Development of Remote Control Technology That Offers a Flexible Working Style

Because of the declining birthrate and aging population, there are serious labor shortages in so-called "3D" (Dirty, Dangerous, and Demeaning) jobs such as manufacturing, and the improvement of working environments is an urgent task. As one of the solutions to this problem, remote control of manufacturing work is required.

Basically, a wired LAN is used to connect to different pieces of factory equipment because Wi-Fi cannot provide adequate responsiveness and reliability. However, there are physical and cost constraints to connecting many pieces of equipment by wire; therefore, it is difficult to realize remote control using wired networks. However, the emergence of private 5G has changed these constraints dramatically. We have carried out development to realize remote control of robots by making networks wireless using private 5G.

Introduction

Japan's population has continued to decline since 2011, and labor shortages due to the declining birthrate and aging population are an issue. Labor shortages are especially serious in so-called "3D" (Dirty, Dangerous, and Demeaning) jobs, and the improvement of working environments is an urgent task.

1 Background

Recently, much attention has been drawn to Smart Factories, where data on workers and equipment in the factory is collected by IoT (Internet of Things) technology, and then analyzed and used effectively to create new added value. Realizing a Smart Factory requires wireless communication, which enables flexible, efficient factory networking; one option for doing so is private 5G.

2 Remote manufacturing

During the COVID-19 pandemic, with regard to office jobs, remote working has become increasingly common, and web meetings have also become widespread. However, for manufacturing jobs, materials are basically processed with machine tools and assembled on site. Therefore, remote working is difficult.

To perform typical manufacturing jobs remotely, including transport, processing, assembly, inspection, and shipment, one option is to automate such jobs as much as possible using AGVs (Automatic Guided Vehicles) and robots and to operate such machines remotely. To do so, there is a need to transmit a control command to equipment via communication while monitoring the shop floor by communication, transmit the next command based on the received operation result, and then repeat these steps. This requires the equipment to be connected to a network, and connecting many pieces of factory equipment by wire requires the installation of a huge number of LAN cables, network switches, and other network devices inside the factory. In addition, if the shop floor layout is changed to manufacture a different product, these numerous cables must be rerouted. Developing a remote environment involves making a large number of arrangements. Therefore, wireless communication is highly beneficial in controlling factory equipment remotely.

Many factories have adopted wireless LAN, but wireless LAN is susceptible to noise and it is difficult to ensure stable communication. In addition, data is transmitted at high speeds between different pieces of equipment, and if data communication suffers delays, the equipment cannot operate normally. Therefore, wireless communication requires high reliability, high speed, and low latency. For these reasons, the 5th Generation Mobile

Communication System (5G) is now attracting attention.

In addition to wireless communication, robots that can be controlled remotely to do jobs that have heretofore been done by humans are necessary, and we have already put Successor [1)] into production as a robot system for controlling such robots. Successor uses a dedicated controller called Communicator to control robot arms remotely. Because of the aging of society, passing down the skills of experienced engineers, who are the successors of advanced manufacturing technologies, is a common issue in many developed countries. Successor is a new robot system developed to solve this issue.

Thus, we worked to outfit remote control robots with wireless communication in order to realize remote control of the shop floor.

3 Technical challenges in making factory communication wireless

5G is a communication system standard for which commercial service began in Japan in spring 2020. 5G is characterized by its ultra-high speed transmission, massive connected devices, and ultra-low latency. There are two types of 5G: carrier 5G and private 5G. While mobile operators provide carrier 5G, private 5G is used by private companies, local governments, and other organizations to build 5G networks on their own as shown in **Fig. 1**. This system was newly introduced for 5G to enable flexible development and operation of optimal 5G networks regardless of the service provision status of carrier 5G.

5G communication is expected to be applied for industrial purposes, but conventionally, information has mainly been communicated wirelessly. Therefore, the following performances, which are required to apply wireless communication for industrial purposes, must be verified.

① Transmission speed

To monitor the progress of processing statuses and other information in remote locations, transfer of high-definition video (HD video, 4K video, etc.) is required.

② Latency

The most important factor in controlling equipment by 5G communication is latency. Production equipment and robots in factories are controlled to an accuracy of milliseconds, and if there is even a slight delay in communication between pieces of equipment, they may not operate normally.

③ Coverage area

Millimeter waves, which enable 5G's high speeds, greatly attenuate in the air; therefore, they can travel only a very limited distance. It must be verified how far these millimeter waves travel on the shop floor.

