Automatic traveling method for the self-propelled Tunnel Inspection System

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In recent years, road tunnels in Japan with severe aging are obliged to check periodically. But there are problems such as lack of engineers and inspection cost.

In order to solve these problems, we are developing a tunnel full-section inspection system.

In this system, inspection devices are arranged at the upper and both side parts. The lower part is protective frame vehicle with portal frame shape secured space through which the vehicle can pass. Although this system travels in a limited space, the position of the inspection device in the tunnel transverse direction is particularly important. Moreover, tunnel is a special environment that the GPS cannot be used, and feature points are few.

Therefore, we examined the automatic traveling control method suitable for this system and carried out driving tests.

As a result, it is confirmed the automatic travel control method using the magnetic sensor and guide are effective for this system.

Keywords –
Automatic operation; Magnetic sensor; Road tunnel

1 Introduction

Approx. half of road tunnels in Japan are over 40 years from the construction and aging is serious. Under such circumstances, due to the collapse of the tunnel ceiling board that occurred in 2012, periodic inspection every five years was obliged. In road tunnels, there are problems such as the shortage of engineer and the inspection cost. This tendency is particularly noticeable in road tunnels in country areas.

In order to solve these problems, we are developing a tunnel full-section inspection system (hereinafter, called this system) aimed at efficiently inspecting road tunnels. The final goal is to use this system for inspection instead of engineer.

The concept of this system is shown in Figure 1. Inspection equipment is arranged at the upper part and both side parts, and at the lower part it consists of a self-propelled portal frame secured space through which the vehicle can pass. Then, these inspection devices are moved to a predetermined position for inspection. The target value of the traveling position accuracy depends on the clearance with the tunnel that the frame and inspection device can tolerate. In this system, the tolerance of traveling position is within ± 75 mm in the tunnel transverse direction. Also, it is desirable that the operation during traveling is as simple as possible. Therefore, we consider mounting an automatic traveling control method in this system. The method can travel along a tunnel linear shape with keeping acceptable traveling position.

The environments of inside the tunnel are follows. Global Positioning System (GPS) cannot be used, and there are relatively few feature points with relatively monotonic shape. Therefore, we compare and study the sensing technologies used for various automatic driving control currently in practical use. And we select a control method considered to be suitable for this system. Then we conduct driving test with control method, and evaluate traveling accuracy.

In this paper, we report on the results of examination of these automatic traveling control methods and the evaluation results of driving accuracy by driving test.

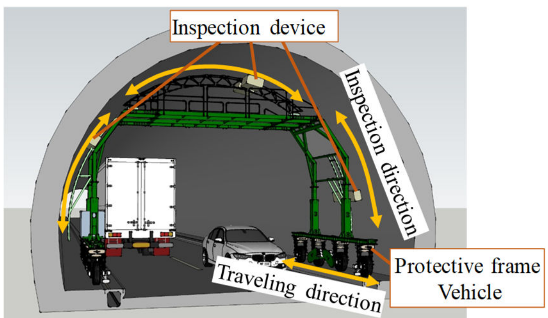

Figure 1 Concept of Tunnel Inspection System

2 Outline of Tunnel Inspection System

The actual machine of our system, which we produced, is shown in Figure 2, and the details of systems are as follows.

1. Crack inspection device: To replace the visual inspection from inspector. Automatic detection of cracks on concrete surface by light sectioning method with color image.
2. Hammering inspection device: To replace the hammering inspection from inspector. By hammering the concrete surface with the same force as inspector, the deformed of the surface layer is automatically found by the hammering sound.
3. Variable Guide Frame (hereinafter, called as VGF): Rail that moves the inspection devices in the transverse direction. In order to avoid an obstacle, it can be deformed into an arbitrary shape.
4. Protective frame vehicle: Travel the inspection system to a prescribed inspection position while securing a space through which the vehicle can pass. An inspector can ride on the upper stage, and it is effective when the inspector approaches the upper part of the tunnel. In turning traveling (minimum turning radius is R50(m)), it is assumed that the speed difference is given to the left and right driving wheels, and steering operation for adjusting the direction of the wheels is unnecessary. Since the device size can be adjusted by exchanging this frame, it is possible to deal with tunnels of various sizes. Table 1 shows main specifications of this system.

