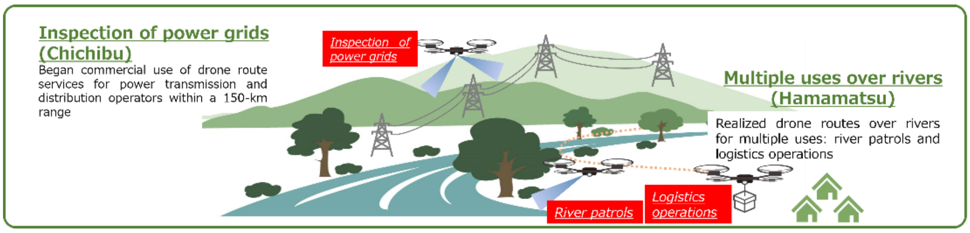


Figure 5-1-1 Use cases in the Chichibu and Hamamatsu areas

ii. <u>Implementation Items</u>

Development of Drone Route System

In order to provide integrated support for safety management necessary for safe and easy operation of drones, information from external systems such as SDSP is used as a spatial digital twin. The system configuration diagram of the drone route is shown in Fig. 5-1-2. SDSP information such as weather information is converted into a spatial ID and distributed in the red frame.

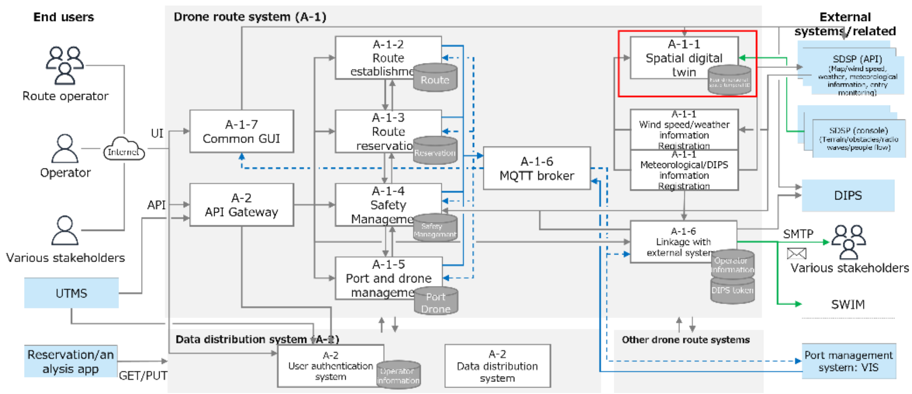


Figure 5-1-2 System configuration diagram

We worked on the development of a system for accumulating and sharing information such as wind speed, weather, and obstacles related to drone flight, and aimed to incorporate it into the 4D spatio-temporal information platform as a function to build a spatial digital twin.

By designing and implementing API specifications based on the API architecture, we have implemented the linkage of 4D spatio-temporal information (terrain, obstacles, wind speed, weather, radio waves, human flow, third-party access monitoring information, no-fly areas, etc.) using the data distribution platform in the drone domain.

The API architecture of the spatial digital twin is shown in Figure 5-1-3. In the feature and obstacle information analysis and processing, which is a console system on the build server, the specifications of the 4D spatio-temporal information platform of the spatial ID business were diverted, and the feature code of the space voxel was switched and registered.

