Platform Development for Drone Utilization in the Architectural Field

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Abstract. *The utilization of drones is expected to streamline the process of building inspection in Japan; however, no known drone utilization platform exists in the region's architectural sector. Therefore, in this study we pioneered the development of a drone platform based on an industry–government–academia collaboration within Japan's architectural field. We first investigated drone-related trends, such as a utilization roadmap, flight rules, the drone market, new technologies and issues relating to the architecture field. Subsequently, we worked on solutions for drone utilization in the building sector, including methods for building inspection, determination of drone-flight risk factors relative to building inspection and the creation of a drone safety operation manual. Through field tests, we validated the effectiveness of the drone platform in building inspection, i.e., the determination of a cost–time relation during inspection, the merits of applying a high-resolution camera for inspection, the possibility of utilizing an infrared camera for exfoliation detection in exterior wall tiles and the development and efficiency of a built-in automatic inspection system. Furthermore, trial tests were conducted for the application of a drone-inspection system in disaster areas and a micro-drone in small building spaces. The findings of this study confirmed that the new drone platform achieved inspection- and disaster-related objectives within the architectural sector.*

Keywords: *Drone, Industrial Advances, Building Inspection, Risk Assessment, Field Test.*

1 Introduction

In Japan, the total number of pre-1980 housing stocks exceeds 13.69 million and is increasing every year. To ensure longevity, the assessment of buildings and their required maintenance has become an urgent issue. As such, efficient regular inspections are required as an important component of building maintenance. For example, periodic inspection reports according to Article 12 of the Building Standards Law are required for building health diagnosis. For the exterior wall inspection of buildings, a manual hammering test is required, especially for buildings that are more 10 years old. However, this test requires the setting up of temporary scaffolding for areas that cannot be reached by the investigator, making it costly for the building owner. There is an urgent need to develop a rational inspection method. In meeting this requirement, the use of drones is expected to play a significant role. An inspection technology for the maintenance of such buildings, the various potential uses of drones are being explored.

In 2016, the authors began research on (i) building inspection technology using drones and (ii) the construction of drone platforms. In the academic field, the Architectural Institute of Japan (AIJ) established a committee relating to the use drones and held the Architectural Drone Symposium to establish the current state of the art in drone usage. In the industrial field, the Japan Architectural Drone Association (JADA) was established in 2017 to address human resource development, technical support and standardization relating to the safe use of

drones. JADA has organized workshops and committees covering the safe operation of drones. In general, the use of drones in industry, government, and academia is gradually increasing.

Based on the above background, we herein report on (i) drone-related trends and levels of technology in the architectural field, (ii) demonstration experiments related to drone inspections and (iii) future prospects for drone usage.

2 Trends in the Use of Drones in the Architectural Field

2.1 Drone Technology Trends in Japan

As seen for Japan during 2018 (Figure 1), the use of drone services in sectors such as agriculture, surveying, aerial photography, inspection, crime prevention and logistics is expanding. Furthermore, by 2024 the infrastructure inspection sector is expected to outpace the agricultural sector. Figure 2 shows the roadmap for the utilization of drones according to the flight levels reported by the Ministry of Economy, Trade and Industry (METI). Level 1 corresponds to surveys such as those of a detached roof. Level 2 corresponds to a large area roof inspection or wall inspection. Level 4 is expected to be used for (i) the inspection of skyscrapers that are assumed to be non-visual flight in the 2022, (ii) logistics and security in cities and (iii) disaster-related issues. Therefore, in the architectural field, it is necessary to create a social infrastructure that assumes the use of drones in population-intensive areas. Table 1 shows the uses of drones in the architectural field. From all the papers submitted up to 2018, the importance of drone use follows the order: inspection, disaster, city/region, construction, environmental measurement, transportation and cultural heritage.

In particular, the use of drones for inspection is increasing, particularly in relation to the inspection of the outer walls of high-rise buildings, which would otherwise require scaffolding. These building inspection surveys are generally classified into primary to tertiary surveys according to the level of inspection, as shown in Table 2. Currently, primary and secondary surveys of a non-contact type are used for building inspection.