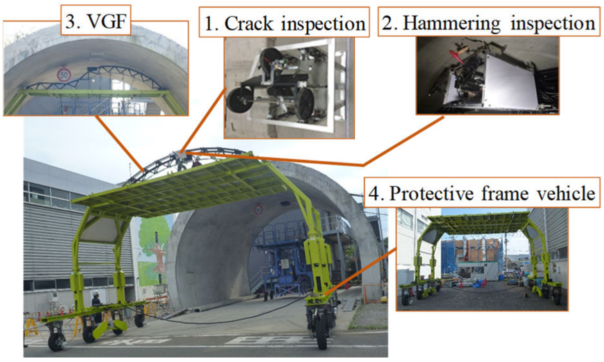

Figure 2 Actual machine of Tunnel Inspection system

Table 1 Specification of Tunnel Inspection System

Specification	
Inspection Speed (m/h)	25
Traveling speed (m/min)	Max 10
Turning diameter (m)	Min R=50
Weight (kg)	4.000
Length (m)	5.000
Width (m)	7.500 (Adjustable)

3 Automatic traveling of the protective frame vehicle

3.1 Travel accuracy and driving environment

This system aims to move the inspection device to a predetermined inspection position while traveling in the tunnel. In particular, the positional accuracy in the tunnel transverse direction is important. And its target tolerance is set to be within ± 75 mm that the frame and inspection equipment can tolerate.

On the other hand, the features in the tunnel are as follows.

1. It is not possible to grasp own position by GPS.
2. It is a relatively monotonous shape with few feature points.

Furthermore, since the vehicle width is large, the blind spot of the operator is large, and the traveling operation relying on the visual confirmation is high in risk. Therefore, we should consider automatic traveling control method to travel accurately in the tunnel.

3.2 Sensing method used for automatic traveling control

Currently, various sensing technologies for automatic traveling control exist. So we compare them and consider methods that are considered to be suitable for this system. The comparison result is shown in Table 2. From this result, it is considered that the magnetic guide sensing technology is suitable for the automatic traveling control of this system.

Table 2 Comparison of sensing method for automatic traveling control

Type	Technology	Issues	Cost	Eval
GPS	Positioning estimation by GPS	GPS signal cannot be received	Mid	Poor
SFM (Structure from Motion)	Positioning estimation from acquired image	Error due to few feature points	Mid	Poor
LiDAR	Measure the forward shape with electromagnetic waves	Need high-spec PC for calculation	High	Average
Laser ranger	Measure distance between tunnel wall and frame	Error due to equipment (ex. road signage, fire hydrant)	Low	Average
Magnetic guided	Scan the position of the magnetic guide and calculate the deviation	Magnetic guide installation required	Low	Good

4 Evaluation of Magnetic Guided Type Automatic Travel Control

4.1 System configuration of magnetic guided automatic traveling

As a result of 3.2, we decide the magnetic guided sensing technology is suitable for this system. This control method is installed in this system and we conduct driving test. The configuration of control system is shown in Figure 3, the mounting appearance is shown in Figure 4, and the specifications of control system are shown in Table 3.

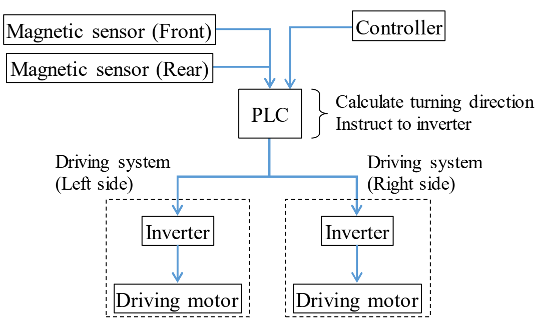

Figure.3 Control System Configuration

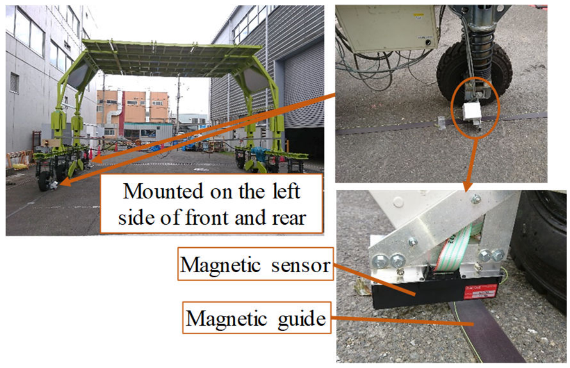

Figure 4 Appearance of magnetic guided sensor

Table 3. Specifications of control system

Equipment	Model	Manufacturer
Magnetic sensor	GS-115	MACOME
Magnetic guide	MGL-50-25	CORPORATION
PLC	KV-N14AT	Keyence

4.2 Driving Test with Magnetic Guided Automatic Travel Control

A driving test of a protective frame vehicle with a magnetic guided automatic traveling control is conducted. The results are shown as follows.