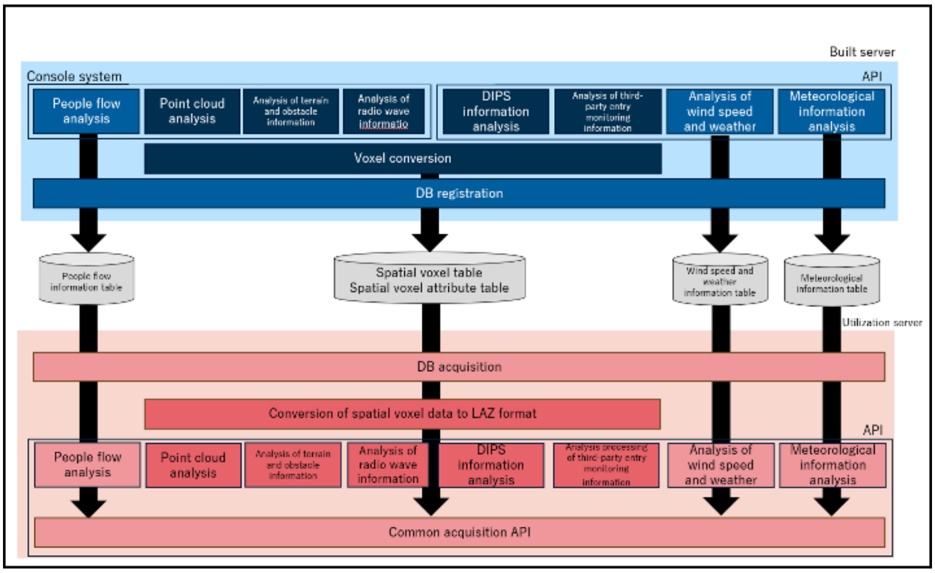


Figure 5-1-3 API architecture of a spatial digital twin

iii. <u>use case</u>

【River route】

show the results and significance in the verification and implementation of the drone route system.The result is the development of a 180 km drone route over the Tenryu River in Hamamatsu City, and the start of a delivery service for local logistics companies using the drone route system. The image of the route in the upper reaches of the Tenryu River is shown in Figure 5-1-4.

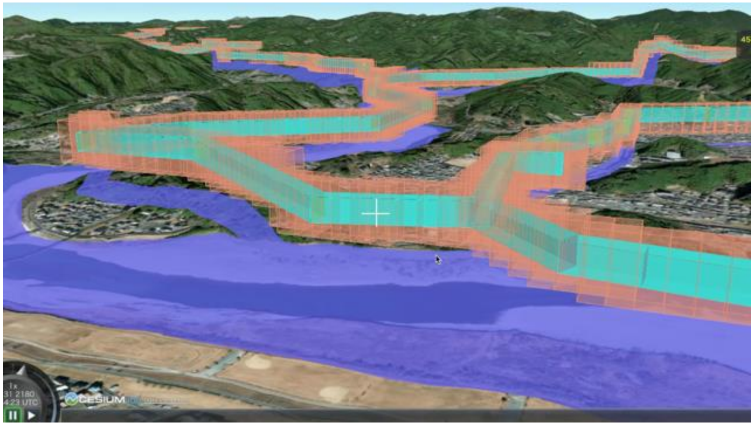


Figure 5-1-4 Drone route image

The significance is to contribute to the maintenance of local living infrastructure.
Local residents: "I'm happy that the medicine, which used to take several days for normal delivery, arrived in about 30 minutes."
Hamamatsu City Hall: "It can lead to the well-being of residents, such as improving the quality of life of the community and supporting isolated villages in the event of a disaster"
I received a comment. Figure 5-1-5 shows the state of handing out medicines at the clinic.


Figure 5-1-5 Giving medicines to local residents

The results and significance of research and development related to river patrol are presented.
The results include research on the realization of multi-purpose use of logistics and river patrols conducted river patrols using images taken by drones for logistics applications. By verifying the effectiveness of images taken by drones for logistics applications, we clarified the structures that could be handled, extracted them according to certain standards, and conducted quality verification of the extracted areas.

The significance is to contribute to the maintenance of river infrastructure. The Hamamatsu River National Highway Office of the Ministry of Land, Infrastructure, Transport and Tourism commented, "In addition to the lack of engineers for river patrol work, it takes time and effort, so I would be happy if we could improve operational efficiency." The image taken during the river patrol is shown in Fig. 5-1-6.


