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Establishment of spraying repair technology for concrete structures using drone

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ABSTRACT In recent years, infrastructure deterioration is remarkable in Japan. Measures against the deterioration of the infrastructure are serious issues. Inspection and management of bridges, tunnels, etc. are carried out periodically by management organizations. This work is often done at high altitudes. In addition, there are lack of personnel involved in checks and work. In recent years, it is expected that utilization of universal availability unmanned aerial vehicles (drone) is possible. In this research, we proposed spraying repair materials to concrete structures using drone. Specifically, repair materials were sprayed on wall structures and tunnels using drone. As a result, it turned out that it is difficult to make the drones fly stably. It also turned out that repaired material sprayed was "unevenness". Therefore, we devised further measures for stable flight. We report the experimental results with the signature of 2D sensor and LED which measures the distance between the drone and the structure by the equipment installed in the drone and the possibility of the application.

1 CURRENT SITUATION AND PROBLEMS IN MAINTENANCE MANAGEMENT IN JAPAN

In Japan, the infrastructure structures have been in use for a long time, and aging is progressing. In figure 1 shows the social problems of infrastructures. In 2025, it is expected that social infrastructures exceeding 50 years after construction will account for about half of the total structures. Recently, in these structures, the accidents that threaten human lives are also frequent due to the collapse of structures in the world. In the Japanese government and local governments, it is urgent to maintain and manage infrastructure. On the other hand, in Japan, the phenomenon that the number of children is decreasing and the number of oldest people increases is occurring. The young work people under the age of 29 is 19% of the total in Japan. In the construction industry, this proportion is remarkably low at 11%, which is a serious problem. Under these circumstances, a method that can reduce the maintenance cost while solving the talent shortage as much as possible is desired. Meanwhile, the Ministry of Land, Infrastructure, Transport and Tourism has proposed "Productivity Improvement on Construction Site (i-Construction)" from the FY 2016. As one method, it is indispensable to improve productivity using unmanned aerial vehicles (hereinafter referred to as drone). Utilization of drone in the construction industry is included as a measure to reflect aerial surveying technology as ICT. Specifically, photographs taken consecutively are converted into a three-dimensional model and used for surveying before and after construction. Research for deployment to inspection work is under way.

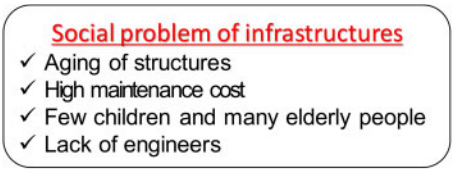

Figure 1. Social problem of infrastructures.

In this project, we further developed and examined repair by drone. Repair work often involves dangerous work at high altitude, and costly to set up provisional equipment, etc. Establishment of repair technology using drone is expected to be beneficial for ensuring lack of personnel and safety and further cost reduction.

2 DEVELOPMENT OF REPAIR TECHNIQUE BY DRONE

For the development of the drone for spraying repair material, we decided to improve the commercial drone.

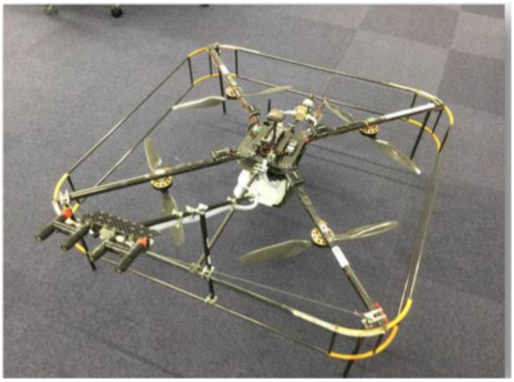

Figure 2. Repairing drone.

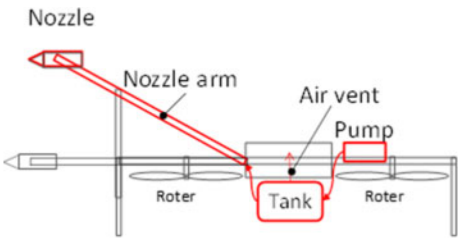

Figure 3. Repairing drone system.

