Remote Control Demonstration of the Construction Machine Using 5G Mobile Communication System at Tunnel Construction Site

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Abstract –

Since March 2020, 5G has been commercialized mainly in urban areas in Japan, and 5G communication infrastructure demonstration tests are actively conducted among various industries such as telecommunications carriers and construction industries.

The authors installed a portable 5G base station close to tunnel portal in "Subcontracting for research and study of technical conditions, etc. for a fifth-generation mobile communication system (Hereafter, 5G). This can handle simultaneous connection requests from various terminals" (Hereafter, 5G demonstration experiment) of the Ministry of Public Management, Home Affairs, Posts and Telecommunications in fiscal 2019, and constructed a high-quality radio wave environment in the tunnel pit, and carried out various experiments to improve working environment such as safety.

This paper describes an experiment in which a long-distance running and lifting work of a construction machine succeeded by remote control, while a high quality radio wave environment was constructed in a tunnel construction site by 5G, and clear multiple images which can surely carry out remote control, and other support information were acquired.

Keywords –

fifth-generation mobile communication system(5G); construction machinery; remote control

1 Summary

Standardization of the next generation mobile communication standard (Hereinafter abbreviated as "5G") is advanced in 3GPP (3rd Generation Partnership Project) which decides the world standard of the mobile communication.

5G can realize high speed and large capacity (eMBB: enhanced Mobile Broadband: up to 10 Gbps or higher), ultra-low delay (URLLC: Ultra-Reliable and Low Latency Communications: One-way transmission delay of 1 ms or less), and multiple simultaneous connections (mMTC: massive machine type communication: 1 million devices/km^2), and is expected to be used not only in conventional communications not only for smartphones but also in various industrial fields [1].

In recent years, there has been a strong movement to improve productivity at construction sites through ICT (information and communication technology) based on the "i-Construction (i-Con)" advocated by the Ministry of Land, Infrastructure, Transport and Tourism. Many IoT and ICT equipment easily used on site, have been introduced and put into operation.

However, even before i-Con was proposed, there was a method using IoT and ICT, which is the focus of this paper, unmanned construction by remote control of construction machinery (Figure 1).

Figure 1. Status of unmanned construction

This method is used at the restoration of natural disasters and in severe places such as radioactive environment, etc., where safety is concerned when person enters and work, and using radio-controlled construction machines communicating by radio and camera images for confirming the construction situation. Therefore, the construction of wireless infrastructure is a very large technical element for this method.

If radio-controlled construction equipment cannot be operated smoothly due to the quality of the wireless infrastructure, or if the quality of camera images for acquisition of construction information is deteriorated, the construction efficiency is affected and construction becomes difficult. Therefore, the present unmanned construction is often carried out in the range of about 150 m in which radio wave surely reaches by utilizing Wi-Fi, etc.

Unauthorized and inexpensive Wi-Fi is said to have a considerable merit, but in reality, there are not many works that can be done within the range of one Wi-Fi communication device.

Even if authorization is necessary, infrastructure which can stably communicate in a wide range will be required in future. Therefore, the experiment was also carried out from the viewpoint of whether the new communication means of 5G can become the communication infrastructure for the remote control of the construction machinery.

Figure 2. Image of remote control

2 Outline of experiment and demonstration site

The Japan islands are divided into the Pacific Ocean side and the Sea of Japan side by chain of mountains. Population tends to be concentrated in lowlands on the sea side and basins in mountains.

Because 70% of the land is mountain and hilly land occupy geomorphologically, the transportation infrastructure between cities in the lowland and basin passes through the mountain.

Since old times, the transportation network has been constructed by cutting down the mountain. In recent years, transportation networks in mountainous areas have been disrupted by disasters caused by abnormal weather.

Losses due to these disasters have social and economic impacts not only on damaged transportation infrastructure facilities but also on the isolation of regions. Therefore, it is highly necessary that the tunnel is newly constructed or improved as a review of the transportation network

The reason we selected "tunnel" is because 1) we thought that tunnels are indispensable infrastructure for modern society as railway transportation infrastructure such as subway and life infrastructure such as water supply and sewerage; and 2) important as social capital in urban areas.

Since the radio wave has the property of reflection and transmission, we thought that it was interesting in the aspect of how much radio wave reaches by repeating reflection and transmission in the tunnel environment.

