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An effective measure for evaluating sewer condition: UAV screening in comparison with CCTVS and manhole cameras

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Abstract

Most of the water/sewer pipes in Japan were constructed after the high economic growth that occurred in the 1970s. Those pipes are now aging, and the water business is shifting from construction to rehabilitation. NJS, as a consulting company in Japan, has had to shift focus to reflect the increasing need for rehabilitation in the water sector and the limited budget available. Doing business efficiently and better managing water assets has become a critical part of the business. NJS has been searching for a way to inspect sewer pipes efficiently, not just a few times in a service life but in increased frequency – in the range of every year or two. During this process, a focus on UAVs (Unmanned Aerial Vehicles) was considered beneficial. However, one that could stably fly through a confined space, such as a sewer, did not yet exist. Hence, NJS decided to develop a UAV for this purpose in cooperation with a partner company. To evaluate the performance of the UAV, the NJS team has inspected an actual sewer section, in cooperation with Yokosuka city, Kanagawa prefecture, Japan. The result shows that the UAV is capable of inspecting more than 1,000 m a day without personnel needing to enter a manhole. The team has also inspected the same section by CCTV and manhole camera to compare the inspection speed, operator's safety and the reliability of data. From the obtained result, it can be said that UAV is an effective screening method to efficiently conduct CCTV inspection; in other words, to prioritize the sections that need a detailed inspection.

Key words: asset management, operator safety, pipe inspection, screening, UAV

INTRODUCTION

Currently, the main method of inspecting sewer pipes is CCTV. To raise the efficiency of CCTV inspection, NJS has begun to consider utilizing unmanned aerial vehicles (UAVs) as a screening method, to be used prior to CCTV. This will help to detect pipe abnormalities before their condition deteriorates significantly. However, the existing models of UAV on the market were not capable of flying stably in such a confined space. Therefore, NJS decided to develop a unique UAV that could fly stably in such a space and conducted an evaluation test in the city of Yokosuka. The result of the evaluation test showed that, although there were some items that showed insufficient data compared to CCTV, the overall data were sufficient to detect the existence of abnormalities. Especially, to be able to confirm the inspection speed of 1,000 m/day without entering a manhole was a breakthrough. From these results, NJS considers UAV inspection as a new pipe inspection method for assessing sewer condition, which is the critical element of asset management.

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BACKGROUND

The majority of sewers in Japan were constructed after the 1970s. In 2017, sanitation coverage reached approximately 80%. Along with the growth of coverage rate, the sewer stock has grown steadily, reaching approximately 470,000 km in the recent statistics (Figure 1).

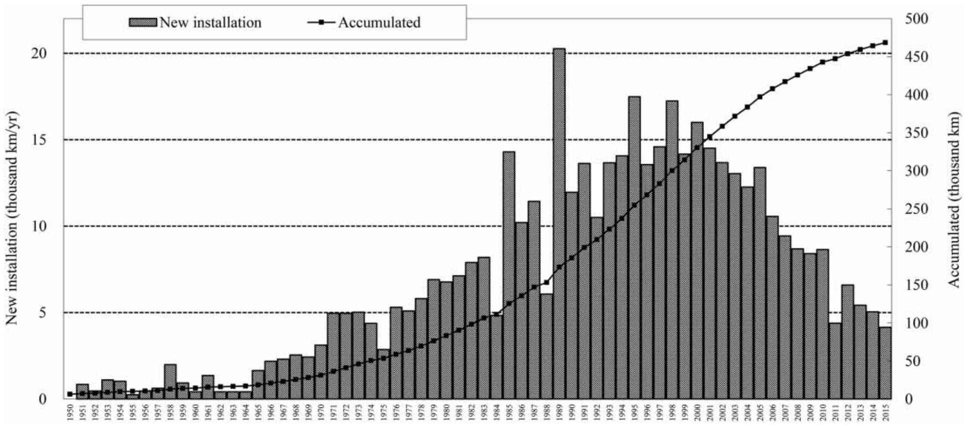

Figure 1 | New sewer construction and accumulated length by year (Japan Sewage Works Association 2015).

