Concrete Inspection Systems Using Hammering Robot Imitating Sounds of Workers

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Abstract -
In Japan, deterioration of many tunnels and bridges have become a serious problem. Moreover, engineers that manage them are insufficient due to aging. Therefore, we developed an under-actuated hammering robot that can imitate hammering sounds of inspection workers. When we use this robot, workers can detect concrete defects by using their experiences. For example, if we attach a video camera or microphones to this robot, they can detect defects as before at remote locations. Furthermore, it can contribute building high accurate automatic inspection systems by learning hammering sounds of inspection workers. Therefore, we developed an under-actuated hammering robot that can imitate hammering sounds of inspection workers. In this paper, we described these systems using this robot. To verify usefulness of these systems, we conducted experiments using a concrete test block and compared the results of an inspection worker with this robot. As a result, we confirmed that this experiments showed the results of this robot is similar to its of an worker.

Keywords -
Concrete inspection; Hammering robot; Under-actuated; Defect; Nondestructive

Figure 1. The hammering test by inspection workers

1 Introduction

In Japan, deterioration of many tunnels and bridges have become a serious problem. Moreover, engineers that manage them are insufficient due to aging. For this reason, it is desired to develop innovative inspection techniques such as robots and implement on site.

Inspection of the concrete structure are using nondestructive test mainly. There are visual inspection and hammering test and so on in that test. Visual inspection is useful to inspect cracks of the concrete surface. For example, systems that find out concrete cracks using a CCD camera or others are actually implemented on site[1][2].

Hammering test is useful to find out defects inside the concrete. For example, the hammering test by workers as shown in Figure 1 is a popular method. In this method, the worker hammer the concrete surface and assesses condition of the concrete from hammering sounds. Another method is that the Schmidt rebound hammer is widely used in the concrete inspection[3]. However, the method takes much time to inspect a wide range. To improve the efficiency of these work, there are researches to find out defects inside the concrete. There are a robot named "Sonic Meister" using an industrial manipulator and impact unit with five hammers[4][5]. This system can obtain hammering sounds at 0.2 s intervals by controlling these hammers successively. However, this system is large and requires eight-ton truck. There are a inspection method using the non-contract laser measurement technology[6]. This technology enables high speed inspection and automation. However, the technology requires high position accuracy in order to irradiate the concrete surface with the laser. The laser may hurts the eyes of workers.

To consider these results, we examined a mobile hammering robot based on the hammering testing method. When we use hammering robot that can imitate hammering sounds of inspection workers, they can detect concrete defects by using their experiences. For example, if we attach a video camera or microphones to this robot, workers can detect its at remote locations as before. Furthermore, it can contribute building high accurate automatic inspection systems by learning sounds of inspection workers.

Therefore, we developed an under-actuated hammering robot that can imitate hammering sounds of inspection workers[7]. This robot and a example of the system as-

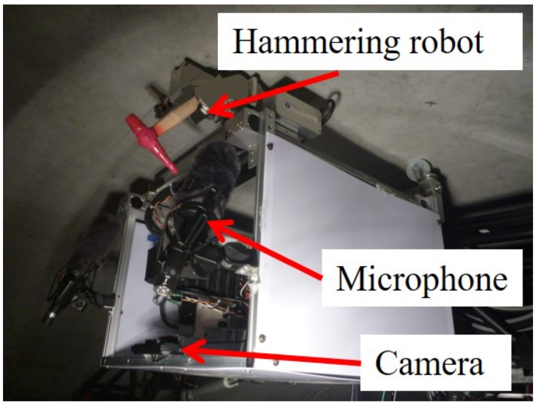

Figure 2. The hammering robot

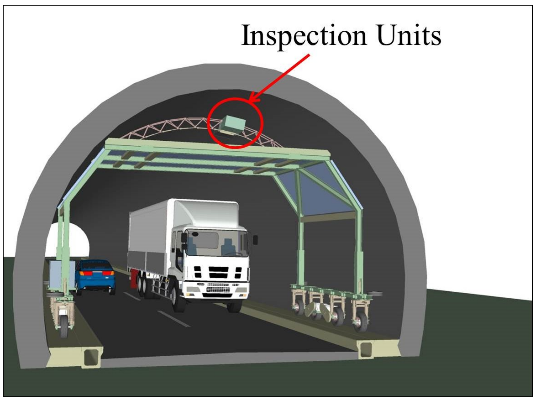

Figure 3. An image of the tunnel inspection system using the hammering robot

sumed to mount it are shown in Figure 2.

In this paper, we described systems using the hammering robot and the results of experiments to verify usefulness of them.

