# Development of New Bridge Inspection System using 5G and AI under Cloud Condition

Mai YOSHIKURA [a], Takahiro MINAMI [b], Tomotaka FUKUOKA [c], Makoto FUJIU [d], Junichi TAKAYAMA [e]

[a,b] *Graduate School of Natural Sience & Technology, Kanazawa University, Ishikawa, Japan*
[a] *E-mail: m.yoshikura@stu.kanazawa-u.ac.jp*
[b] *E-mail: taketaka0503@stu.kanazawa-u.ac.jp*
[c,d,e] *Department of Environmental Design, Kanazawa University, Ishikawa, Japan*
[c] *E-mail: tfukuoka@se.kanazawa-u.ac.jp*
[d] *E-mail: fujiu@se.kanazawa-u.ac.jp*
[e] *E-mail: takayama@staff.kanazawa-u.ac.jp*

**Abstract**: In Japan, bridges constructed in the high economic growth period are deteriorated. Road administrators are required to conduct close visual inspections once every five years for the maintenance. However, municipalities face difficulties due to lack of financial and human resources. Therefore, the research of efficient inspection method using new technology such as AI analysis of bridge image data is advanced.

In this study, we developed a bridge inspection support system that automatically detects cracks in concrete bridges from images. This system uses AI image processing technology by deep learning, and can detect cracks in a short time and carry out inspection work more efficiently. However, the capacity and number of images required for inspection are large, and it takes time to import image data into a system by mobile communication. Then, the system operation was verified using 5G in which high speed and large capacity communication were possible.

*Keywords*: Bredge, Crack, AI, 5G, Inspection

## 1. INTRODUCTION

Bridges built during the high-growth period are deteriorating in Japan. 10 years later, approximately 52% of the 720,000 bridges across Japan will be 50 years old or more (MLIT, 2019). In 2014, road administrators were required to conduct close visual inspections once every 5 years to maintain and manage road structures efficiently. Approximately 70% of all bridges are managed by municipalities (MLIT, 2019). In the near future, municipalities will face financial difficulties due to the repair of bridges. Especially, it is considered that the cost of scaffold inspection vehicles and labor costs will be high (JASST, 2016). In municipalities with insufficient financial and human resources, it is difficult to achieve continuous close visual inspection. Besides, there is a problem that the result of diagnosis varies depending on the inspector (JASST, 2016).

Therefore, a new inspection method is required to replace the close visual inspection using a new technology. New alternative technologies are expected to reduce inspection costs, operating time and inspect dangerous areas. For example, there have been many researches on detecting cracks in concrete structures from image data of bridges (Imai,2016; Nishimura,2013; Okada,2016; Kimoto,2017; Fujita,2018; Minami,2018).

In this study, we developed damage diagnosis support system, which analyzes bridge images with AI (Artificial Intelligence) using ultra high resolution image data and extracts damaged parts. The system is called "Systemized engineer's eye for Crack (SeeCrack)". SeeCrack imports bridge image data, and AI automatically detects length and width of the crack and supports the diagnosis of damage. SeeCrack is available to even an inspection workers having no deep knowledge or an inexperienced inspector. Furthermore, we built SeeCrack on the cloud in order to connect the inspector in the field with the engineer in the remote place. It makes inspection work efficient and short time.

The inspectors upload the photos from the bridge site by the mobile communication. Thus, they can do AI analysis without taking the photos back to the office. As bridge images to be inspected, we used 100 million pixel images to reproduce almost the same inspection environment as the actual visual inspection. The image data of 100 million pixels has a capacity of 600 MBytes per picture, and inspection needs many images per bridge. Therefore, it takes time to upload the image, and as a result, the inspection work time increases. To reduce the inspection work time, we utilized the 5th generation mobile communication system (5G) with features of high speed and large capacity.

## 2. System development

We developed the bridge inspection support system called SeeCrack. This system saves images of bridges, detects crack damage, supports soundness diagnosis, and manages them geographically. SeeCrack can automatically detect cracks, which is one of the inspection items of close visual inspection, by image analysis using AI. In Chapter 2, we describe the outline of SeeCrack and interview a bridge inspection engineer about SeeCrack.

### 2.1 System Overview

The four phases of SeeCrack are as follows.

1) We take photos of the bridge with the iXU-RS 1000 aerial camera, an ultra-high resolution camera. The iXU-RS 1000 aerial camera can take 100 megapixel (11,608 x 8708) photos. We can see cracks in photos as well as the close visual inspection. Photographic image data taken by this camera has a capacity of about 600 MBbytes per sheet. The camera is easy to carry because it measures 97.4 x 93 x 170.5mm and weighs 930g. If it is under the condition that it can be photographed, it is easy to inspect a bridge that needs a bridge inspection car, a height work car, a scaffold or a boat for inspection. Figure1 shows the situation that take by an ultra-high-resolution camera from 17m away from the pier. We were able to see cracks as small as 0.2mm from that image.