The procedure of maintaining assets such as sewers typically has the following steps: (1) analyze the present state; (2) evaluate the risk; (3) simulate a fiscal plan in the long-term; and (4) set the inspection/rehabilitation plan. Among those steps, securing budgets for inspection is the most difficult part, requiring a way to develop a new method that can inspect pipes efficiently without losing quality.

Currently, small diameter pipes are commonly inspected by a vehicle-mounted CCTV. This method requires an operator to assemble the CCTV on site and usually to enter a manhole, which takes a certain amount of time before completing the section. To take measures against the growing amount of aging pipes, reducing inspection time was crucial. To solve this problem, NJS started to look for a new inspection method and began to examine the possibility of utilizing a UAV.

EVALUATION BY COMPARISON TO OTHER INSPECTION METHODS

Method of evaluation

To examine the reliability of data obtained by UAV, the team inspected the same section with CCTV and manhole camera.

Inspected section

The sections used for evaluation were as follows:

- Pipe usage: combined sewer
- Pipe diameter: 400 mm to 600 mm
- Number of lines: 30
- Total length: 1,324.8 m

Device specification

The devices used for inspection were CCTV, manhole camera and UAV. CCTV had a resolution of 410,000 pixels and the manhole camera, 2,000,000 pixels, both used commonly in Japan. The

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specification of the UAV can be found in Table 1 and its appearance in Figure 2. This model was jointly developed by NJS and Autonomous Control Systems Laboratory Ltd. (ACSL), a Japanese UAV company.

Table 1 | Specification of the UAV

Weight	1.5 kg (includes a Li-Po battery)
Size	W:250 mm, L:570 mm, H:120 mm
Flight duration	Approx. 5 min
Flight speed	0.5–3 m/sec
Camera	SONY DSC-RX0
Resolution (video shooting)	Approx. 2,000,000 pixels
Viewing angle	84°

Figure 2 | Appearance of the UAV.

COMPARISON OF THE INSPECTED RESULTS

The comparison of the three inspection methods was evaluated by (1) inspection speed, (2) operator's safety and (3) reliability of data. Details of each evaluation are described below.

Inspection speed

The indexes of the 'inspection speed' were the number of days required for inspection, the number of manhole openings, the average inspection path per manhole (Figure 3) and the average of inspected length. Table 2 shows the result of inspection by each method. The number of days required to inspect the total length of 1,324.8 m were CCTV = 4 days, manhole camera = 2 days and UAV = 1 day. The UAV's average inspection time per manhole was 12 min 23 seconds. The total duration time that UAV took to inspect the whole length was 4 hours and 18 min, including preparation, tuning of devices and clean up.

The number of manhole openings required to inspect the whole length was, CCTV = 30 openings, manhole camera = 36 openings and UAV = 15 openings, showing UAV to have the least number of openings of all. This is owing to the fact that UAV was able to inspect one path in the upstream direction and two paths in the downstream direction, resulting in a maximum of three paths from a single opening. The average number of inspection paths per manhole was CCTV = 1.0 path, manhole camera = 0.8 path and UAV = 2.0 paths. The average length of inspection per manhole was CCTV = 44.16 m, manhole camera = 36.8 m and UAV = 88.32 m. The results indicate that UAV inspection is

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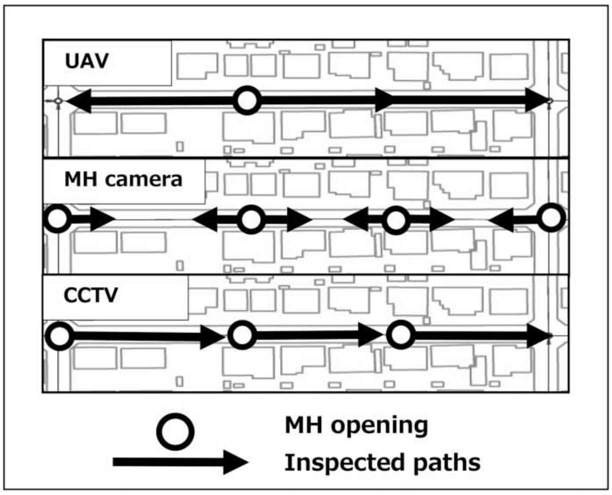

Figure 3 | Manhole openings and the inspected paths.