2 Concrete inspection system

There are concrete inspection systems using the hammering robot. For example, we have assumed a tunnel inspection system such as Figure 3. This system will equip the robot and can inspect tunnel automatically by using vehicles. This robot has a camera and microphones and can record image of concrete surfaces and hammering sounds. As a more simple system, you can attach this hammering robot to the tip of a pole.

In this system, we have thought that there are two ways to detect concrete defects. The first way is that inspection workers use measured data “Type-A”. For example, inspection workers can detect concrete defects at remote locations by using data sent from this inspection system. The second way is that systems learn this data by the ensemble learning method to detect automatically “Type-B”[8]. If hammering sounds of this robot is similar to inspection workers, we can collect reliable learning data by using hammering sounds of inspection workers. To verify usefulness of these systems, we conducted hammering experiments assuming these systems.

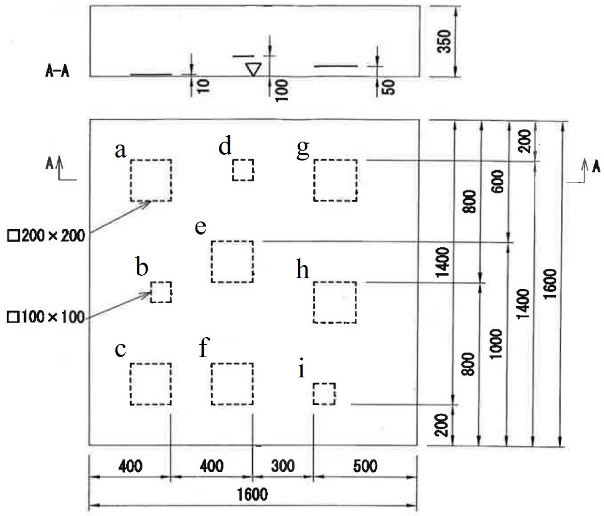

Figure 4. Drawing of the concrete test block

3 Hammering experiment

In this experiment, we verified usefulness of these systems comparing the results of assuming Type-A with the results of previous works by expert inspection workers. If Type-A is useful, we can verify that sounds of the robot are similar to inspection workers. Therefore, this robot is also useful with Type-B.

3.1 Concrete test block

The concrete test block which is used in this experiment is shown in Figure 4. In this block, there are some artificial cavity which are shown as Table 1 simulating defects.

Table 1. Specification of the defect

Defect	Area[mm2]	Depth[mm]	Thickness[mm]
a	200×200	10	1
b	100×100	10	1
c	200×200	10	20
d	100×100	100	1
e	200×200	100	1
f	200×200	100	20
g	200×200	50	1
h	200×200	50	20
i	100×100	50	1

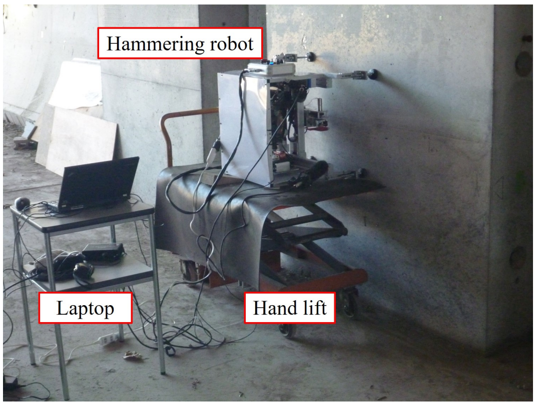

Figure 5. Appearance of a test using the robot

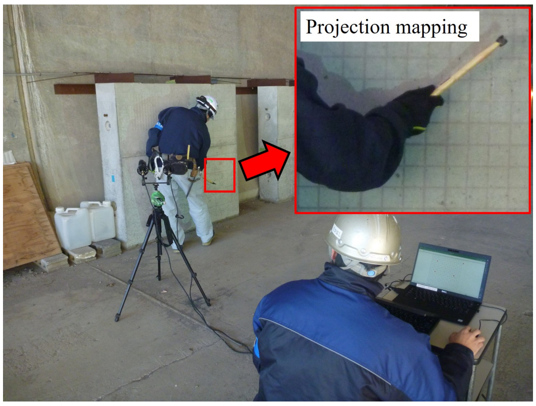

Figure 6. Appearance of a test by an expert

3.2 Hammering device

Figure 5 is a device with the hammering robot we developed. This device can hammer the concrete surface at equal intervals because it can move a hammering robot at the same speed. When this device fixed, the robot can move within 300[mm]×300[mm] area. This device has a camera and microphones and can record images of concrete surfaces and hammering sounds. This hammering robot have equipped with a hammer weighing 100g using by many inspection workers.