From such background, this experiment was carried out on a subject of "tunnel", assuming actual possible phenomena, and considering to propose a solution. As shown in Figure 3, it is assumed that a site survey and response are carried out when an inaccessible place occurs in a tunnel. A 5G base station is installed near the entrance (Hereinafter, the pit mouth) of the tunnel, and radio waves are outputted toward the tunnel pit. We decided to carry out remote control of the construction equipment within the range of radio waves.

At present, when such a situation occurs, preliminary investigation and consultation with experts are carried out as much as possible, but there are cases in which eventually carried out by human power. In the future, these cases should be avoided from the viewpoint of worker safety, and they should be dealt with by IoT/ICT or 5G communication technology. This experiment is considered to be a practical use case.

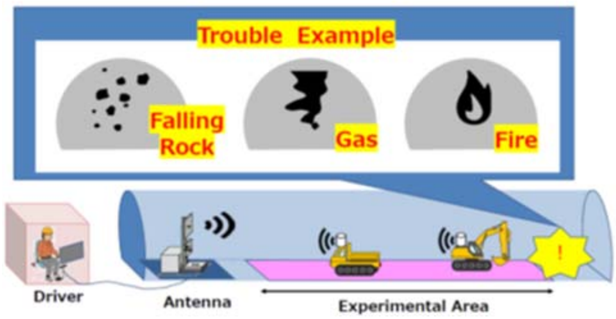


Figure 3. Outline of this experiment

In the experiment, we mainly carried out the following two points.

1. 5G radio wave propagation characteristics (reach distance)
   A 5G radio base station was installed near the tunnel portal to the face, and determined the experimental area by measuring where it reaches in the tunnel.

2. Remote operation of construction machinery The remote control of the construction machine was carried out in the experimental area. (4-ton class crawler carrier and 12ton class hydraulic excavator

2.1 Experimental Location

Project names: Hokkaido Shinkansen Line, Shiribeshi Tunnel (Ochiai)
Owner: Japan Railway Construction, Transport and Technology Agency (JRTT)
Contractor: Taisei, Sato, Tanaka, Horimatsu JV
Construction period: March 26, 2015 - June 24, 2022
Main construction: Tunnel excavation 4,865 m (Standard cross section: 65 m2)

2.2 Use of portable base stations

In conventional mobile communications, in order to deal with data communication traffic of mobile phones such as smart phones, base stations are often installed mainly from urban areas where the number of users is large. On the other hand, in 5G, by utilizing the features of eMBB, URLLC, and mMTC, it is considered that IoT (Internet of Things) will become the mainstream along with smartphone.

However, when it is applied to IoT, not only in urban areas but also in suburban areas where the number of users is relatively small, a large amount of traffic processing will be periodically required. Construction sites are one of such IoT use cases, but constructing new base stations in suburban areas requires more time and cost than constructing in urban areas.

In this experiment, we used a portable 5G base station developed by Softbank Corporation, which can construct a local 5G communication infrastructure (Figure 4). In this base station, not only antennas and radios but also core equipment in the data center can be arranged in the field. Therefore, in the field, the collected data can be processed at high speed and in a complicated manner.

And, if prior adjustment such as license application is completed, 5G communication area can be rapidly developed in a few days, and will be suitable network solution for the development of IoT to the suburb.

Figure 4. Portable 5G facility installed in the tunnel (4.85 Ghz, 120 W).

2.3 Use of on-board remote-controlled robots

For the remote control, we used the construction machine mounted remote control robot (hereinafter referred to as Robot) developed by Kanamoto Co., Ltd. The experiment was carried out by mounting this robot on each of the two construction machines mentioned above.

The robot is a humanoid twin-arm bipedal robot (Figure 5) with the total length of about 1.5 m and the weight of about 20 kg, which can be installed in the operator's seat of a construction machine. (conversion to radio-controlled equipment). By transmitting the image mounted on the construction machine in real time from the driver's viewpoint and transmitting the state of inclination and vibration of the vehicle to the driver's seat bilaterally, the system is capable reproducing the driving remotely feeling close to the real machine.