④ Environmental tolerance (noise immunity)

Various working machines, including large cranes and forklifts, operate in factories. These may be sources of noise or obstacles for radio waves. Therefore, communication stability must be verified while the factory is running.

4 Overview of verification

To tackle these technical challenges, we introduced a 5G facility at the Harima Works on a trial basis from November 2020 to January 2021 and conducted a Proof of Concept (PoC) to verify 5G performance.

This test utilized 5G NSA (Non Standalone), while 4G was utilized for the core network (equipment having

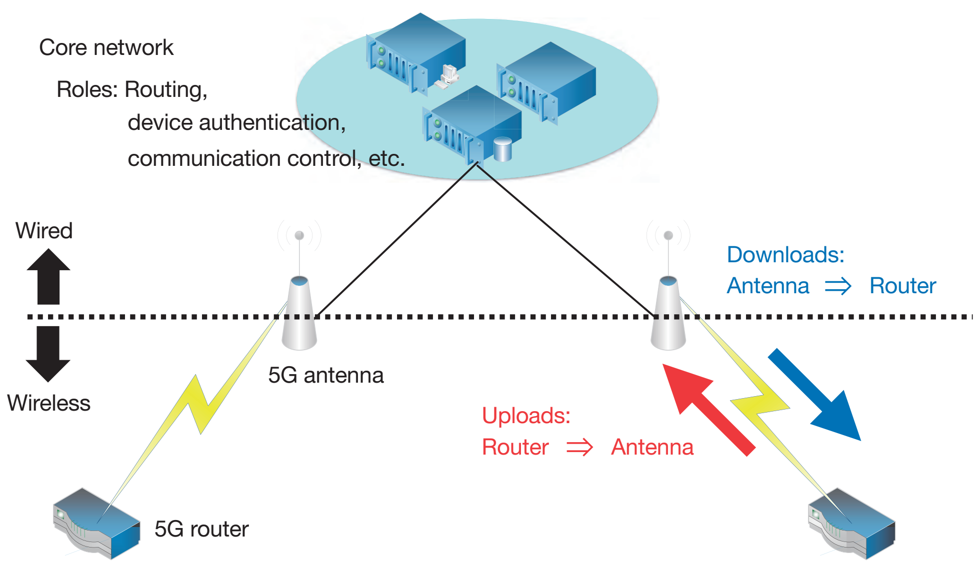

Fig. 1 Private 5G system

authentication, data packet transfer route configuration, mobility management, and other functions). Normally, however, 5G SA (Standalone) should be used, and all base station equipment, from the wireless communication equipment to the core network equipment, should be designed exclusively for 5G, but products for doing all of this are not yet available. Among 5G's three features, only high speed and high capacity can be achieved with the NSA system; with this system, 5G's latency is almost the same as that of 4G.

Successor-G [2] in the Harima Works was used as the remote control robot. Successor-G is a robot system for grinding, deburring, and surface finishing. The worker operates the communicator, which eliminates the need to perform heavy work and relieves the worker from working under adverse conditions, such as in a hot and dusty environment.

Remote control with the current Successor-G assumes that the operated robot is located within line of sight, and the communicator and robot are connected via wired LAN. This time, as shown in **Fig. 2**, private 5G was used to establish wireless communication and to verify whether the robot could be operated remotely by monitoring the 4K video, and whether remote control was possible.

The test steps are shown in **Fig. 3**. First, we set up a 5G antenna on the first floor of the skills training facility at Harima Works and conducted a basic performance test and remote control test with Successor-G. Next, we moved the 5G antenna to the tank manufacturing factory at Harima Works and verified the communication area and noise immunity. We set up the core network in the administration office of Harima Works.