Figure 1. Situation of taking a photograph

2) Automatic detection of cracks by image processing technology using deep learning. The bridge images are estimated in pixel units "cracked piece" and "uncracked piece" from the previously learned model. Furthermore, crack maps are created by calculating the length and width of the extracted cracks.
3) Determining soundness in four stages based on image analysis results. Past crack detection results, site conditions, and past inspection records are also taken into consideration. As shown in Figure 2, scale, shape and position of crack are extracted from the image by pattern matching, and this information is useful for diagnosis. Although this phase is being studied and not yet implemented, it is not necessary for the purpose of this paper.

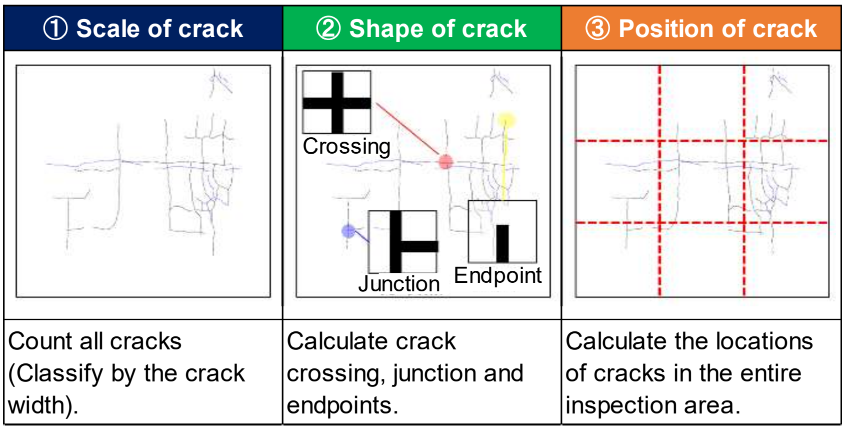


Figure 2. An example of crack feature extraction

4) The system marks the results of the bridge inspection on the map. These results are useful for the examination of bridge repair. In order to prioritize detailed inspection and repair, it is useful to group bridges by items such as manager, diagnosis result, and inspection date. The image of SeeCrack screen is shown in Figure 3.

Figure 3. SeeCrack Screen Image

## 2.2 Evaluation of the system

We interviewed a bridge inspection engineer about the function and usefulness of SeeCrack. We obtained opinions that SeeCrack provides objective damage detection, and shares images of the bridge at the same time with engineers and bridge managers in remote areas. In addition, it was able to find cracks in the photos which photographed bridge pier from the distance of 17 m by the camera of 100 million pixels. It was praised for being inspected by the photo taken without getting close to the bridge. In addition, we also got advice that if the system had a voice call function, it would be a better system. Because field workers could receive guidance from skilled engineers in remote areas while seeing images of bridge photos at the same time.

On the other hand, it was pointed out that it was better to confirm which part of the whole bridge was damaged on the screen of the system, not only the image of the damaged part. Because the degree of damage is judged not only by the size of the damage but also by the structure of the bridge and the damaged part. If the details of the damage and the damage part are known at a glance, skilled engineers in a remote area can make a quick judgment.

It is important to comprehend the bridge condition accurately by periodic inspection. Therefore it is a problem that the diagnosis varies depending on the inspector. AI analysis is one way to detect and record cracks based on objective criteria. If there is a crack, we can accurately compare with the past data whether the original crack progressed or suddenly appeared. And, because the diagnosis of the damage greatly affects the natural environment and the structure and type of the bridge, the judgment of humans is indispensable in the end. If photos of the bridge and damage automatic detection by AI can be shared, the quality of the inspection work will be improved. In addition, AI picks up the features of cracks, the engineers will be able to judge easily. Thus, the combined use of AI and human judgment is expected.

## 3. Target bridge

### 3.1 Overview of the target bridge

The target U-bridge has a length of 344 m, a width of 16.5 m, and 3 spans of continuous PC cable-stayed bridge. It was constructed in 2001, and the main tower height is 95 m, and 9 diagonal members extend from 2 A-type main towers of 54 m height.

### 3.2 Evaluation of the target bridge

Concerning the structure and close visual inspection method of the U-bridge, hearing was conducted with the bridge inspection engineer as described in Chapter 2 Section 2. The U-bridge needs to inspection with a vehicle for work at height or a vehicle. The bridge is not closed during the inspection, but the inspection is expected to be 5 or 6 people a day for 4 or 5 days. The inspection cost is estimated to be several millions yen, but this is based on the view that the U-bridge is new, and it takes time to inspect it with the service years, and the inspection cost after 10 years will be increased.