As shown in Fig. 2 and Fig. 3, a pump unit, shown in Fig. 4, is mounted so that a repair agent can be sprayed on a drone for bridge inspection and repairing. The specifications of the drone are shown in Table 1. Here in drone, it becomes a big problem on the weight. Originally it is desirable to be able to freely fly with a pump unit, repair agent tank and battery installed. However, there was a fear that it would be impossible to fly if all the equipment was mounted on the drone. Therefore, in consideration of the loading weight to the drone, in this research, we decided to install the repair material and place the battery on the ground. This will result in a flight from the ground by wire, but when lowering the repair agent tank to the ground, it is necessary to carry the repair agent to the drone with great pressure, which is not easy. With this in mind, we put the battery on the ground.

It is basically desirable to be capable of automatic flight by GPS on the regarding flight. However, in this assumption, the tunnel and the lower surface of the bridge are also supposed to be necessary for repairing. Furthermore, in order to prevent collisions with structures, a general drone also has the function of keeping the airframe away from the structure by the action of the GPS when approaching the structure. Originally it is difficult to spray the repair agent unless it approaches the structure to a certain distance. Therefore, this time, we aimed to fly in non-GNSS environment. Since it aimed at non-GNSS environment, it became a very difficult condition regarding flight. We installed a barometric pressure sensor for

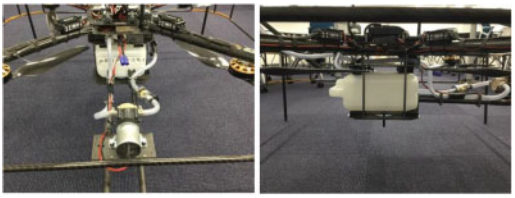

Figure 4. Tank for repairing material.

altitude management and adjusted to keep flight altitude constant. However, taking into consideration the influence of the wind etc. in the horizontal direction, the flight depended on the skill of the pilot.

For spraying system in Fig. 5, we installed a nozzle on the airframe and injected repairing agent by pumping it. For selection of the nozzle, it was adjusted by being able to discharge with mist and direct water flow.

Table 2 shows the development history of repair drone. We have made various studies from the concept, and have reached the present. Fig. 6 are shown for first applying tunnel. Fig. 7 shows applying experimental wall in June. 2016. And Fig. 8 shown the experiment with repairing material on real tunnel structure. Based on the developed prototype, we are conducting tests using tunnels and simulated wall structures, as shown in the photo to date. In addition, spraying experiments in the wall and ceiling directions were also conducted. Currently, further improvements are added to the problems described below, and we are developing a second prototype equipped with a battery.

3 THE PROBLEM OF SPRAYING DRONE AND ITS APPROACH

3.1 *Construction quality problem (countermeasures against spraying unevenness)*

Drone is flying with lift by generating airflow by propeller. Therefore, when the repairing agent is sprayed in the form of mist, the repairing material sprayed in the form of mist is rolled up, and the repairing material is blown (rebound) on the machine body. For that reason, it is necessary to make the injection from the nozzle a direct water flow. However, in this method (direct water flow type), spraying unevenness occurs and it is difficult to uniformly spray repairing material on the surface of structures.

Also, in order to spray in a plane, it is necessary to spray repair agents more than designed.

Therefore, as a countermeasure to prevent spray unevenness, the nozzle was improved. The first improvement is the interlocking of the nozzle and the fuselage. As shown in Fig. 9, when moving forward and backward of the airframe, the nozzle was devised so as to be linked with the expected movement so that the direction of the nozzle was constant. Until now, it was necessary to adjust the nozzle every time the distance between the wall and the airframe was adjusted. However, by imparting this interlocking property, it

Table 1. The specification of Spraying Drone.

[Drone]		[Nozzle part]	
*kind of drone	Quad type	*Discharge volume	1.6 liters/mins at 4 nozzles
*Name	ZionPG700		1.2 liters/mins at 2 nozzles
*Products	enRoute	*Weight	approx.. 1.0 kg
*Total Weight	4 kg (Drone 3.5 kg)	*Tank capacity	2 kg
*Size	987.85 mm*987.85 mm* (H)500 mm	*Distance nozzle and machine: 300–350 mm	
*Rotor diameter	ϕ 457.2 mm	*Select from 1 to 4 nozzles	
*Fright time	30 mins (max 45 mins)	*Tilt function	
*Attitude stabilization control	Barometric pressure detection method	*Nozzle up/down operation function	
*Power supply method	Wired power supply 350W * 2 units	[Others]	
[Pump units]		*Devices Drip shield	
*Machine mounted type		*Compact digital video camera is mounted	
*DC24V		*Video transmission device and monitor	

Figure 5. Spraying system.