Figure 5-1-6 River patrol image

【Power Transmission Line Route】

Approximately 150 km of maintenance was completed over the power line in the Chichibu area, and service for infrastructure inspection purposes was started. We are continuing research to realize multi-purpose use in future infrastructure inspections and material transportation.
The image of the drone route over the power line is shown in Figure 5-1-7. It aims to contribute to the reduction of manpower in infrastructure inspections, realize work

efficiency, and develop drone routes over the nationwide power grid to achieve the social implementation of drone services such as patrols and inspections of infrastructure facilities and logistics

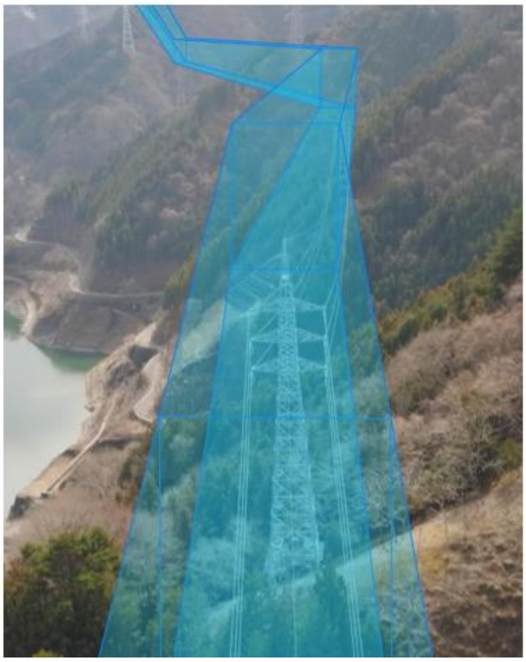


Figure 5-1-7 Transmission line route image (Source: GirdSkyWay)

iv. API Specifications and OSS

【API】

The API list of spatial digital twins is shown in Table 5-1-1.

Table 5-1-1 API List

API Type	function	API Name*
Registration API	Wind speed and weather information registration	wind
	Weather Information Registration	weather/now
	Weather Forecast Information Registration	weather/forecast
	Third-party access control information registration	area
	Register no-fly area information	flight_prohibited_area
	Drone route registration	drone_route
Get API	Get API	
	Acquisition of feature and obstacle information	ground_feature

		Acquisition of wind speed and weather information	wind
		Obtaining live weather information	weather_now
		Obtaining weather forecast information	weather_forecast
		Acquisition of radio wave information	radio_wave
		Acquisition of human flow information	average_population
		Obtaining information on no-fly areas	flight_prohibited_area
		Acquisition of third-party access control information	area

API Storage Location:https://github.com/ODS-IS-UASL/webapi-oas-UASL

*Since the acquisition API is common, specify the object type.

【OSS】

An overview of the OSS and functions of the spatial digital twin is shown in Table 5-1-2

Table 5-1-2 OSS and Function Overview

Library Name: Spatialid

OSS	use	Feature Overview
PROJ 9	Coordinate Transformation	a library for converting coordinate systems such as latitude–longitude and plane rectangular coordinate systems.
Bullet Physics SDK	Collision Determination	a physics simulation library, used as an auxiliary tool for collision detection of spatial voxels.
SQLite3	Spatial voxel preservation	a database system, used for storing spatial voxels

OSS storage Location:https://github.com/ODS-IS-UASL/airway-digitaltwin-db

5.2. Infrastructure Management DX (NTT DATA Corporation, NTT InfraNet Corporation, NTT EAST, Inc.,TEPCO Power Grid, Incorporated, TOKYO GAS NETWORK Co., Ltd.,EARTHBRAIN Ltd., SoftBank Corp.)

i. Demonstration Overview

We will unify the equipment and other data held by infrastructure management companies in the form of spatial IDs, and use cases for underground buried object inquiry, machine guidance, and disaster equipment information sharing using the infrastructure management DX system will be demonstrated and verified in Saitama City and Hachioji City, which are the pre-implementation areas. The outline of the demonstration is shown in Figure 5-2-1.