2.2 Drone Technology Development and Dissemination Efforts in the Architectural Academic Field

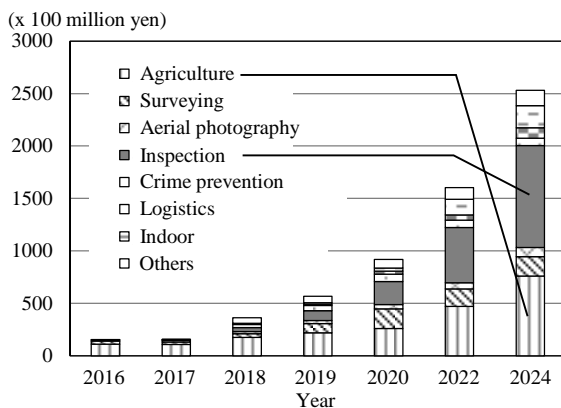In April 2016, "WG on Application Guide of UAV to Building Performance Survey"

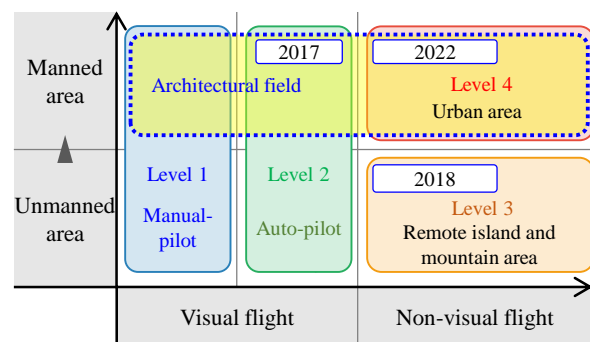**Figure 1**. Drone service market in Japan.

Figure 2. Utilization in architectural field at different flight levels.

(currently, Sub-committee for utilization of drone technology; Chairperson: H. Miyauchi) was established in the Durability and Maintenance Steering Committee, AIJ. The main foci of this WG were (i) the use of drones for the survey of building exterior walls, (ii) the collection of technical information, (iii) field trials and (iv) the examination of data collection and analysis methods. In May 2017, the first Architectural Drone Symposium was held with the aim of highlighting the advantages of drone technology across the entire architectural field. In 2019, a third symposium provided the latest information on the use of drones, covering regular use through to their use in disaster situations.

2.3 Challenges and Initiatives for the Utilization of Drones in the Construction Industry

The challenges facing the use of drones in the architectural field can be divided into (i) the damage caused by drone collisions and (ii) human issues. Regarding (i), Figure 3 shows the number of accidents caused by drones, based on information provided to Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Compared with the 45 accidents for which no application for flight was required by the MLIT, 96 accidents (i.e., more than double) did require an application for flight. In particular, there are many population-intensive areas assumed during surveys of buildings and accidents when flying less than 30 m, and so sufficient safety measures are required when using drones in urban and architectural areas. Regarding (ii), there is a risk that video taken by drones may infringe privacy, as related to the

Table 1. Research topics with keyword "Drone and UAV" in AIJ annual paper.

Uses of drones in the architectural field	Year						Total
	2012		2015	2016	2017	2018	
Inspection	0		0	3	6	11	20
Disaster	0		0	0	3	3	6
City/Region	0		3	0	1	0	4
Construction	0		0	1	1	1	3
Environmental measurement	0		0	0	3	0	3
Transportation	0		0	0	1	1	2
Cultural heritage	1		0	0	0	0	1
Total	1		3	4	15	16	39

Table 2. Technical levels for drone use in building inspection.

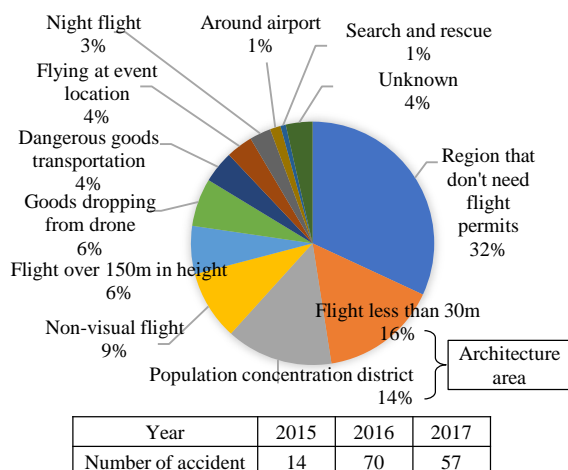| Inspection level	Inspection contents
Primary	Non-contact: Comprehensive inspection (Camera)
Secondary	Non-contact: Detailed inspection (High resolution camera, Infrared camera etc.)
	Proximity, Contact investigation (Hammering test etc.)
Tertiary	Contact investigation (Hole drilling etc.)