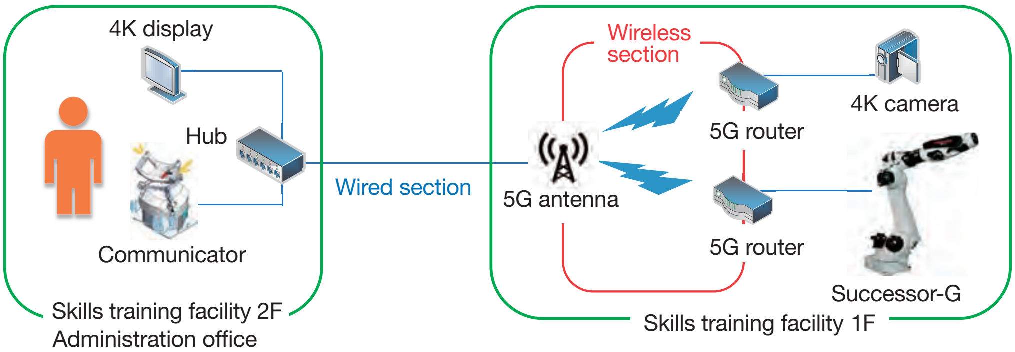

Fig. 2 5G system configuration for Successor

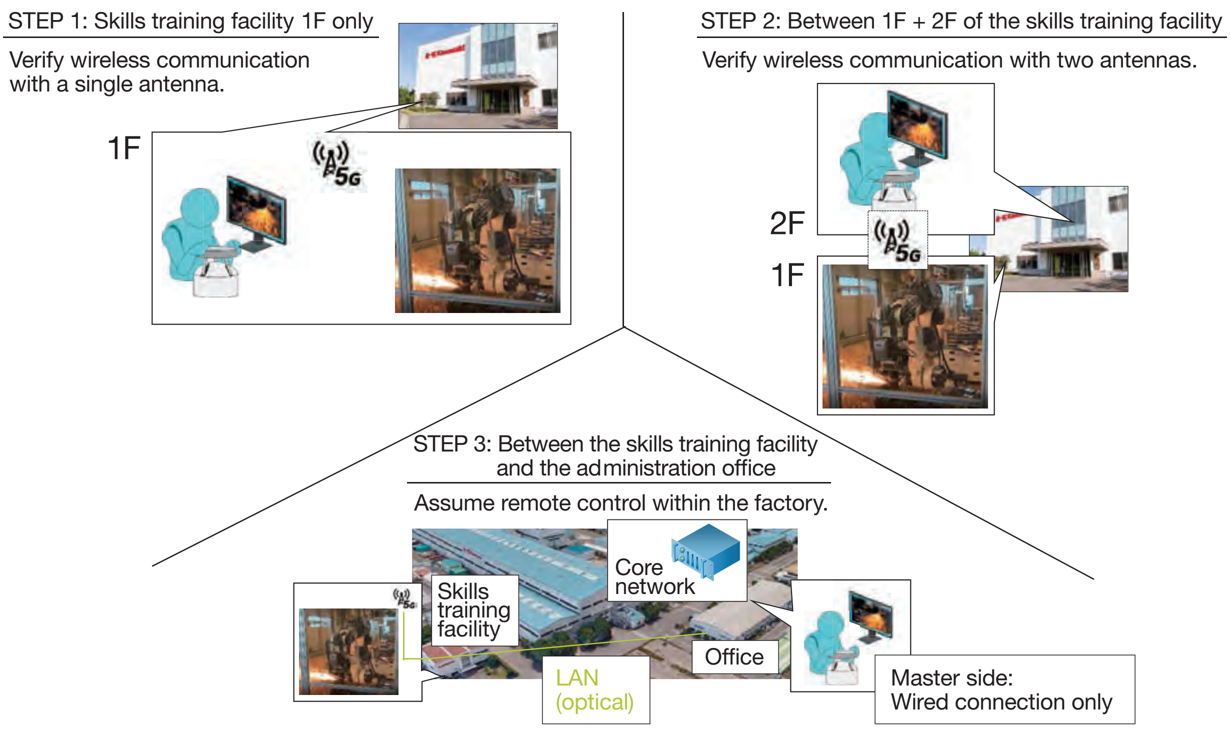

Fig. 3 Test steps

5 Details and results of verification

(1) Basic performance test for private 5G

We measured the transmission speed, latency, and radio field intensity with a network tester while changing the position of the 5G antenna in the skills training facility and in the tank manufacturing factory.

①② Transmission speed and latency

The maximum download and upload speeds were 650 Mbps and 120 Mbps, respectively, and these were as specified. The average latency was 6 ms. In terms of 5G NSA performance, 6 ms was a lower latency than expected, suggesting high performance.

Next, we conducted a high-definition 4K video transmission test. The results indicated that video could be transmitted from three 4K cameras at the same time, and we could transmit video of the shop floor to the administration office while patrolling the factory. Remote control via high-definition 4K video makes it possible to significantly reduce the amount of monitoring work performed under adverse working conditions.

③ Coverage area

We measured the radio field intensity and transmission speed at various points while moving around inside the tank manufacturing factory, which is 300 m deep. The results indicated that the upload speed exceeded 25 Mbps, at which 4K video can be transmitted, when the distance from the antenna was 50 m or less, and performance decreased when the distance was 100 m or more. In particular, visibility from the antenna is important, and without any obstacles, the upload speed reached 30 Mbps, at which 4K video can be transmitted, even at a distance of 260 m. Since factories have various working machines of differing sizes, where to set up the antenna should be considered. Regarding the area for millimeter wave communication, we were concerned that communication would be greatly affected by the surrounding environment, but when the antenna was set up on the first floor of the skills training facility, communication was possible from the second floor of the same building.