4.2.1 Conditions of driving test

The conditions of driving test are shown in Table 4. And the laying situation of the magnetic guide as the driving target is shown in Figure 5. The driving road is a flat asphalt pavement surface in a dry state.

Table 4 Conditions of driving test

Driving mode	Driving direction	Driving speed	Number of driving
Intermittent Every 40 cm	Forward / Backward	10m/min	Every 3 times
Continuance	Forward / Backward		

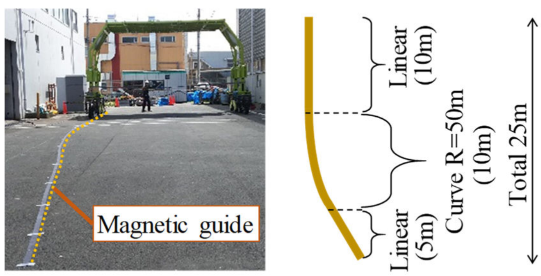

Figure 5 Magnetic guide laying situation

4.2.2 Measuring method of driving locus

In this test, automatic tracking type Total Station (hereinafter, called as TS/ST15P and ST16, Leica) is used for measurement of the magnetic guide position and the driving locus. Particularly the measurement of the driving locus, the TS target is located on front and rear of the magnetic sensor side. And the measurement is performed continuously using two TSs. This measurement method is shown in Figure 6.

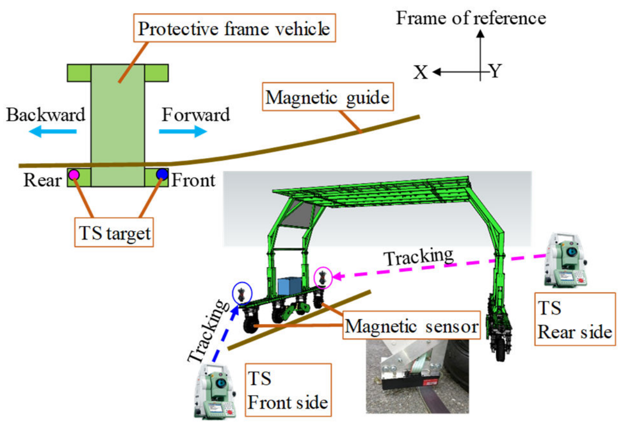

Figure 6 Measuring method of driving locus

4.2.3 Test results

Figure 7 shows the result of comparing the magnetic guide position and traveling locus in this test (excerpt of the first driving result). The numerical value in the graph indicates the maximum deviation amount (right and left with the magnetic guide position as the center) and its position.

Magnetic guide of this test is combining the linear part and the curve part (Turning radius R=50m). As a result of the automatic driving test with the magnetic guide control, the maximum deviation amount from the magnetic guide is 79mm. The large deviation points are before and after turning area. No difference is confirmed by running conditions (continuous driving / intermittent driving, forward / backward).

In this test, since the deviation amount is almost within the target. It is considered that the magnetic guided automatic travel control can be used for this system.