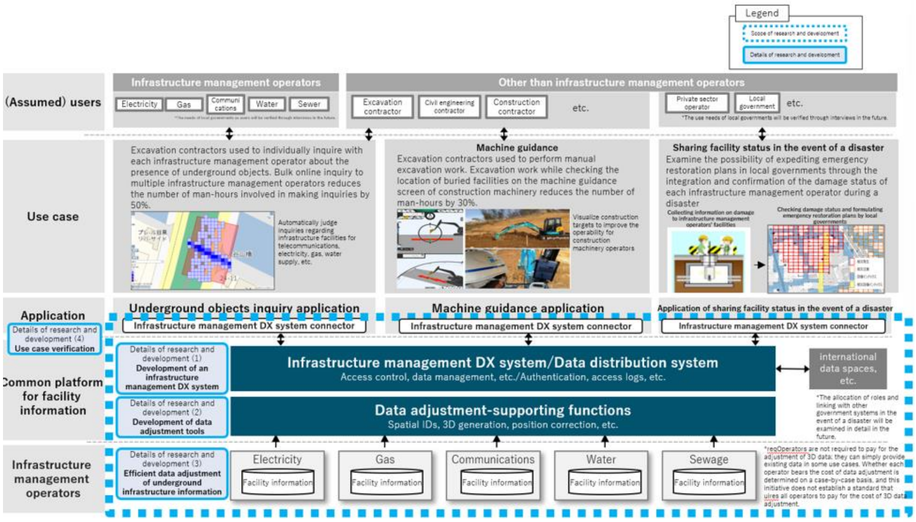


Figure 5-2-1 Demonstration outline

ii. Implementation Items

[Development of data maintenance tools]

Infrastructure management DX consists of a data development tool that converts information on underground buried facilities of infrastructure operators into spatial IDs, and an infrastructure management DX system that distributes spatial ID information to use cases that utilize underground buried objects.

The data maintenance tool converts underground buried equipment into a 3D city model, and the location where the underground buried equipment exists is expressed with a spatial ID. The spatial ID generation by the data maintenance tool and data conversion tool of the infrastructure management company is shown in Fig. 5-2-2, and the spatial ID representation of the underground buried facility is shown in Fig. 5-2-3.

Data maintenance tools contribute to the efficiency of the data maintenance process through common formatting in data maintenance. In the generation of spatial IDs, it contributes to the generation of spatial IDs based on GIS data (and the generation of 3D urban models as intermediate products).

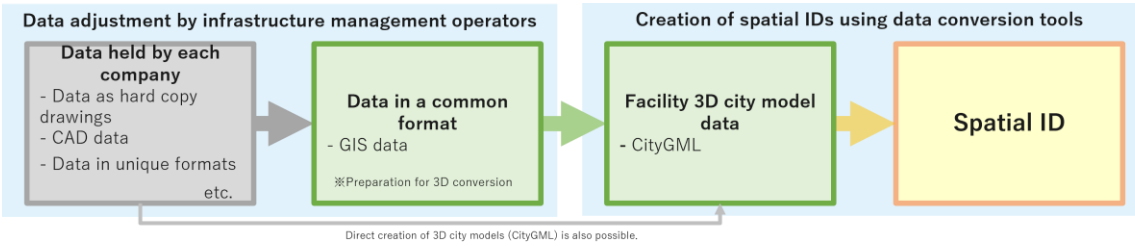


Fig. 5-2-2 Spatial ID generation using a data maintenance tool

Fig. 5-2-3 Spatial ID representation of underground buried equipment

[Development of infrastructure management DX system]

The location information of the existence of underground buried objects expressed as spatial IDs is managed by the infrastructure management DX system and distributed to use cases that utilize underground buried objects. Figure 5-2-4 shows the system configuration diagram of Infrastructure Management DX. The spatial ID is used in the red frame, (A)The spatial ID is used in the application in each of the use cases in (C) through the application linkage IF function in (B).