Table 2. Developing history of repairing Drone.

Period	Purpose	Remarks
Aug. 2015	Spray drone project started	
Nov. 2015	Prototype No. 1 compited	
Dec. 2015	Flight experiment	Tunnel in Kanagawa pref.
June. 2016	Dedicated experiment site construction (wall) Flight experiment for wall	Wall in Saitama pref.
Aug. 2016	Presented at the National Convention of the Japan Society of Civil Engineers	
Nov. 2016	Mounted with 2D sensor	
Mar. 2017	Implement spraying as construction	Tunnel in Fukushima Robot Special Zone
Mar. 2017	Prototype No. 2 completed	

has become possible to always inject perpendicularly to the wall.

The second is imparting nozzle mobility. As a result, Fig. 10 shows the injection angle from the nozzle can be freely set, fine spraying becomes possible and spraying unevenness is reduced. Finally, we made the Nozzle systems in Fig. 11.

3.2 *Damage to the aircraft due to rebound*

As mentioned above, there was a case that flight ability was impaired by rebounding repair material blown on the drone fuselage. Particularly in the case of spraying on the top surface, rebound to the propeller occurred, and there were many cases that the flight became difficult. Therefore, although it is the place where you want to completely shield the aircraft, it is not possible to shield including the propeller on the mechanism of the drone.

In Fig. 12, as a countermeasure to that, first, in the main body of the aircraft, protection by a drip-proof shield was carried out. However, barometric pressure sensors and motor parts cannot be shielded. Therefore, searching for a sensor to replace the barometric pressure sensor used for maintaining altitude is necessary. We are also studying the possibility of mounting underwater motors. Furthermore, we are considering a flexible guard frame that can be recovered even if the aircraft touches a structure by any chance.

3.3 *Maneuverability in non-GNSS environment—toward stable flight*

Drone (Fig. 13) will be able to autonomously fly by using positioning technology by GNSS. However, as

Figure 6. Experiment for tunnel.

Figure 7. Experiment for wall.

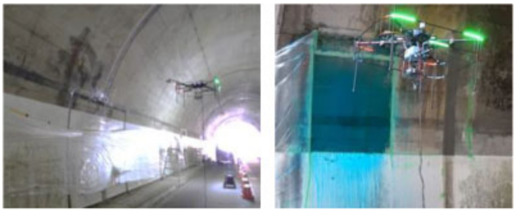

Figure 8. Experiment for tunnel with repairing liquids.

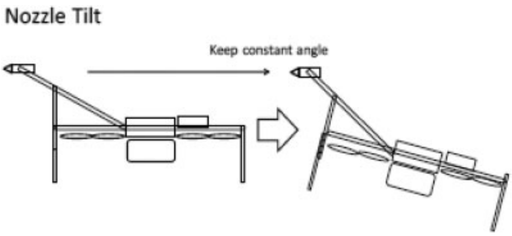

Figure 9. Nozzle tilt.

mentioned above, it is also imagined that the GNSS environment may not be established in the tunnel, the lower part of the bridge, etc., and it becomes impossible to operate. Even in this non-GNSS environment, if the autonomic flight can be made to a certain extent, stable flight and repair to the target place become possible.

For the improvement of maneuverability, we mounted a range sensor. The sensor used is the 2D laser range finder (smart – URG mini USt – 20 LX), realizing control by a small computer. As shown in

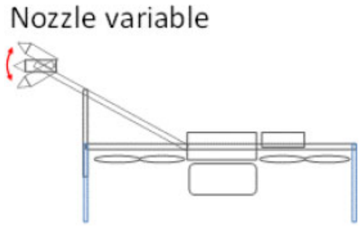

Figure 10. Nozzle variable.

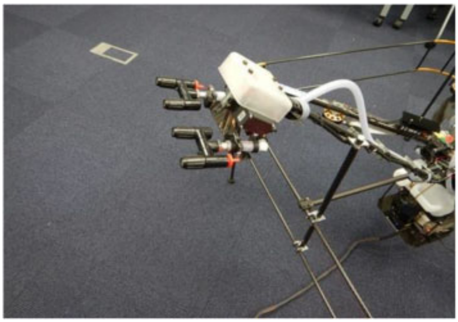

Figure 11. Nozzle system.

Figure 12. Protection method for water.