Year	2015	2016	2017
Number of accident	14	70	57

Figure 3. Number of accidents caused by drones (as of December 8, 2017).

<Technical section>
Chapter 1: Basic drone utilization in the architectural field
Chapter 2: Architectural knowledge relating to use of drone
Chapter 3: Drone technology and safe operation
<Practical section>
Chapter 4: Construction management using drone
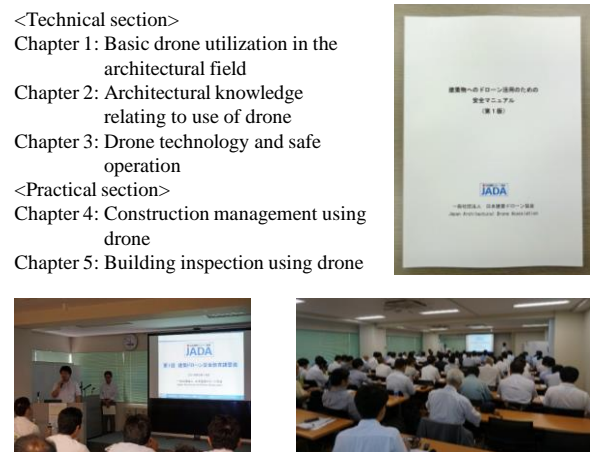Chapter 5: Building inspection using drone

Figure 4. Safety Manual for Drone Utilization in Buildings and safety education workshop.

Personal Information Protection Law. There are also problems relating to noise during drone flight; therefore, it is necessary to give sufficient consideration to residents.

Against this background, JADA was established in September 2017 to develop human resources that can utilize drone technology across various applications in the architectural field. JADA also provides technical support and standardization. Activities were commenced with the aim of contributing to the realization of a safe, secure and sustainable society when conducting business. In particular, we are strengthening efforts relating to the safe operation of drones for building inspections. For example, as shown in Figure 4, the "Safety Manual for Drone Utilization in Buildings" was created, explaining basic knowledge relating to (i) drone utilization, (ii) drone technology and safe operation and (iii) construction management and inspection surveys for buildings. In addition, this manual is used in the "Building Drone Safety Education Workshop" to ensure thorough safety education.

3 Evaluation of Building Inspection using Drones

3.1 Effects of Cost and Time during Drone Inspection Surveys

Judgment criteria that show the superiority of drone usage over existing building inspections include (i) cost and time requirements from inspection to analysis and (ii) whether or not the level can be inspected under the same conditions as it can from the ground. From the above, using a six-story experimental wooden house at the Building Research Institute (BRI), the

(1) Inspection using a high work vehicle   (2) Inspection using ground photography   (3) Inspection using drone photography

Figure 5. Inspection methods.

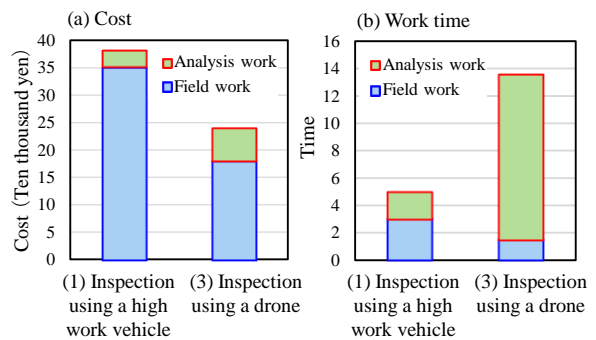**Table 3**. Visualization of buildings by drone.

Figure 6. Comparison of cost and time requirements for high level manual inspection and drone photography inspection.

advantages of using a drone for building inspection were evaluated by comparison with a conventional inspection, as shown in Figure 5. Table 3 shows the results of comparing (2) ground photography and (3) drone photography. If a drone can secure a safe flight distance from a target object, it can photograph to the same accuracy as a visual inspection from the ground. For example, because the image size and image quality of the object can be kept constant during photographing by the drone, it is easy to subsequently analyze the image.