④ Environmental tolerance (noise immunity)

No noise was generated intentionally in the test, but the factory was running as usual during the test, so noise was generated by working machine operation and welding. Even in such an environment, communication during the test was not interrupted or unstable. Thus, adequate noise immunity can be expected even in a factory environment.

(2) Successor-G remote control test

We conducted verification of steel grinding. A grinder is a tool that causes a disk-shaped grinding stone to rotate at high speed and is used for grinding work. Each grinder weighs 2 to 3 kg, and it must be kept flush against the workpiece during grinding work as shown in **Fig. 4 (a)**, which is heavy work. In addition, noise is generated and grinding swarf flies into the air during grinding work, which subjects the worker to severe working conditions.

Successor-G has a force feedback function, with which, when the communicator is operated to bring a robot with a grinder into contact with a steel material, the reaction force is transmitted to the communicator. This function enables the worker to sense the actual force pushing the grinder flush against the steel material during grinding work as shown in **Fig. 4 (b)**. This provides the same level of operability as holding the grinder in one's hand without requiring the worker to hold a heavy grinder. This system has been realized by feeding back the output of the force sensor attached to the robot to the communicator with low latency. However, if there is a delay in communication between the communicator and the robot, the sense of contact cannot be reproduced correctly, leading to poor operability.

The robot was located on the first floor of the skills training facility, while the communicator was set up in the administration office, from which the grinder work was performed remotely.

Massive 4K video data and robot control signals were transmitted simultaneously via 5G, so the worker could operate the grinder based on force feedback from the communicator while monitoring how the steel material was being ground according to the high-definition 4K video displayed on a 50-inch display.

Multiple workers performed the grinder work, and some said that they could not operate the grinder smoothly and felt some resistance. This is presumably because ultra-low latency could not be achieved with the private 5G NSA system used for this test, resulting in an operational feeling that is inferior to that obtained by wired communication. If 5G SA is put into practical use, we can expect the same level of operability as that obtained by wired LAN. Although further verification is required as to the safety and reliability of wireless communication, if wireless communication can be used, robots that move freely within a factory can be operated remotely, so jobs done on the shop floor can be done remotely. Workers relieved of the burden of heavy work and adverse working conditions thanks to Successor-G will then be relieved from working on-site thanks to 5G.

In this test, the robot was operated from the administration office, which is located at a linear distance

(a) Manual work

(b) Successor-G

Fig. 4 Grinder work

of approximately 200 m from the skills training facility, but if the robot is operated remotely from another factory, or from a worker's home, the distance between the factories or the distance between the factory and the home will be an issue. Such a distance can be covered by a wired connection that employs optical fiber. The latency with optical fiber is 5 μs/km, and the round-trip latency is 1 ms when the one-way distance is 100 km. In the test, operability decreased at a latency of 6 ms. Even if an ultra-low latency of 1 ms can be achieved with 5G SA, the latency will be 6 ms if the wired section is 500 km long. If the latency can be decreased to 2 to 3 ms, the current level of operability can be achieved when the distance is 100 to 200 km. In addition, network devices, such as routers, are installed midstream in the communication path. Considering the latency of these devices, the distance at which force feedback is possible is expected to be 50 to 100 km. This means that even factory workers could work remotely from inside the factory's commuting area.

6 Future development

The distance at which force feedback is possible with a remote-controlled robot is estimated to be 50 to 100 km, and if the robot is operated from a more distant location, the work is expected to be done in a virtual space with a simulator. Although accurate simulation is required, digital twin technology, which seamlessly connects virtual and physical spaces, is attracting attention, and this field is expected to grow. Another approach is to operate a remote-controlled robot with a simple device such as a game controller, and operational precision is attained with the help of the AI onboard the robot.

In addition, we will link this system with, for example, operation data and production schedules with the aim of offering products to customers that have the optimal quality, cost, and delivery schedule in the factories of the future.

Conclusion

Although there are challenges in operating private 5G, such as the need to obtain a license for operation and the high cost, it will make it possible to do various kinds of work remotely via wireless communication, and in combination with other solutions, such as Successor-G, private 5G is expected to contribute to addressing the labor shortage due to the declining population, relieving workers of the need to do 3D (Dirty, Dangerous, and Demeaning) jobs, and passing down experienced workers' skills to the next generation.

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