## 4. Demonstration experiment

We demonstrated automatic damage detection of U-bridge in SeeCrack. Photographs of the U-bridge taken in advance were uploaded to SeeCrack, and crack damage was automatically detected by AI analysis.

### 4.1 Experimental environment

In this study, we set up two categories: communication environments and cloud systems (Figure4). Table 1 shows items by category.

In the communication environment, there are 4 types of LTE (Mobile network carrier

A), LTE (Mobile network carrier B), eLTE and pre-commercial 5G. Mobile communication systems started with 1st Generations (1G) in the 1980s and evolved every 10 years. 4th Generations (4G) has been used since the 2010s. 4G has LTE and eLTE (enhanced LTE). 5G commercial service is scheduled to start in the spring of 2020 in Japan. 5G has three features of high speed, large capacity, low delay, and simultaneous connection of other numbers, and is expected to be able to transmit large image data with super high resolution. Since 5G had not started when we verified the demonstration, we conducted an experiment using pre-commercial 5G in February 2020.

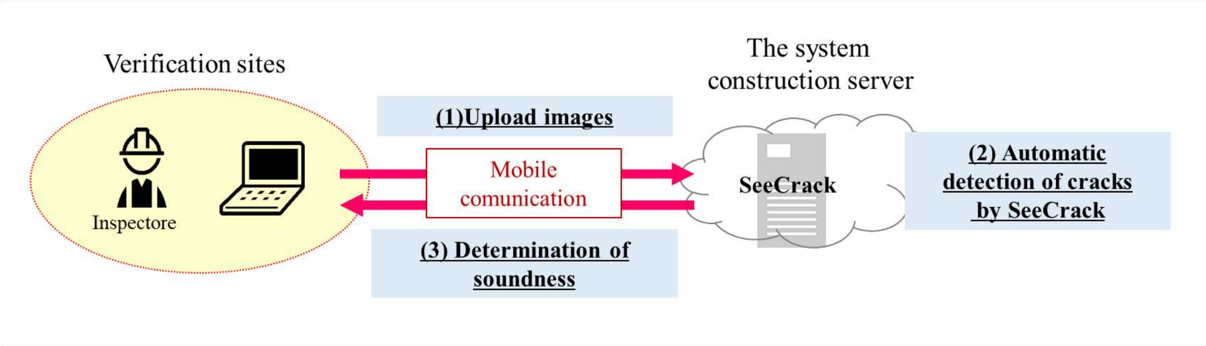


Figure 4. Diagram of the experiment

We constructed SeeCrack on the on-premises server and the cloud server. The on-premises server is an original production including a graphics board with GALAKURO GAMING model NVIDIA GEFORCE RTX 2060. The cloud server is docomo Open Innovation Cloud.

The verification sites are the pre-commercial 5G verification room (LTE(A), eLTE, pre-commercial 5G), the visual simulation room in the university (LTE(B)), and the bridge sites in I-Prefecture(LTE(B)).

Table 1. Examination items of the demonstration experiment

| Category | Item | Function |
|---|---|---|
| Mobile communication system | LTE (mobile network carrier A) | communication system, commonly called "4G" |
| | LTE (mobile network carrier B) | Verification by LTE communication of Company B for comparison with Company A. |
| | eLTE | It is means "enhanced LTE". "eLTE" evolved from conventional LTE. |
| | pre-commercial 5G | We experimented in "pre-commercial 5G" environment, because it was outstanding before "5G" service was launched. |
| The system construction server | On-premise | SeeCrack constructed on our University’s servers. We manage it ourselves. |
| | Cloud | The cloud server that we used was docomo Open Innovation Cloud. |

### 4.2 Evaluation object

Table 2 shows the processing time for each combination of survey items.The processing time was determined from the start of the registration of the object bridge to the system, to the upload of the photograph, the AI analysis on the server, and the feedback of the analysis result. In the case of U-bridge, 15 photographs were uploaded and 11 of them were analyzed by AI. The 15 photos uploaded are compressed in order to reduce the capacity.

Table2. Processing time in SeeCrack

| | *On-premise saver (sec)* | *Cloud Sever (sec)* |
|---|---|---|
| ***LTE (A)*** | *1,446* | *1,712* |
| ***LTE (B)*** | *1,979* | *1,859* |
| ***eLTE*** | *1,385* | *1,439* |
| ***pre-commercial 5G*** | *1,241* | *1,388* |

## 5. Analysis of demonstration experiments

From the results of Chapter 4, we analyze the inspection time, upload time, and inspection cost in SeeCrack.

### 5.1 Inspection work time

In the case of a close visual inspection of a U-bridge, it takes four or five days to check for cracks in the concrete. However, if we use SeeCrack, it takes only 0.5 hours to detect the damage automatically by AI, and it is estimated to be 1.5 hours in total including the photographing time required for the system.