Figure 6 shows the results of comparing the cost and time requirements between (1) inspection using a high work vehicle and (3) inspection using a drone. Inspection by drone photography can be implemented at a lower price than that for a high work vehicle. On the other hand, the cost and time of image processing of drone images is higher; in particular, the analysis work is time consuming. These finding indicate the potential efficiency of on-site drone inspections but also suggest that image processing needs to be simplified and incorporate automated processing techniques.

3.2 Assessment of the Use of a High Resolution Camera

One of the important criteria that can be applied to building inspections is inspection accuracy in relation to specified requirements. Therefore, using a general-purpose 20-million pixel camera and a 100-million pixel camera (upper limit of resolution), we conducted a drone photographing experiment to evaluate the building inspection accuracy. Table 4 shows the performance values of the cameras used in the study. Figure 7 shows the visibility results of both cameras when a crack scale is attached to the outer wall and the drone flight shown in Figure 8 is taken. At a photographing distance of 5 m, it is difficult to see a 1.5-mm wide crack when using the 20-million pixel camera. However, at 100 million pixels, visual confirmation is possible down to a crack width of about 0.25 mm.

3.3 Assessment of the Applicability of using an Infrared Camera

When tiles are used for the exterior of a building, there is a risk of them peeling off due to a loss of adhesion between the base and the tiles. As an investigation method for this peeling, an expected inspection method is the use of a drone-mounted infrared ray camera. A demonstration experiment of this approach was conducted by MLIT in 2017–2018. At BRI,

Table 4. Specifications to satisfy 1-mm/pixel resolution

Performance	100-million pixel camera	20-million pixel camera
Distance	32.6 m	13.7 m
Photography area (H x W)	8.7 m x 11.6 m	5.3 m x 4.0 m
Viewing angle	15.2^{o}	16.4^{o}

Original image of crack scale scanned by scanner

100-million pixel camera (Photographing distance:5m)

20-million pixel camera (Photographing distance:5m)

Figure 8. Images from different resolution cameras.

Figure 7. Inspection test by drone.

the test specimens included defect part between substrate and tile with 1m wide x 1m high were made as parameters with defect area and peeling depth. As shown in Figure 9, these specimens were placed on the roof of the building and aerial photographs were taken using two types of infrared camera mounted on a drone. An example of the detection of the defective part of a tiled specimen, as shown in the infrared image, is shown in Figure 10. When environmental conditions, such as solar radiation and temperature, and the performance of the applied infrared camera were appropriate, the detection rate of tile peeling was high. However, it was found that it is important to define the application range when using a drone-mounted infrared camera because the peeling conditions and photographic environment may differ in an actual building.

3.4 Development of Automatic Inspection and a Building Inspection System

Although drones are generally controlled by GPS, it is difficult to capture GPS signals in areas where buildings are densely packed, increasing the risk of crashing and potentially decreasing building inspection accuracy. In this study, we used SLAM (Simultaneous Localization and Mapping), as shown in Figure 11, which estimates the position of the camera based on the image information of the camera (i.e., independent of GPS signal). Figure 12 shows the results of a demonstration experiment of automatic drone inspection using an
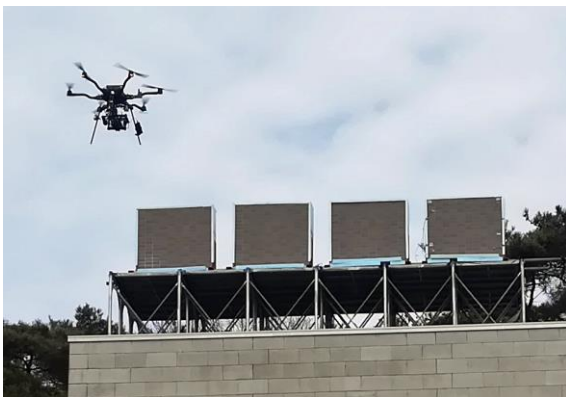

Figure 9. Inspection of tiled specimens using drone.