Table 2 | Comparison of the three inspection methods

	CCTV	Manhole camera	UAV
Number of days needed	4	2	1
Number of manhole openings	30	36	15
Average inspection path per manhole	1.0	0.8	2.0
Average of inspected length per manhole	44.16	36.8	88.32

the most efficient of the three methods tested, in terms of the number of days required, average number of inspection paths and inspection length per manhole.

Operator's safety

The index for the operator's safety was set to be the number of manhole openings that operators had to enter. The numbers were CCTV = 30 openings, manhole camera = 0 opening and UAV = 1 opening. The one opening recorded for UAV had happened when the operator misguided the UAV to a deep gap and had to enter the manhole to retrieve it. This could have been prevented by examining the construction drawings prior to the inspection. Basically, an inspection by UAV was able to carry out the whole process from above ground, including preparation, inspection and clean up (Figure 4).

Reliability of data

The reliability of the data obtained by UAV was examined by the number of abnormalities matched to the CCTV results; that is, setting CCTV as a benchmark. The results of CCTV are shown in Table 3 and the levels of severities (A-C) are explained in Table 4, with A being the most serious level. The criteria shown in Table 4 were taken from the *Guideline for sewer management* (Japan Sewage Works Association 2014), issued by Japan Sewerage Works Association (JSWA) in 2014. A manhole camera was also used to inspect the same section and the result was compared to that of CCTV. The visibility (screen clarity) was evaluated by how many abnormalities the method detected for each item (Table 5). Figure 5 shows a crack image obtained by UAV and a manhole camera.

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Figure 4 | Operators working from above ground in UAV inspection.

Table 3 | The result of the CCTV inspection

Corrosion			Sagging in vertical direction			Breakage			Cracks			Displaced joints			Infiltration			Extrusion of lateral pipes		
A	B	C	A	B	C	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
0	1	2	0	0	0	3	8	6	1	5	8	0	0	3	0	0	1	0	0	1
Root intrusion			**Attached deposit (mortar)**			**Others**			**Total**											
a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**A**	**B**	**C**	**Total**	**a**	**b**	**c**	**Total**				
0	3	0	0	0	4	0	0	1	0	1	2	3	4	16	24	44				

Explanation for each level A(a) - C(c) is in Table 4.
Whole length assessment: A = most severe → C = less serious.
Pipe-wise assessment: a = most severe → c = less serious.

The matching rate (of 11 items) to CCTV was 11% for manhole camera and 68% for UAV. Out of these results, the rate for critical defects (item 1–6) was 8% for manhole camera and 74% for UAV and managerial results (item 7–11), 22% and 44%.

THE WAY FORWARD

UAV matching results at 74% for critical defects that affect structural integrity can be considered as a high matching rate. Among the items, corrosion, displaced joints and extrusion of lateral pipes scored a 100% match to the result of CCTV inspection. This score owes to the UAV's capability of being able to fly to the center of the sewer section, collect images from a close distance and detect abnormalities, whereas a manhole camera could only collect images from a manhole. On the other hand, cracks, root intrusion and mortar deposit showed a matching rate of only 50% or less. The reasons for this low matching rate could be the low visibility that UAV occasionally encounters – the downwards airflow generated by the UAV splashes the water and the water sticks to the lens. Or, the narrow viewing angle may have blurred the image and made it difficult for the operator to detect the abnormalities. Therefore, camera selection will be an issue for future development. The result that lateral blockage showed as low as 0% matching came from the UAV not having a lateral vision. Without this capability, detecting lateral blockage was difficult.

To summarize, it can be said that even though some items showed less accuracy to CCTV, the overall score was better than that of a manhole camera. Therefore, UAV can be seen as a possible screening method for pipe inspection.