In addition to such reproducibility, it is highly possible to respond more quickly than the method of procuring radio-controlled construction machinery with limited number of units. For the construction site, there is an economical merit that the construction machinery in the site can be utilized. In this experiment, it was also the first execution to control the Robot by 5G communication in the environment in which the visual observation was not effective at all.

Figure 5. Robot

2.4 Use of Human Body Detection Cameras

There is a report from advanced driver-assistance systems (ADAS) to support the driving operation of the driver of the car that the number of "Rate of contact accidents with people" is decreasing in the cars equipped with "Human body detection system". ADAS is a function to automatically stop a vehicle when a person is detected in a traveling direction by a camera mounted on an automobile, and is an epoch-making technology to improve safety of a driver and a pedestrian.

One of the three major industrial accidents in the construction industry is "construction machinery", and there are many reports of cases in which people and machines come into contact. Taisei Corporation is developing technology to eradicate this disaster.

In this experiment, we plan long distance running by remote control by crawler dump with high rough terrain running performance as an initial action. We also assumed that it was necessary to explore whether there were people left in the tunnel in an emergency. In this experiment, we used a technology that automatically stops construction machinery by sending a stop signal to the construction machinery side when a person enters the movable range of the construction machinery during remote control.

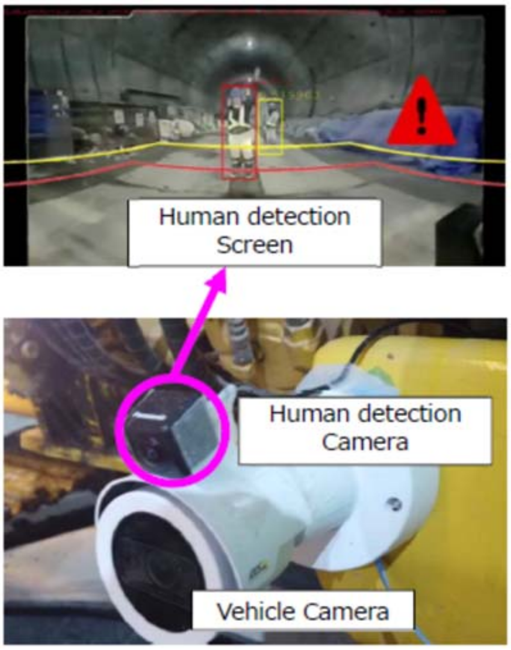


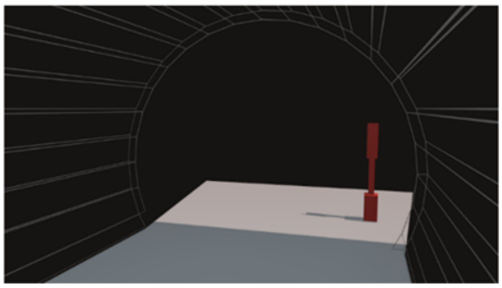
Figure 6. Human body detection camera
(Above: Detected human body)

3 Experiments and Results

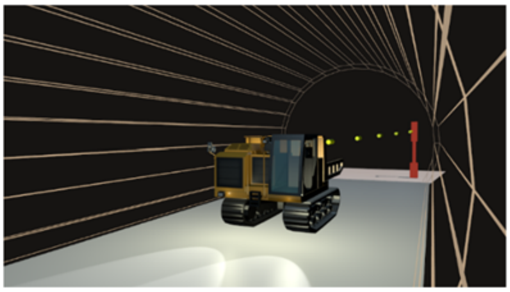
Troubles such as “fire”, “toxic gas”, and “rockfall” shown in Figure 3 are supposed in a tunnel pit, which is difficult for a human to approach. For such trouble, the experiment was carried out by the following procedure. (This is an assumption and is not related to the experimental site.)