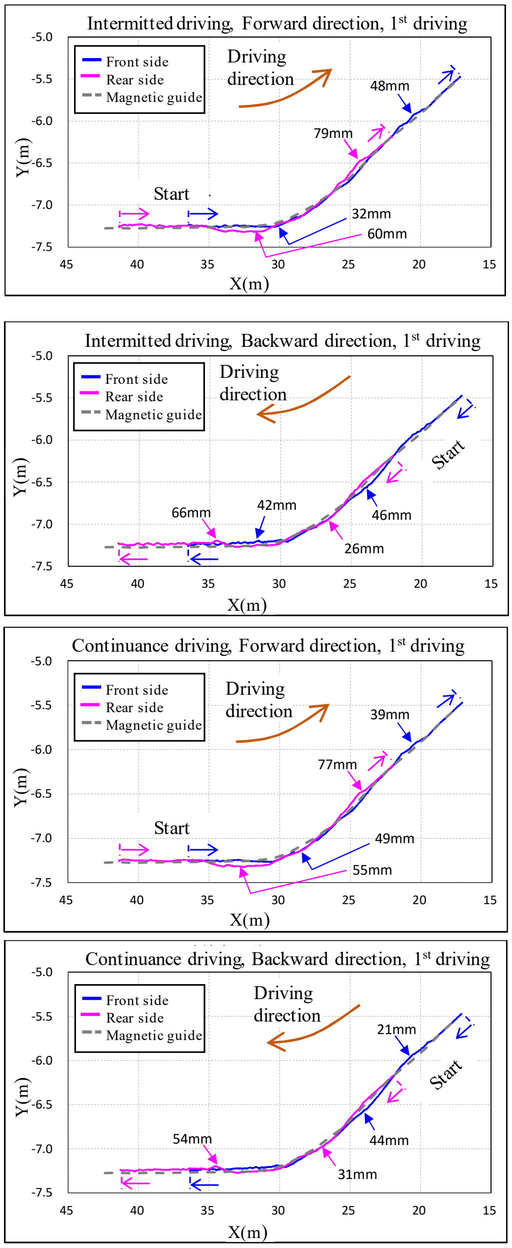

Figure 7 Comparison of magnetic guide and driving locus

5 Implementation of magnetic guided automatic traveling control system

Magnetic guided automatic traveling control system confirmed effectiveness is mounted on actual machine. Installed system configuration is shown in Figure 8, and detail of magnetic guide is in Figure 9. The main improvements based on test results are as follows.

1. Increase number of sensors (From one side to both sides): To improve the accuracy of traveling control by sensing magnetism on both sides.

2. Add the distance guide: This system should stop at every 40cm at inspection. Therefore, a marker is incorporated in the magnetic guide as a stop target.
3. Magnetic guide indicator: An indicator is added in operation interface. Operator can check the deviation amount of each magnetic guide.
4. Output of running position and deviation amount: For grasping position information, the position in the traverse direction is calculated from the deviation amount of the four magnetic sensors. The traveling distance is calculated from encoder count. And these information are output to inspection system.
5. Magnetic guide installation method: The magnetic guide is installed in the tunnel at the timing of inspection. The installation position is set to a certain distance from the tunnel wall surface, and it is installed simply and accurately with a JIG. Also, magnetic guides are connected by connecting 1 m straight lines. Since it is possible to handle all straight and curved sections, it is not necessary to prepare multiple types of magnetic guides.

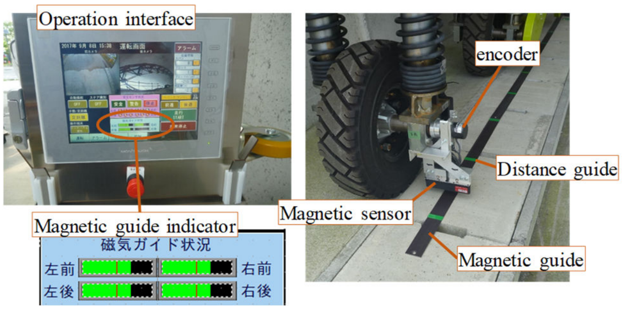

Figure 8 Installed system configuration

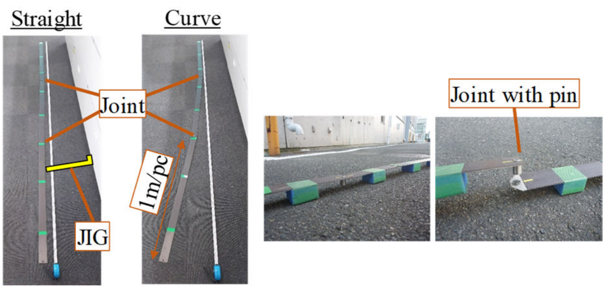

Figure 9 Detail of magnetic guide

6 Conclusion

In this paper, we evaluated the automatic traveling control method of the tunnel full cross section inspection system. As a result, it is found that the automatic traveling control method using the magnetic guided is effective and reasonable.

In the future, we will try to optimize the frame structure and the turning method by measuring the twist of the frame during turning and structural analysis.

In addition, it is now supposed to complement self-position information that is detected only by a deviation from the magnetic guide. Since we will study a system that measures the distance between the entire frame and the tunnel wall surface at several places.

With these improvements, we aim for practical application of this system.

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