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DEVELOPMENT OF NEW BRIDGE INSPECTION SYSTEM USING 5G AND AI UNDER CLOUD CONDITION

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Abstract

In Japan, the deterioration of bridges constructed in the high economic growth period is progressing, and the maintenance of those bridges is a problem. Municipalities, as road administrators, are required to conduct close visual inspections of bridges (longer than 2m) once every five years, but municipalities face difficulties due to lack of financial and human resources. For this reason, the research of inspection and diagnosis technology is advanced for efficient inspection work. Especially, it is the new technology of ICT (information and communications technology), such as AI analysis of image data of bridge photographs.
In this study, we developed a bridge inspection support system that automatically detects cracks in concrete bridges from bridge photographs. This system uses AI of image processing by deep learning. By using AI, we will be able to detect cracks in a short time and inspect bridges more efficiently. However, it requires many photographs of huge amount of data for image analysis. And those images take time to upload to the system by mobile communication. Therefore, we verified the system operation using 5G mobile communication, which is characterized by high speed and large capacity.

Keywords: bridge inspection, ICT technology, image processing

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 [1]. 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 [1]. 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 [2]. In municipalities with insufficient financial and human resources, close visual inspection becomes impossible in the future. In addition, the result of the inspection differ depending on the inspector [2].
Therefore, a new inspection method using new technology is required to replace the close visual inspection. Alternative methods are expected to reduce inspection costs and operating time. There are many researches using new technology such as detecting cracks from image data of bridges [3-8].
In this study, we developed damage diagnosis support system, which analyzes high-resolution bridge images by AI (Artificial Intelligence) . This system is called “Systemized engineer’s eye for Crack (SeeCrack)”. When bridge images are imported into SeeCrack, it au-

tomatically detects the length and width of crack. SeeCrack can be operated by unskilled or inexperienced inspectors. Furthermore, SeeCrack was built on the cloud computing, and inspectors in the field and the engineers in the remote place were connected. It can perform inspection work efficiently in a short time.
The inspectors can upload images from bridge field via mobile communication and conduct AI analysis on the field. We used 100 million pixel images that has almost the same visibility as the actual visual inspection. The image data of 100 million pixels has a capacity of 600 MB per picture, and many images are necessary for the bridge inspection. Therefore, it takes time to upload images, 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 precise visual inspection, by image analysis using AI. Chapter 2 describes the outline of SeeCrack and the interview of a bridge inspection engineer about SeeCrack.

2.1 System overview

The four phases of SeeCrack are as follows:
Phase 1: To take photos of the bridge with the ultra high-resolution camera "iXU-RS 1000". The iXU-RS 1000 camera can take 100 megapixel (11,608 x 8708) photos. By enlarging the image, the visibility of small crack of the bridge can be easily recognized, which is like aclose visual inspection. Photographic image data taken by this camera has a capacity of about 600 MB per image. The camera is easy to carry because it measures 97.4 x 93 x 170.5 mm and weighs 930 g. Bridges with space for photography can be inspected more easily than 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 17 meter 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

Phase 2: Automatic detection of cracks by image processing technology using deep learning. The bridge images are predicted in pixel units "piece with cracks" and "piece without cracks" from the previously learned model. And the system calculates the length and width of the extracted cracks and dreates a "crack map".

Phase 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.

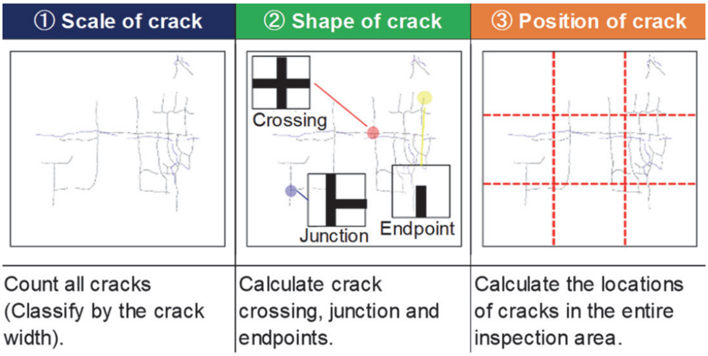

Figure 2 An example of crack feature extraction

Phase 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 data according to items such as manager, diagnosis result, and inspection date.The image of SeeCrack screen is shown in Figure 3.