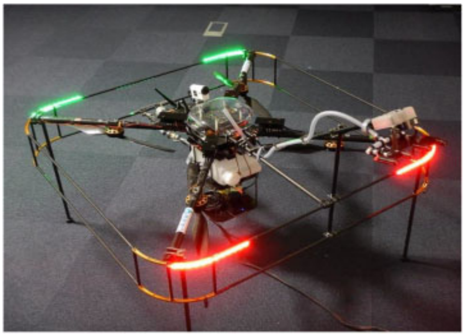

Figure 13. Improvement for our drone.

photo 9 in consideration of the weight balance, the attachment was made by a suspension type by a stray from the central part of the airframe. It became possible to measure the distance to the object with a sensor.

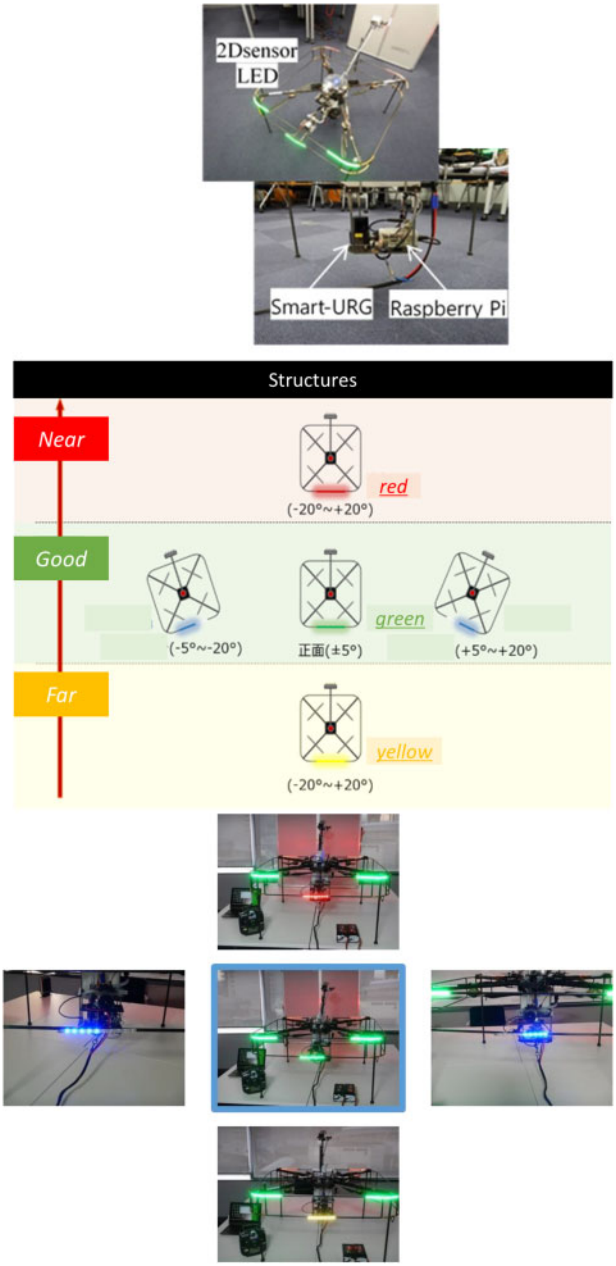

Figure 14. New systems of LED sensor for preventing crash.

However, maneuvering is difficult even if information on the distance to the structure is given to the pilot on the ground. Therefore, in order to be able to visually judge the pilot during flight, the LED sensor was attached to the fuselage. When the distance between the object and the tip of the nozzle becomes 0.75 m or less, the LED is colored in red to prompt the danger of contact. On the other hand, when it became 2.25 m or more, it turned to yellow, indicating that it is difficult to spray repair material. Fig. 14 shows this display format. By such improvement, spraying unevenness by visual observation of the pilot was reduced.