3.3 Experimental method

First of all, we described about hammering tests by the robot based on Type-A. In this tests, we used a device such as Figure 5 and hammered the surface of a concrete test block. The hammering interval was set to 25mm. The height of this device was adjusted using hand lift. We recorded images of concrete surfaces and hammering sounds by this device. Furthermore, we prepared an expert inspection worker who had not know the position of defects. An expert detected defects using this data at a later date. In this process, an expert had not know where these image are on the test block.

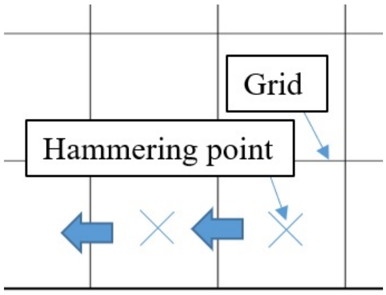

Figure 7. Hammering points

Secondly, we described about hammering tests by inspection workers. An inspection worker was the same as an expert who detected defects in Type-A. He used a hammer weighing 100g that he always use. We displayed grid which size is 25mm on the concrete test block by the projection mapping such as Figure 6. He hammered at the center of each grid such as Figure 7. To compare quantitatively, we adjusted the position of grid to hammer the same place as Type-A.

3.4 Evaluation method

We recorded positions detected defects and qualitatively compared. Furthermore, we recorded the number of grids $P[points]$ detected defects, and quantitatively compared by detection rate of defects $R[\%]$. When inspection interval is $D[mm/points]$, defect area $S[mm^2]$ is written by,

$$S = P \times D^2. \tag{1}$$

If defective area in a concrete test block (Figure 4 or Table 1) is $S_0[mm^2]$ and it detected in this experiment $S[mm^2]$, detection rate R is written by,

$$R = \frac{S}{S_0}. \tag{2}$$

We compared the results of the robot and an expert using this detection rate.

3.5 Experimental Results and Consideration

The result of defective area by the robot based on Type-A is shown as Figure 8. An expert were able to detect defects a, b, c, g, h from images of the concrete surface and hammering sounds of this robot. This experimental result showed that it is difficult to detect defects of depth is 100mm. Moreover, it is difficult to detect defects of area is 100[mm]×100[mm] even if depth of defects are 50mm. Similarly, the result of defective area by an expert is shown as Figure 9. As shown in Figure 9, he were able to detect

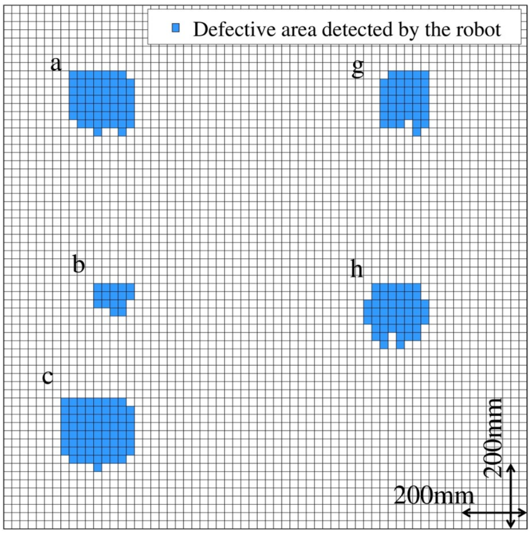

Figure 8. Defective area by the robot (25mm)

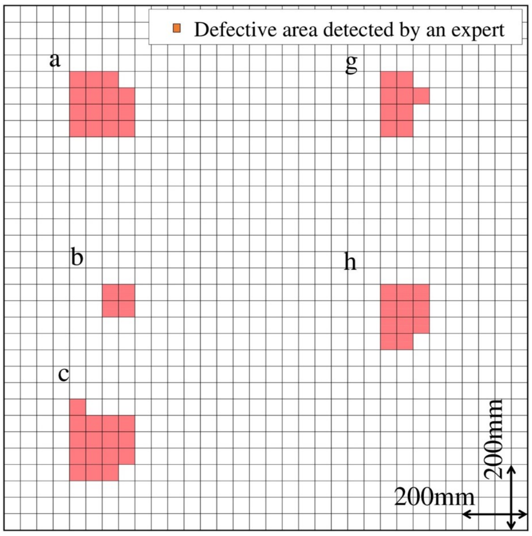

Figure 11. Defective area by an expert (50mm)