3.1 Experimental Scenarios

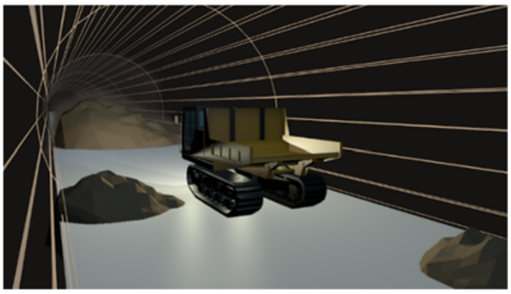
1. Portable 5G base station installed near the tunnel portal



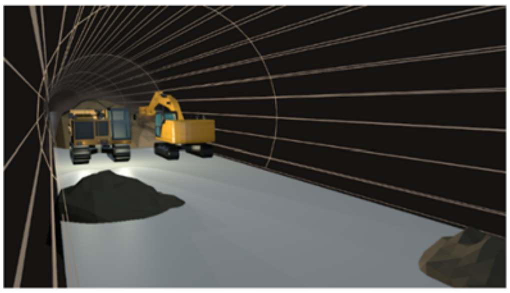
2. Investigation by crawler carrier. In addition to cameras, gas detectors and scanners are installed on vehicles.



3. Since the vehicle has high traveling performance, it is possible to search for long distance while avoiding obstacles

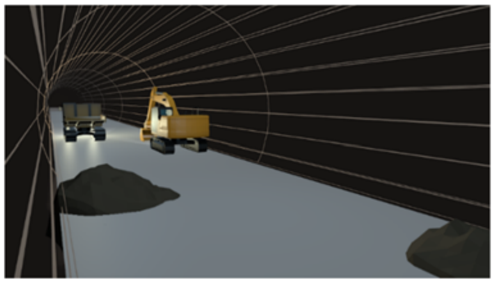


4. A loading machine is installed to remove the obstacle



5. Image of Obstacle Removal

6. Removal completed. go further into



3.2 5G Radio Wave Propagation Characteristics (reach distance)

A radio wave measuring vehicle was used to measure the processing speed (UL side throughput) of the 5G radio wave in the tunnel pit for each distance. The results are shown in Figure 7.

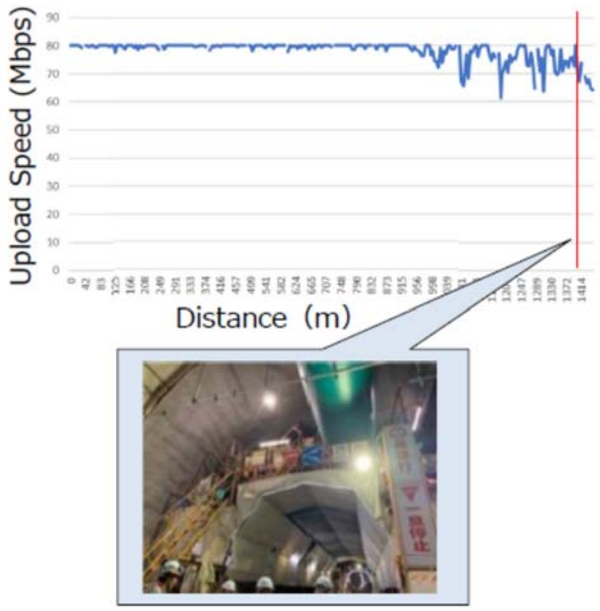


Figure 7. Measured results of the distance reached.

The site had a section including a curve (R = 6,500 m), and it was an environment in which the back side could not be viewed directly, and in addition, it was an environment in which materials and equipment for construction were placed. Therefore, in the preliminary examination, the reach distance of several hundred meters was estimated. However, actually, the radio wave reached far exceeding it. At the 1,400 m point, the "tunnel lining form" which covers most of the tunnel section is located (Therefore, the radio measurement vehicle was not measured on the face side.), and the processing speed is expected to drop rapidly beyond this point.