・External temperature: 11.4 ^{o}C
・Drone model: ALTA
・Onboard infrared camera: FLIR A65 (Number of display pixels: 640H x 512V)
・Photography distance: 5m, Flight altitude: 11m

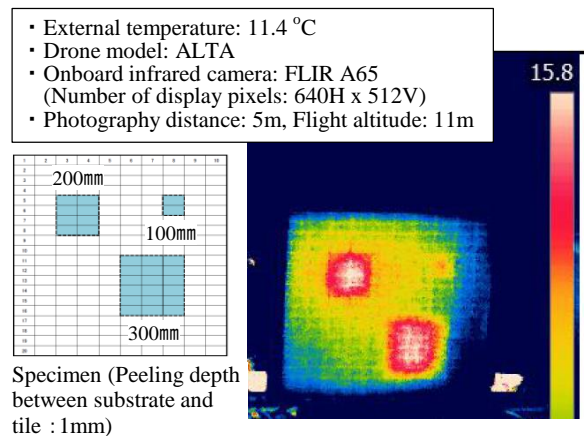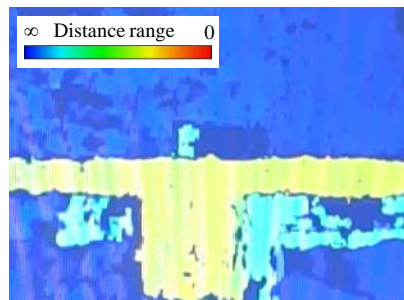Specimen (Peeling depth between substrate and tile : 1mm)

Figure 10. Inspection of defective parts of tile specimens by drone-mounted infrared camera.

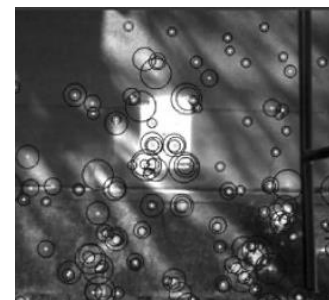Monocular camera (Estimation of altitude and horizontal position)

Twin-lens stereo camera (Horizontal distance control)

Figure 11. Visual SLAM type drone.

Color information to maintain a distance from the drone

Self-position estimation of horizontal direction by monocular camera

Figure 12. Test results for drone with Visual SLAM technology.

experimental building. The left of Figure 12 shows the use of a stereo camera to identify distance based on color information while maintaining a distance of 3 m from the drone. Furthermore, a downward camera was able to estimate self-position in the horizontal direction of the drone flight based on characteristic points on the asphalt pavement surface, as shown on the right of Figure 12.

3.5 Use for Data Recording and Analysis

It is important to record and measure building deterioration information on a regular basis. This information then needs to be stored and later used for building maintenance as required. Therefore, in Figure 13 we show an example of recording and storing deterioration information relating to a waterproof membrane sheet on the building roof. The resolution of the image was set to 1.2 mm/pixel and the altitude was set to 38 m from the roof. The entire roof surface was photographed during an automatic flight and a series of deterioration conditions for the roof were acquired. As shown in Figure 14 (m units), the flow of drainage on the waterproof sheet and the roof area could be measured. In cm units, the situation around the drain was able to confirm, in mm units, the crack and repair status of the waterproofing sheet. Therefore, it is possible to simultaneously record these states of degradation using a drone and archive them for use in future repairs.

3.6 New Methods for Building Inspection

Many natural disasters such as earthquakes, typhoons and floods occur in Japan and it is expected that drones will be used following such events to assess damage. A demonstration experiment using a drone was conducted on a three-story building damaged by the earthquake in Kumamoto Prefecture in 2016. The flow of the experiment is shown in Figure 15. Initially, the drone operator takes a picture of the building near the crack. The investigator wears VR goggles at a position away from the building and verifies whether the image information taken by the drone can be determined by extracting cracks that the investigator wants to confirm. Based on this assessment, it is considered possible to investigate damaged buildings via drone by remote control.
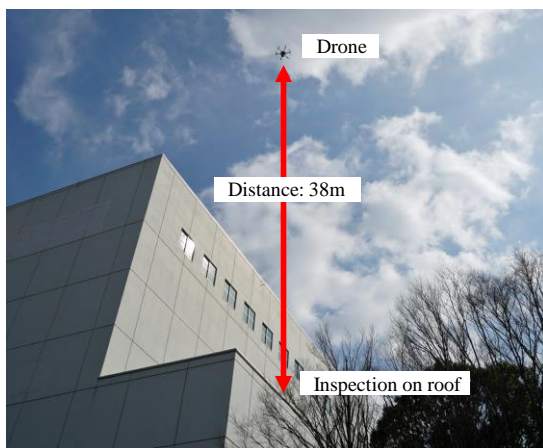