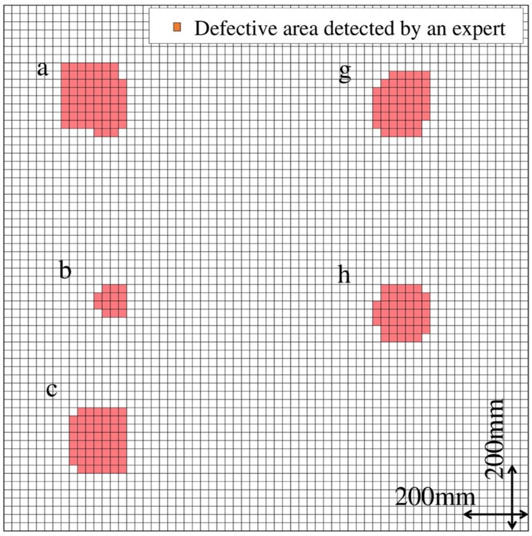

Figure 9. Defective area by an expert (25mm)

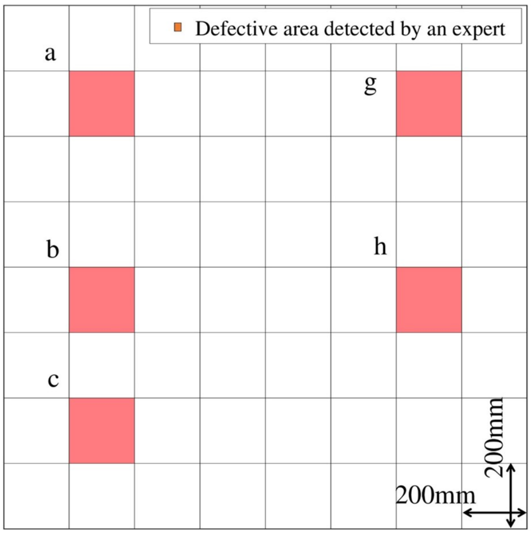

Figure 12. Defective area by an expert (200mm)

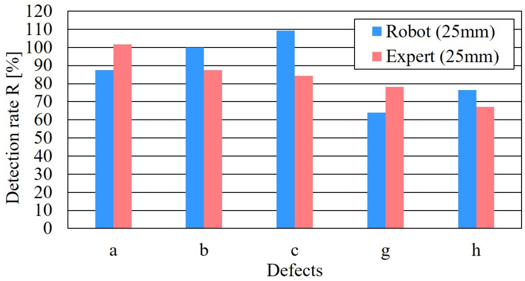

Figure 10. Detection rate

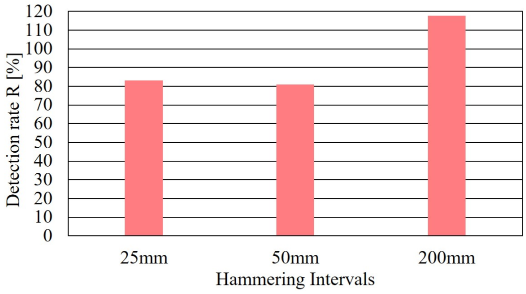

Figure 13. Detection rate of an expert

the same position of defects as the robot. As a result of qualitatively comparing, the results of defective area by the robot and an expert are similar. Therefore, we verified usefulness of our concrete inspection systems using the hammering robot.

We compared these results quantitatively using Equation (2). As shown in Figure 10, the robot can simulate an expert within ±15% at defects of a, b, g, h. We think that it is not a problem although there is a difference of about 25% at a defect of c. Because the robot detected a defect wider than an expert of it.

In this paper, we conducted hammering tests at 25mm interval. In fact, the more this distance larger, the more inspection speed large. Therefore we conducted hammering tests 50mm interval and 200mm interval by an expert. This result is shown as Figure 11 and Figure 12. Both tests could be detected a, b, c, g, h as in the Figure 9. Moreover, detection rate at whole defects is shown as Figure 13. As shown in Figure 10, the difference between 25mm and 50mm was within 3%. However, 200mm detected defects about 35% wider than 25mm and 50mm. This experimental results showed that hammering inspection at 50mm intervals is useful for accurate defective area. We think that it is useful to inspect at 200mm intervals and then inspect a detailed at 50mm at the defective area.

4 Conclusion

In this paper, we described usefulness of the way to detect concrete defects by an expert inspection worker using sounds of the robot. To verify usefulness of this system using the hammering robot, we conducted hammering experiments using a concrete test block at 25mm interval. As a result of the experiments, the results of defective area by the robot and an expert are similar. Moreover, the experimental results showed that the robot can simulate an expert within ±15% at almost defects. Therefore, we think that inspection workers can detect concrete defects using data sent from this robot. In addition, we think that they can automatically obtain inspection results using this robot that adopted the ensemble learning. method.

We also conducted hammering tests at 50mm, 200mm intervals by an expert to improve inspection speed. As a result of the experiments, the difference between 25mm and 50mm was within 3%. However, 200mm detected defects about 35% wider than 25mm and 50mm. We think that it is useful to inspect at 200mm intervals and then inspect a detailed at 50mm at the defective area.

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