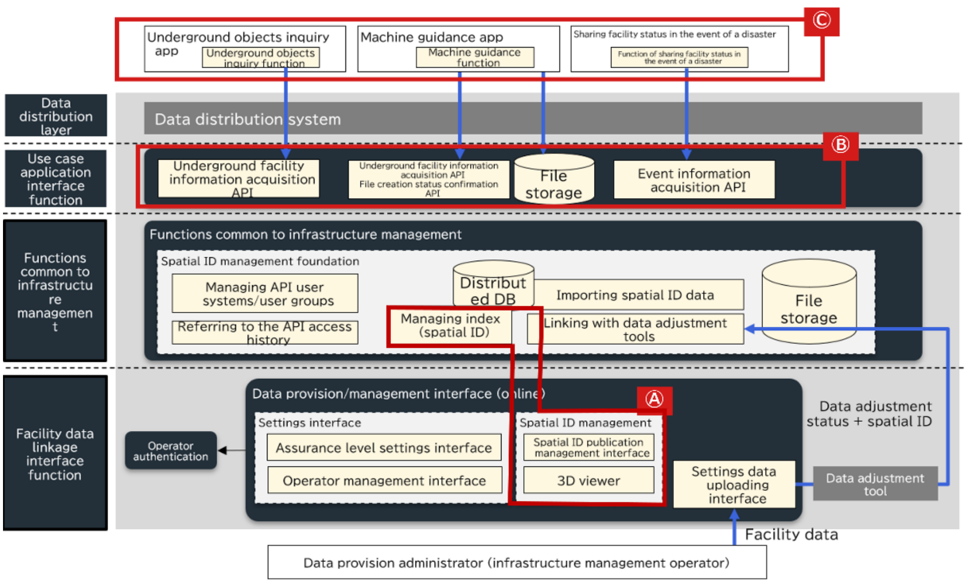


Figure 5-2-4 System configuration diagram

iii. <u>use case</u>

[Buried object inquiry]

For the existing buried object inquiry application, a function was implemented to obtain the spatial ID of the place where the underground burial object exists through the infrastructure management DX system and determine whether there is an underground buried object in the construction area. Compared to the current man-hours for inquiring about buried objects, it was confirmed that the application workload could be reduced by more than 50% and the reception workload by 20%. The buried object query method and buried object query application in the use case demonstration are shown in Figure 5-2-5.

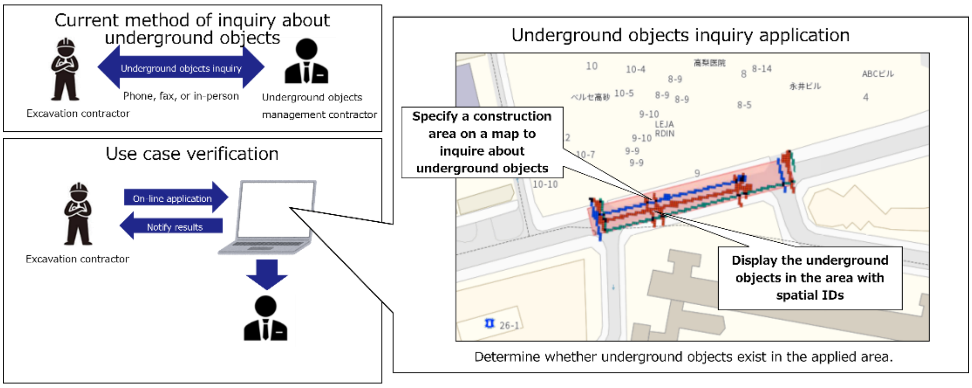


Fig. 5-2-5 Buried object inquiry method and buried object inquiry app

[Machine Guidance]

For the machine guidance application of construction machinery, a function was implemented to obtain the spatial ID of the place where the underground buried object exists through the infrastructure management DX system, and to issue an alert with voice and screen display when the spatial ID exists in the alert detection range of the excavation bucket.

The screen of the machine guidance app is shown in Figure 5-2-6.

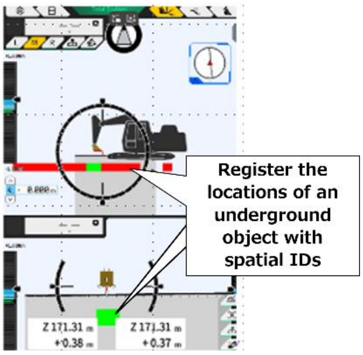


Figure 5-2-6 Machine Guidance App Screen

A conceptual diagram of alert issuance is shown in Figure 5-2-7. Alerts are issued if a space ID exists within 30 cm of the center of the drilling bucket.