4 VERIFICATION OF IMPROVEMENT EFFECT

First, improvement of spraying efficiency by using sensors was verified. As shown in the Fig. 15, 12 targets were placed on the wall. Here, a water absorbing material was used for the target. Spraying drone was

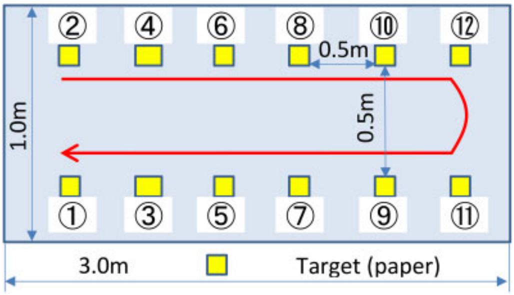

Figure 15. Target setup for checking the improvement effect.

carried out continuously, and the amount applied by measuring the weight was determined to what extent each target was sprayed. The results of the five areas as shown in Table 3, the two areas using the sensor and the three areas without the sensor are shown in the Fig. 16 and Fig. 17. From both figures, it can be seen that variations are suppressed by using sensors. Also, when the sensor was not used, there were targets that fell under the required amount, however in the case of using the sensor, there was no target such as fell under the required amount of materials. It is shown that using a sensor makes it easy to spray. Also, it was found that there is no unevenness and it is possible to blow more efficiently.

Next, Fig. 18 shows the difference in fatigue degree of the pilot in order to confirm the sensor effect. The subjects were one veteran with 3 years of flight experience. The degree of fatigue urged a response by questionnaire. After flying three times in sensor non-use state, I flew three times in sensor use state. From the figure, fatigue level was lower when using sensor.

Thirdly, we confirmed the improvement effect of the nozzle part. With the distance from the tip of the nozzle to the wall set at 1.5 m, it was set with the front part of the drone raised 300 mm as shown in Fig. 19. Confirmation of nozzle tilt function due to such unstable state was carried out. We examined how much sprayed water can be prevented from spreading depending on the tilt function. When the tilt function is not used, H = 0.95 m, however with the tilt function, it is H = 0.60 m. With this, it can be said that spraying to necessary parts became possible. Next, Fig. 15 shows the number of times of upward and downward movement of 500 mm or more in the tunnel and the time required for the movement from both the movements of the drone and the movement of the nozzle. The result is shown in Fig. 20. From the results, it took 1–2 seconds to move the drone, but it turned out that it is possible to move the nozzle in just 1 second or less. In addition, since the number of times to move the nozzle is many times. On considering ease of movement, it is considered that nozzle movement control is effective. However, it is noted that this operation system often depends on the pilot's skill as many operations occur.

Table 3. Spraying area in detail.

Area		I	II	III	V	VI
Time		14:31	14:14	13:56	13:12	11:38
sensor		×	×	○	×	○
wind speed	max.	2.1	2.5	2.1	3.3	1.9
(m/s)	ave.	0.6	0.6	0.8	0.4	0.8

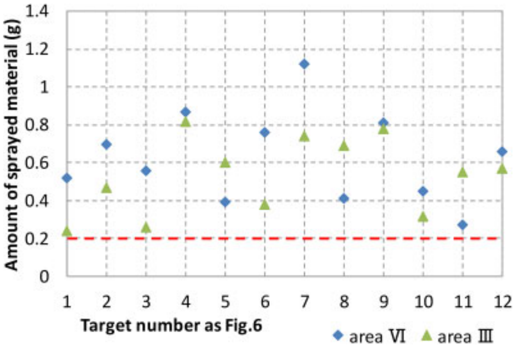

Figure 16. Amount of materials using sensor.

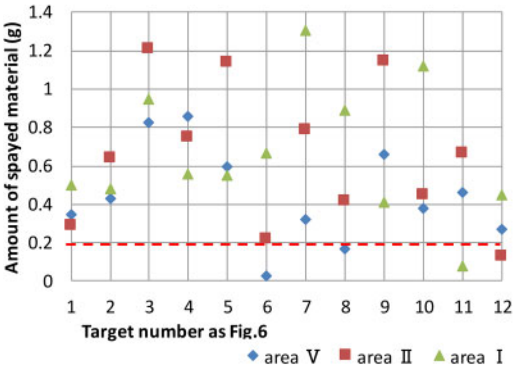

Figure 17. Amount of materials without sensor.

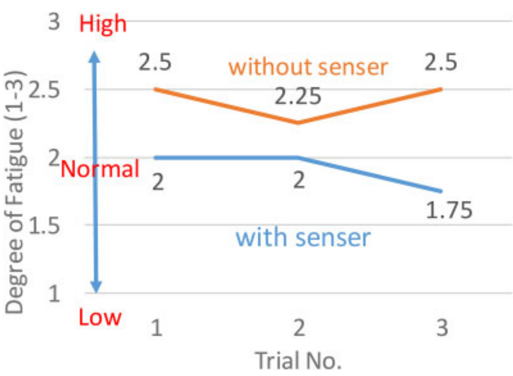

Figure 18. Fatigue point compared using sensor and without sensor.