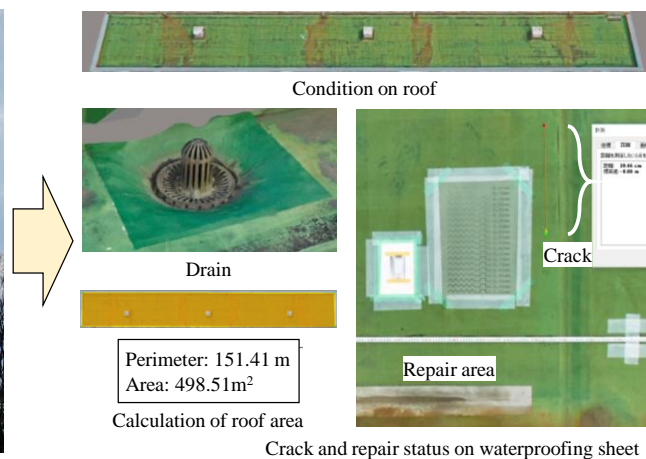**Figure 13**. Flight test for checking degradation condition using drone.

Figure 14. 3D model of degradation information (100-million pixels).

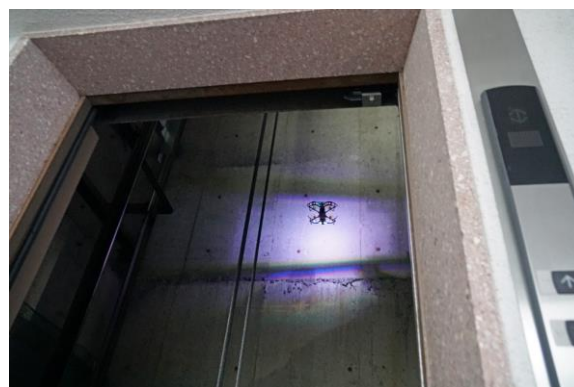**Figure 15**. Remote investigation by drone in damaged building.

Figure 16. Drone inspection in confined space (elevator shaft).

Many external spaces related to buildings can be assessed using drones; however, drones are also highly usable in narrow spaces where human access is difficult, *e.g.*, behind ceilings and under floors. Therefore, in this study, we investigated the inner wall of an elevator shaft using a micro drone with a non-GPS control function that weighs less than 200 g, as shown in Figure 16. It was found that this approach can be used for inspection even in dark and confined spaces.

4 Conclusions

In this study, we investigated drone use trends in industry–government–academia for application to the architectural field. In addition, drone flight safety, cost reduction and labor-saving, inspection accuracy, application to archiving, and inspection automation were evaluated by field tests. Overall, the effectiveness of drone utilization was demonstrated. In addition to building inspection, drone technology is expected to be used across a wide range of fields, including disaster surveys, architectural education, information systems, facilities, design, urban planning, environmental engineering, architectural history, crime prevention and so on. It will be possible to create a new construction drone platform by strengthening the connected industries that link drones with various technologies (AI, AR, the cloud, etc.). For this purpose, it is very important to work with related parties so that the technology can effectively contribute to society.

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References

Impress (2018). Drone Business Survey Report 2018. Japan.

Japan Architectural Drone Association (2018). Safety Manual for Drone Utilization in Buildings. Japan.

Ministry of Economy, Trade and Industry (2017). Roadmap for utilization of the drone according to the flight level. Japan.

Ministry of Internal Affairs and Communications (2013). Housing and Land Survey. Japan.

Ministry of Land, Infrastructure, Transport and Tourism (2017-2018). Building standard maintenance promotion project T3. Japan.

Ishida, T. and Miyauchi, H. (2018). Verification of building inspection technology utilizing autopilot UAV by Visual SLAM: *Summaries of technical papers of annual meeting, Architectural Institute of Japan*. 561-562.