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Table 4 | Levels of severities (Japan Sewage Works Association 2014)

	Sewer conditions \ Levels		A	B	C
Whole length assessment	Corrosion of pipes		Steel reinforcement visible	Aggregate visible	Surface roughness
	Deformed in vertical direction	(Inner diameter) less than 700 mm	100 % or greater of inner diameter	50 % or greater of inner diameter	less than 50 % of inner diameter
		(Inner diameter) between 700 mm and 1,650 mm	50 % or greater of inner diameter	25 % or greater of inner diameter	less than 25 % of inner diameter
		(Inner diameter) between 1,650 mm and 3,000 mm	25 % or greater of inner diameter	12.5 % or greater of inner diameter	less than 12.5 % of inner diameter
	Sewer conditions \ Levels		**a**	**b**	**c**
Local (pipe-wise) assessment	Breakage/longitudinal crack	Reinforced concrete pipe, etc.	Collapsed Longitudinal crack 5 mm or greater in width	Longitudinal crack 2 mm or greater in width	Longitudinal crack less than 2 mm in width
		Clay pipe	Collapsed Longitudinal crack 50 % or greater of pipe length	Longitudinal crack less than 50 % of pipe length	–
	Circumferential crack	Reinforced concrete pipe (RC) etc.	Circumferential crack 5 mm or greater in width	Circumferential crack 2 mm or greater in width	Circumferential crack less than 2 mm in width
		Vitrified clay pipe (VC)	Circumferential crack two-thirds or greater of the circumferential length	Circumferential crack less than two-thirds of circumferential length	–
	Displaced joints		Extruded joints	Reinforced concrete pipe etc.: 70 mm or greater Vitrified clay pipe: 50 mm and over	Reinforced concrete pipe etc.: less than 70 mm Vitrified clay pipe: less than 50 mm
	Infiltration		Gushing	Running	Seeping
	Extrusion of lateral		50 % or greater of inner diameter	10 % or greater of inner diameter	Less than 10 % of inner diameter
	Attached deposit, grease		Blockage of 50 % or greater	Blockage of less than 50 % of inner diameter	–
	Roots intrusion		Blockage of 50 % or greater	Blockage of less than 50 % of inner diameter	–
	Attached deposit, mortar		Blockage of 30 % or greater	Blockage of 10 % or greater	Blockage of less than 10 %

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Table 5 | The number of abnormalities detected by each inspection method

Abnormalities		CCTV [1]	Manhole camera [2]	UAV [3]	Manhole camera Matching rate to CCTV [2]/[1]	UAV Matching rate to CCTV [3]/[1]
Defects (critical)	1. Corrosion	3	0	3	0%	100%
	2. Sagging in vertical direction	–	–	–	–	–
	3. Breakage	17	3	14	18%	82%
	4. Cracks	14	0	7	0%	50%
	5. Displaced joints	3	0	3	0%	100%
	6. Infiltration	1	0	1	0%	100%
	Subtotal	38	3	28	8%	74%
Defects (managerial)	7. Extrusion of lateral pipes	1	1	1	100%	100%
	8. Attached deposit (grease)	–	–	–	–	–
	9. Root intrusion	3	0	1	0%	33%
	10. Attached deposit (mortar)	4	1	2	25%	50%
	11. Blockage of lateral	1	0	0	0%	0%
	Subtotal	9	2	4	22%	44%
Total		47	5	32	11%	68%

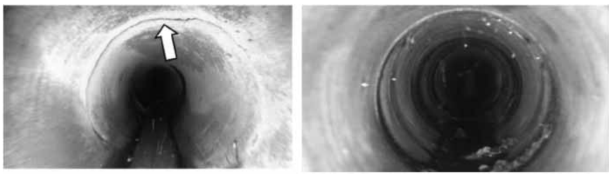

Figure 5 | (Left) Crack obtained by UAV, (Right) crack obtained by manhole camera.

CONCLUSION

NJS has been searching for a way to raise the efficiency of CCTV inspection. During this process, NJS has focused on UAV as a possible screening method to be used prior to CCTV and has worked to develop a UAV for this purpose. To evaluate the performance of this UAV, NJS inspected a 1,324.8 m length of combined sewer with Yokosuka city. The same section was inspected by CCTV and manhole camera also and the result was compared to that of UAV.

The result by UAV inspection was as follows:

- UAV detected as many abnormalities as CCTV in many inspection items
- In the standard inspection procedure, there is no need for personnel to enter a manhole
- Over 1,000 m of pipes can be inspected in a day
- UAV inspection has a low detection rate for cracks, root intrusions, etc.
- Detection of lateral blockage remains to be solved

From this result, it can be concluded that NJS has established a new method of inspection with UAV being a method to detect the presence of abnormalities but not the severity level in detail. NJS will continue to work on improving the image quality, which will lead to a higher detection rate.

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