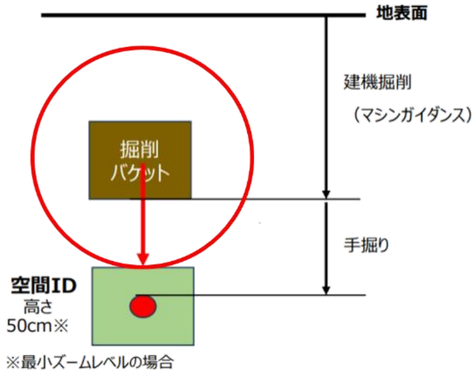


Figure 5-2-7 Conceptual diagram of alert issuance

A comparison of construction methods is shown in Fig. 5-2-8. Previously, it was necessary to have a worker who would call out to the operator near the excavation bucket of construction machinery, but the introduction of machine guidance has made it possible to reduce the number of workers. It was confirmed that the number of on-site workers can be reduced by 33%.

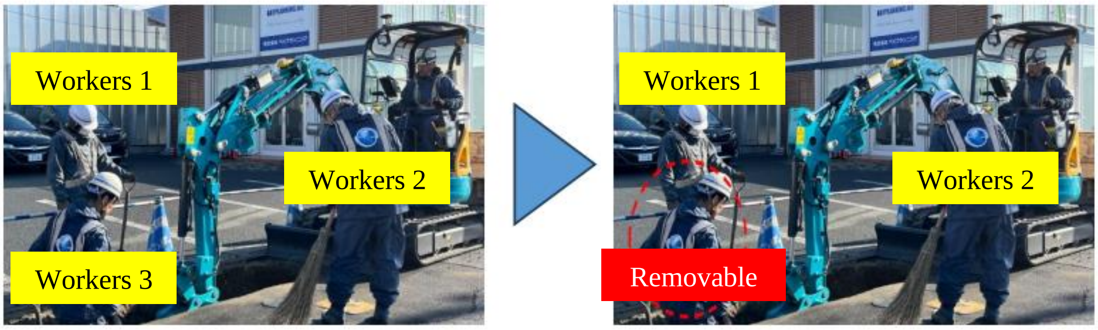


Fig. 5-2-8 Comparison of construction methods

[Disaster Information Sharing]

We interviewed local governments to see if it was possible to reduce the operation of staff by displaying the area where infrastructure services were suspended, the number of houses that were suspended from service, and the scheduled time for restoration in the disaster information sharing application. It was confirmed that sharing the status of infrastructure services with local government officials in the event of a disaster has a time-saving effect of about 35% in various activities during disasters.

Examples of areas where infrastructure services are stopped due to a disaster, indicated by spatial IDs, are shown in Figures 5-2-9 and 5-2-10. The yellow cells in Figure 5-2-9 and the gray cells in Figure 5-2-10 indicate the areas where infrastructure services have been suspended, respectively.

※地図情報を表示する「D-Resilio Viewer」の地図情報は、国土地理院が提供する地理院地図（国土地理院ウェブサイト地理院地図（地理院地図 / GSI Maps｜国土地理院（https://maps.gsi.go.jp/#13/36.263307/139.617434/&base=std&ls=std&disp=1&vs=c1g1j0h0k0l0u0t0z0r0s0m0f1&d=m）を加工して作成）を利用しています。地理院地図については、利用規約（https://maps.gsi.go.jp/help/termsofuse.html）を遵守するものとします。

Figure 5-2-9 Spatial ID display of infrastructure service outage areas -1

地図：©Mapbox, ©OpenStreetMap

Fig.5-2-10 Spatial ID display of infrastructure service outage areas -2

iv. <u>API Specifications and OSS</u>

【API】

The API specifications for infrastructure management DX are shown in Table 5-2-1. This specification defines each API in the use case application linkage IF function of the system configuration diagram in Figure 5-2-4.

Table 5-2-1 API Specifications

API Type	API Name
Buried Object Information Acquisition API	facility-information
Buried Object Information Acquisition Reception API	facility-output-task
File creation status check API	output-task
Event Information Retrieval API	event-information

API Storage Location:https://github.com/ODS-IS-IMDX/webapi-oas-IMDX

【OSS】

The storage location of the related repository of the Infrastructure Management DX Data Linkage Platform, as well as the function names and function overviews of the data maintenance tools, are shown in Table 5-2-2. Data development tools are used in the "common format data development" and "facility 3D city model data generation" in the data development and spatial ID generation process by infrastructure management companies in Fig. 5-2-2