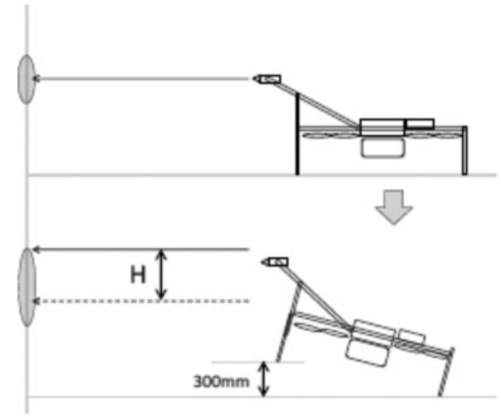

Figure 19. Experiment for effective of nozzle tilt.

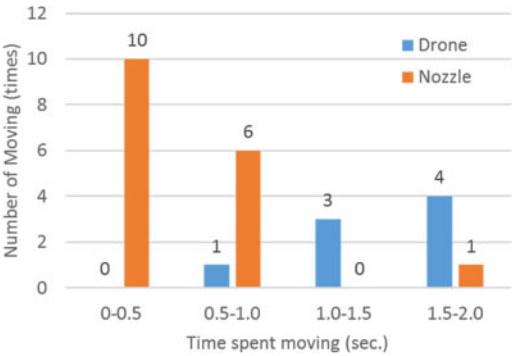

Figure 20. Experiment for effective of nozzle variable.

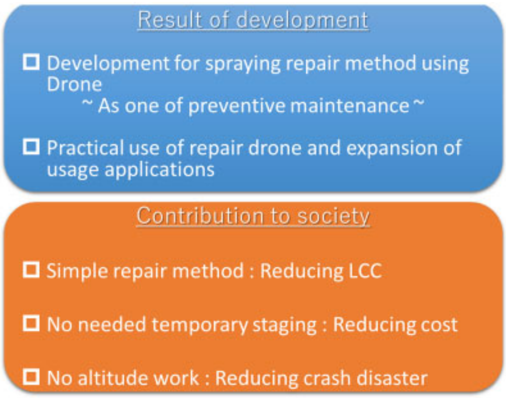

Figure 21. Concept for using of repairing drone.

5 CONCLUSIONS

Ease of use: Improvement of operability of the spray drone was confirmed by utilizing the area sensor. By visually confirming by LED, the hit rate to the target is also easily transversal. Also, the burden on the pilot could be reduced.

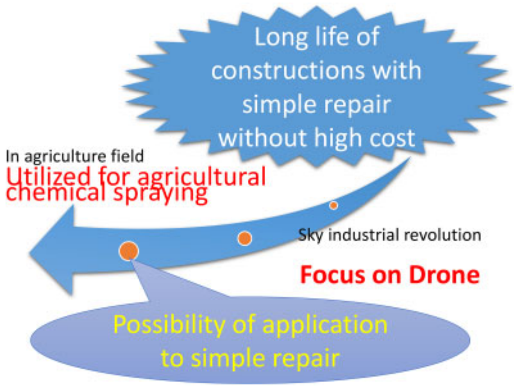

Figure 22. Result for development of repairing drone and contribution to society.

Spraying unevenness: By operating the nozzle, it was possible to eject perpendicularly with the object at all times. From this fact, remarkable reduction in spraying unevenness can be expected.

6 FUTURE

The spraying of the repair material by this method is not applied to a structure with remarkable degradation but is considered to be applied to preventive maintenance of newly constructed structures or application to fine cracks. It is assumed that people can not easily accessible, such as elevated bridges where structures are difficult to construct and structures built in valleys. We believe that it is possible to contribute to the reduction of LCC by aiming to extend the life of the structure by implementing spraying by this method at the earliest possible stage after discovering construction and troubles and cracks.

In addition, since the use of temporary scaffolding and aerial work vehicles is reduced, safety and total cost can be reduced. According to the estimate, it is possible to hope to reduce about 30% by temporary scaffolding and indirect cost reduction.

This repair method has great versatility. For example, we are considering spraying antiseptic and worm insecticide on wooden buildings with small influence of spraying unevenness. Also, it can be expected to be applied to assistance for cleaning work at high places.

The results of this research may be able to reduce dangerous work by working drones on behalf of humans in the near future.