3.3 Remote Control of Construction Machinery

Two models shown in Figure 8 and 9 were remotely operated

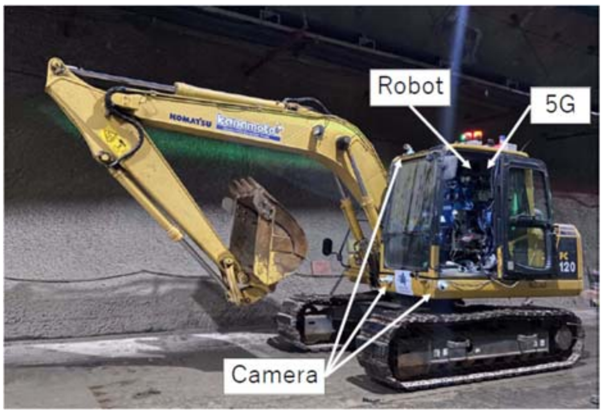


Figure 8. 12ton class hydraulic excavator

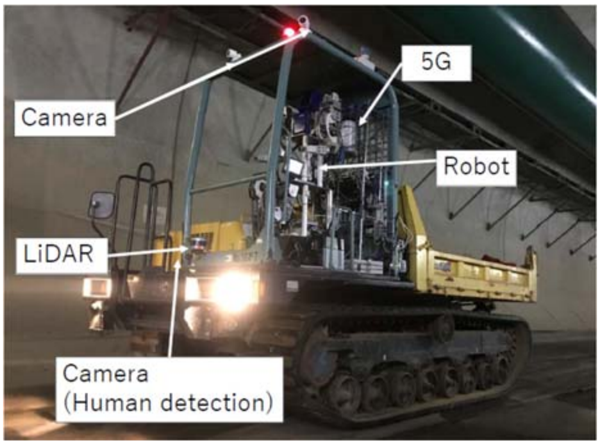


Figure 9. 4ton class crawler career

The remote control which steers while watching the video information is usually carried out by in-vehicle video and bird's-eye view video. However, it is difficult to make a large numbers of birds-eye image acquisition facilities for remote control, because of technical and economic difficulties.

Therefore, in this experiment, by taking advantage of the feature of large-capacity 5G communication, by adding a large amount of sensor information in addition to in-vehicle video as in the past, all remote operation support information was installed in the vehicle, and no birds-eye view video was used (Figure 10).

Figure 10. Remote operation support information

Table 1 lists the remote operation support information for this experiment. Here are two sensors to be noted.

One is the detection of obstacles on the tunnel wall and ahead from the large-capacity point cloud information obtained by sensing with Lidar (Generic 16 Line). The other is the adoption of the human body detection system by AI developed by Taisei Corp.

In both systems, smooth transmission and reception are difficult using conventional Wi-Fi and low-power communication, but 5G communication is possible.

Table 1. List of Remote Operation Support Information.

type	Direction	Units	Capacity (bps)
Vehicle Camera	Up	4	60M
Robot Control	Down	1	40K
Vehicle Vibration	Up	1	40K
Lidar	Up	1	70M
Human detection	Up	1	15M

Each construction machine was able to carry out the following by remote control. Both were successful without birds-eye view (Figure 11).

1. A crawler carrier ran 1,400 m by remote control.
2. 2) Hydraulic shovel: lifted and moved 1ton sandbag by remote control.

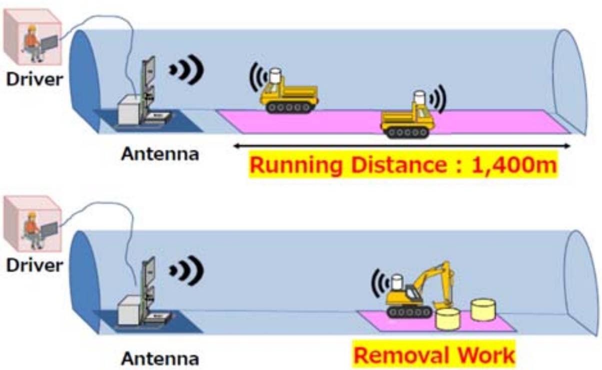


Figure 11. experiments

4 Conclusion

The verification of the portable 5G facility was carried out in the tunnel environment this time, following the external environment in fiscal 2018 [2]. From the result, it is considered a communication infrastructure which can be adapted to many construction sites.

In the construction site, the construction is started by improving temporary facilities in accordance with the construction contents. In order to advance the ICT in the construction field, "temporary communication" will be necessary in future, and the possibility that 5G will become highly influential in the selection of the communication radio wave.

The case verified this time is the technology which can be utilized for investigation of tunnel disaster and emergency work even in the present stage, and it is considered to be one of the effective utilization of 5G. We would like to continue our research on the improvement of construction productivity using 5G.

I would like to take this opportunity to thank all of you who are participating in and cooperating with this experiment.

References

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[2] Aoki et al., Construction of Construction Production System using (5G) (CHAPTER 1), JSCE Annual Lecture, Sep. 2019