Table 5-2-2 Data Maintenance Tool Function Names and Function Overview

Repository name: data-adjust-tool

Feature Name	Feature Overview
Extracting equipment from drawings	Analyze drawing data and convert underground buried information into shapefiles
Equipment extraction from CAD	Analyze CAD data and generate GIS data for underground structures
Position Correction Tool	Applies high-precision position correction based on GIS data
3D City Model Conversion	Generate 3D urban models of underground buried objects (PLATEAU compliant) based on GIS data
Spatial ID Conversion	Convert 3D city models to spatial ID formats
Image processing capabilities	Analyze drawings and image data to extract information on underground buried objects

OSS storage Location:https://github.com/ODS-IS-IMDX

5.3. Autonomous Driving Service Support Roads (Dynamic Map Platform Co., Ltd., BIPROGY Inc.,NEXT Logistics Japan, Ltd., Yamato Transport Co., Ltd.)

i. Position of this demonstration

The autonomous driving service support path aims to solve various issues related to autonomous driving and promote the use of autonomous driving technology in human flow and logistics services. The services that the autonomous driving service support road aims to realize are shown in Figure 5-3-1. In the "Development of a Data Linkage System for Autonomous Driving Operation", which is one of the contents of this demonstration, we developed a vehicle information linkage system to integrate quasi-static, quasi-dynamic, and dynamic information such as traffic information and weather information using spatial IDs, and to distribute them with low latency in relation to 3D map data. Among the contents of this implementation, we developed and demonstrated a system (vehicle information linkage system) that supports the safe driving of autonomous vehicles by associating 3D map data with various information provided by existing traffic information providers, roadside infrastructure, vehicles, etc., and distributing it with low latency as high-precision, lane-by-lane, and legible integrated information. This chapter shows the use case of spatial ID in this demonstration.

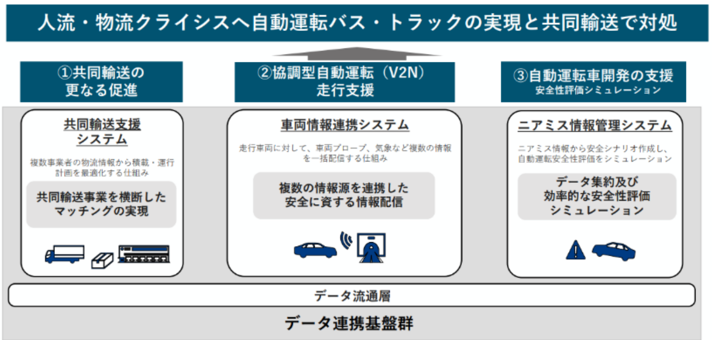


Figure 5-3-1 Services to be realized

ii. <u>Demonstration Overview</u>

By efficiently searching, integrating information, and distributing information in batches using spatial IDs, we have built a system that integrates and provides information with different retention characteristics (links, coordinates, meshes, etc.) and information with different temporal characteristics for the purpose of reducing the processing of user systems.

Specifically, weather information (mesh information) held by spatial ID and traffic information held by road links are integrated, and information is integrated and provided in units of spatial ID upon request. The system configuration is shown in Figure 5-3-2.