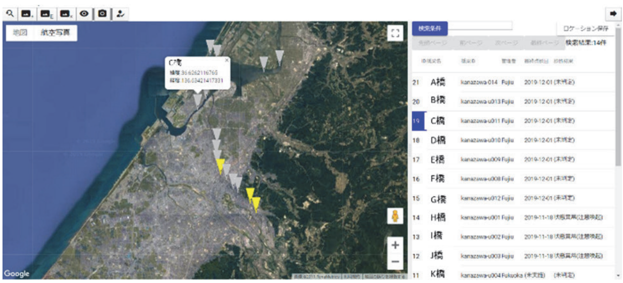

Figure 3 SeeCrack Screen Image

2.2 Evaluation of the system

We interviewed a bridge inspection engineer about the function and usefulness of SeeCrack. According to it, SeeCrack conducts objective damage detection, and workers in the field and engineers in remote places can share images of the bridge at the same time. In addition, it was able to find cracks in the photos which photographed bridge pier from the distance of 17 meter by the camera of 100 million pixels. It was valuable to be able to inspect with photos taken without getting close to the bridge. Additionally, we also got advice that if the system had a voice call function, it would be a better system. That's because field workers could receive guidance from skilled engineers in remote areas while checking images of bridge.
Furthermore, there was a comment to display not only the image of the damaged part but also which part of the whole bridge was damaged. The structure of the bridge and the damaged place also influence the damage decision. If the details of the damage and the damage part are easily identified, skilled engineers in a remote area can make a quick decision.
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. With an objectie crack record, we can accurately compare whether the original crack progressed or suddenly appeared with the

past data. Finally, human decision is indispensable, because the diagnosis of the damage greatly influences natural environment and structure and type of the bridge. If photos of the bridge and damage automatic detection by SeeCrack can be shared remotely, the quality of the inspection work will be improved. AI can detect the crack from images, and the engineers can decide easily. The combination of AI and human decision 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. Built in 2001, 9 diagonal members extend from 2 type A towers, 95 m in height and 54 m in height from the outer surface of the main girder.

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. This bridge is not closed during the inspection, but the inspection is expected to be 5 ~ 6 people a day for 4 ~ 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. In general, the older the bridge, the longer it takes time to inspect it, so the cost of this bridge inspection after 10 years will increase.

4 Demonstration experiment

We demonstrated automatic damage detection of U-bridge using SeeCrack. Images 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 (Figure 4). Table 1 shows items by category.

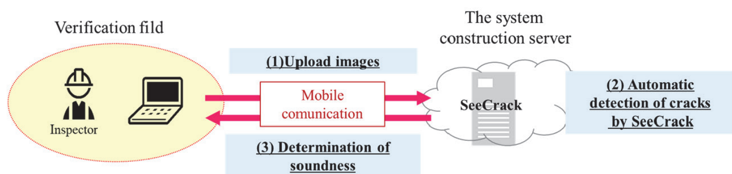

Figure 4 Diagram of the experiment

In the communication environment, there are 4 types, 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 was 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 which was not a sufficient spec in February 2020.

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 feilds 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 feilds 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	In the demonstration, we used “pre-commercial 5G” because “5G” was before it was launch.
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 images, the AI analysis on the server, and the feedback of the analysis result. In the case of U-bridge, 15 images were uploaded and 11 of them were analyzed by AI. The 15 images uploaded were compressed in order to reduce the capacity.

Table 2 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 4 ~ 5 days to inspect 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 for the inspection including the photographing time.

The images analyzed by SeeCrack were prepared in advance and the photographing 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

It is necessary to upload a large number of high-resolution images (about 600 MB per image) to SeeCrack for the inspection of bridges. Since it takes time to upload large data images, it is beneficial to upload using high-speed mobile communication. By using 5G, we expect to reduce the upload time and make the inspection more efficient. In the future, 5G is said to be 100 times faster than 4G [9]. At the time of the experiment, 5G service was not started in Japan, and we used pre-service 5G, which was not a sufficient spec. Therefore, there was no significant difference in upload time compared to 4G. However, in the real service of 5G, it is expected that the upload time difference will increase rapidly in future. We will need to experiment with real 5G 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 instecion 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 ultrahigh-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 are increase. Therefore, even on the same bridge, the cost will increase after 5 or 10 years. On the other hand, the cost of usng 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. SeeCrack is a system which can be utilized in the Internet environment, and it can be expected to be utilized not only in Japan but also in overseas bridge 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.
Automatic damage detection by SeeCrack using 5G will reduce inspection time and cost and improve safety compared with convnentional inspection methods. And this new inspection method will promote the efficiency of preventive maintenance management of bridges.
We show the possibility that SeeCrack can improve the efficiency of bridge inspection work. However, in this study, it was not clear how much inspection time could be reduced depending on the size of bridges. In the future, It is necessary to measure the inspection time using SeeCrack in some bridge fields.

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