The images analyzed by SeeCrack were prepared in advance and the shooting time was not measured, therefore it is not evaluated in this paper. Further experiment will be needed to comprehend the total working time for crack inspection including photographing time.

### 5.2 Upload time

The longer it takes to upload bridge images to SeeCrack, the longer it takes to inspect them. The upload time was shorter in the high-speed mobile communication environment. Ultra-high resolution images have a large data capacity of approximately 600 MB per one image. Furthermore, to inspect the entire bridge, multiple pieces images are uploaded to SeeCrack. We use large capacity images for SeeCrack analysis to view a wide range of components with high resolution in the same environment as close visual inspection. Since it takes time to upload images of large data capacity, uploading them in a high speed mobile communication environment. Using 5G, we reduce the upload time and perform the inspection more efficiently. The pre-commercial 5G used in this study is not an official speed. We will need to experiment with 5G commercial service to measure upload times.

We also compared two servers, On-premise and cloud. On-premise was faster than cloud, and we have concluded that it was the influence of the Internet environment. In the future, it is necessary to examine including the internet environment.

### 5.3 Inspection cost

The inspection cost of the U-bridge was estimated at several millions yen assuming the inspection work for 4 ~ 5 days with 5 ~ 6 workers a day by the close visual inspection. On the other hand, using SeeCrack, we assume the cost of the ultra-high resolution camera and using system, and 2 ~ 3 workers can do it in a few hours. From examining the findings, the inspection cost can be reduced by using SeeCrack.

Moreover, as the bridge becomes older, the time and labor required for inspection of damaged parts in the close visual inspection become larger. Therefore, even on the same bridge, the cost will increase after 5 or 10 years. On the other hand, the cost of SeeCrack does not change even after 5 or 10 years because it takes the same amount of time and effort to photograph the bridge and analyze by AI.

## 6. Conclusion and future work

In this study, we developed "SeeCrack", a system to analyze crack damage of concrete bridges by AI and to support diagnosis, as an alternative technology to close visual inspection. In addition, the image data of the bridge was uploaded to SeeCrack using pre-commercial 5G, and the result of automatic damage detection was obtained from the system. Our data suggested that SeeCrack can be operated in an environment over the internet, and upload time are reduced in fast mobile communication environments.

In the future, if automatic damage detection by SeeCrack using 5G will be utilized, the inspection time and cost will be reduced compared with the past, and the safety will be also improved. Thus, it is expected to contribute to the efficiency improvement of preventive maintenance management of bridges.

We proved that SeeCrack could improve the efficiency of bridge inspection work. However, in this study, it is difficult to evaluate how much inspection time can be reduced concretely depending on the size and type of bridges at inspection sites. It is necessary to verify the required time in actual inspection work using SeeCrack in the bridge inspection sites in future.

## REFERENCES

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2019) Road Mai ntenance in Japan, Problems and Solutions, http://www.mlit.go.jp/road/sisaku/yob ohozen/torikumi.pdf.

Japan Society of Next Generation Sensor Technology (JASST) (2016) Survey rep ort on bridge inspection work in local government, http://www.socialinfra.org/p_ technology/Apdf_H.pdf.

Imai, M., Ohta, M., Tsuyuki, K., Imai, H., Miura, S., Murata, K., Takada, J. (2016) Video image based dynamic behavior analysis of concrete structures by using digital image correlation method, Journal of Japan Society of Civil Engineers, Ser. A1 (Structural Engineering & Earthquake Engineering), vol. 72, No.1, 279-289.

Nishimura, S., Kimoto, K., Matsuoka, N., Otani, H., Ogata, T., Matsuda, H. (2013) The Development and Evaluation of Telemetry in Bridge Maintenance, Journal of applied survey technology, 24, 52-61.

Okada, Y., Okatani, T. (2016) Evelopment of UAV with Passive Rotating Spherical Shell for Bridge Inspection and its Evaluation of Inspection Capability in Real Bridges, Journal of the Robotics Society of Japan, Vol.34, No.2, pp119-122.

Kimoto, K., Yamaguchi, K., Okumatsu, T. Kawamura, T. Matsuda, H. (2017) The Development of Inspecting Method about Bridge without Temporary Scaffold Using Optical Measurement Techniques, 47(89), pp.59-66.

Fujita, Y., Taguchi, T., Hamamoto,Y. (2018) Image mosaicking and semi-automatic crack evaluation for visual inspection of concrete structures, Journal of Japan Society of Civil Engineers, Ser. F3 (Civil Engineering Informatics), Vol.74, No.1, pp18-32.

Minami, T., Fujiu, M., Takayama, J., Suda, J., Okumura, S. (2018) A Study on Image Diagnostic Technology for Bridge Inspection Using Ultra High Resolution Camera. 5th International Conference on Road and Rail Infrastructure : 79-85.