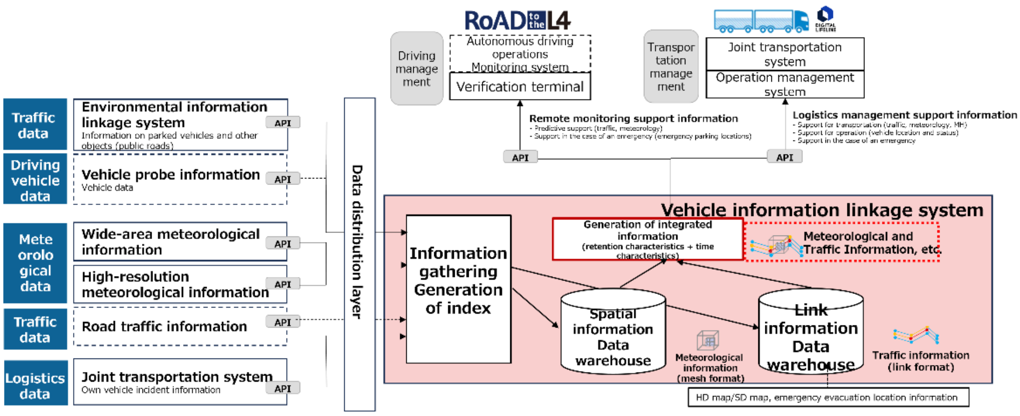


Figure 5-3-2 System configuration

iii. <u>use case</u>

Information was distributed according to the driving position of the autonomous driving vehicle, demonstrating the smooth and safe driving support of the autonomous driving vehicle.

We have established an efficient information retrieval, information integration, and batch distribution mechanism using spatial IDs, and confirmed that it is possible to obtain heterogeneous information in bulk and reduce processing in the user system. In addition, we examined the expansion of information to be collected and distributed, and the ideal way of information integration and distribution, and confirmed that it is necessary to shorten the processing time when expanding information, and to consider distribution methods according to the needs of the client side for distribution. Vehicle information linkage using spatial ID is shown in Figure 5-3-3. The explanation in the red frame is as follows.

A) Spatial Information Distribution of External Data Sources with Spatial Identifiers as Query Parameters.
B) Integrated multi-information distribution at once
C) Registration and collection of various external data used for driving support

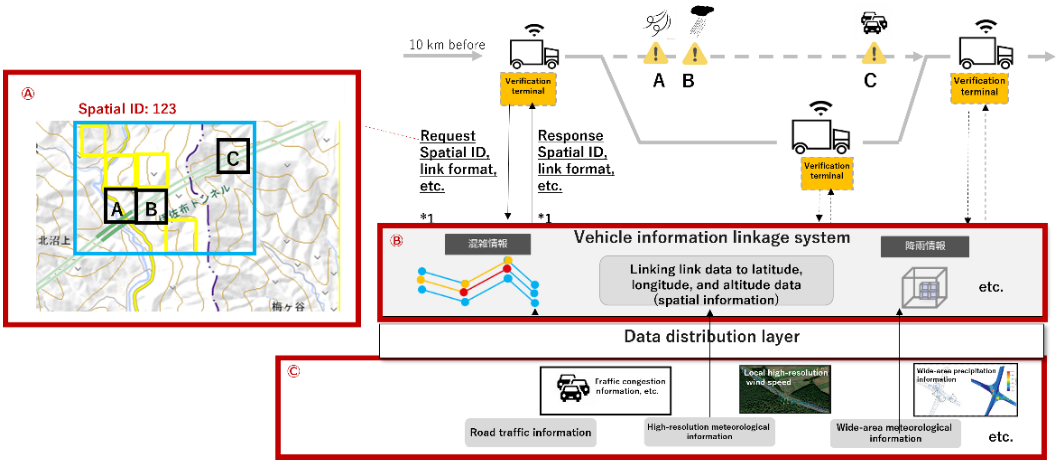


Figure 5-3-3 Vehicle information linkage using spatial ID

iv. API Specifications and OSS

【API】

The API specifications for the autonomous driving service support road are shown in Table 5-3-1. This API applies to the remote monitoring support information and logistics management support information of the system configuration in Figure 5-3-2.

Table 5-3-1 API Specifications

API Types	API Name
Dynamic Information Retrieval API	dynamicInfo
Quasi-dynamic information retrieval API	semiDynamicInfo

API Storage Location: https://github.com/ODS-IS-CAVC/webapi-oas-CAVC

【OSS】

The storage location of the related repository of the autonomous driving support road data linkage platform, as well as the function name and function summary of the integrated information generation tool, are shown in Table 5-3-2.

Table 5-3-2 Integrated Information Generation Tool Function Names and Function Overview

Repository Name: vehicle-information-integration-system

Feature Name	Feature Overview

Integrated Information Generation	Aggregate and integrate the generated information based on the index and provide it to external systems
Data Transformation Libraries	General ⇔ Libraries for Spatial ID and Coordinate Conversion.

OSS storage Location:https://github.com/ODS-IS-CAVC/