Industry Paper

LoRa Communication Method for Growth Management using Image Data

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Abstract - "Nototemari" which is a kind of mushroom, is a representative agricultural product of Ishikawa Prefecture. It is cultivated in a greenhouse in Noto's Satoyama. In this paper, we report the results of a study on the construction of a remote monitoring system for Nototemari cultivation. The Nototemari cultivation greenhouse is far away from the management office, so it is costly to visit the greenhouse to monitor the growth. In addition, many producers are elderly. Therefore, we thought that we could improve the efficiency of cultivation work at low cost by constructing a private LoRa network and periodically sending image data of the growth status to the management office. However, due to the slow transmission speed of LoRa communication, it took a long time to send the image data as it was. Therefore, we have built a mechanism to transmit image data in a practical time by recognizing important monitoring points using the object detection based on deep learning, not degrading the image quality of that part, and transmitting the other image parts with degrading or trimming the image quality. In this paper, we show the image data compression method, and the experimental results of the communication method. We will explain the effect of the proposed method.

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Keywords: LPWA, LoRa, Production control, Agriculture, Image data

1 INTRODUCTION

In Ishikawa Prefecture, producers, agricultural organizations, markets, prefectures, etc. have come together to brand the grown shiitake mushrooms as Nototemari, which is suitable for the climate of Noto's Satoyama, and is located in the OkuNoto area. However, since the Noto's Satoyama, especially the greenhouse that grows Nototemari, is located in the mountains of Noto, it is a blank area of radio waves and almost no communication environment [1]. In addition, it is difficult to get the power supply. Therefore, it is difficult to use a remote monitoring system that uses cameras and sensors, and all cultivation is carried out manually. Many producers are elderly, and it is desired to reduce the man-hours for patrols.

In recent years, the use of LPWA, which does not require communication charges, has been progressing. No license and application is required as it uses a license-free frequency band. In particular, the private LoRa allows us to install the base station ourself, enabling flexible system design. In addition, 250mW LoRa has a long transmission distance and is often used in mountains [2]. As shown in Fig. 1, we thought about build a private LoRa wireless communication network in Noto's Satoyama, to manage the growth of Nototemari. The problem is that it has a narrow bandwidth and very little data can be sent. It is possible to send sensor data such as temperature and humidity in a short time, but it is very difficult to send image data and video data. Therefore, research is being conducted to send image data with LoRa [3 - 6].

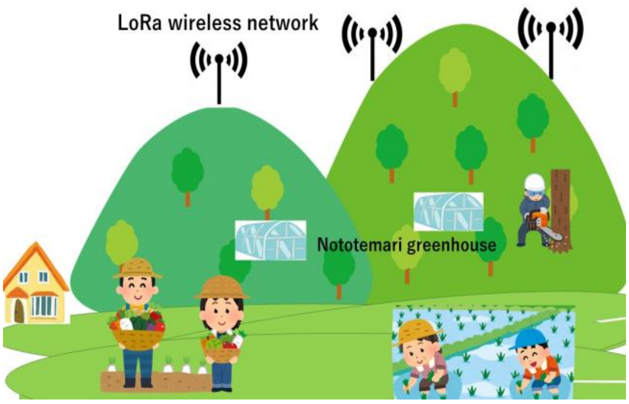


Figure 1: Wireless communication environment aimed to build in Noto's Satoyama

In LoRa technology, total transmission time is limited from the viewpoint of the occupancy prevention and affects to the entire transmission time for large data like image data. Therefore, it is said that it is difficult to send image data and video data. In addtion, generally, LoRa platform assumed to be inappropriate to transmit high bit rate data, such as image data or voice data, due to its narrow bandwidth accessible for physical layer modulation. Bandwidth (BW) and spread rate (SF) can be changed with LoRa technology. The narrower the bandwidth and the higher the diffusion rate, we can detect the signal farther. However, the narrower the BW and the larger the SF, the longer the transmission time and the higher the power consumption. In other words, it takes time to transmit data to fly far.

The first attempt to transfer image data over a LoRa network was presented in [4] by C. Pham in 2016, a year after the introduction of the LoRa framework. C. Pham proposed a low cost and power visual supervision platform based on image data compression and a change detection technique. The image data compression implemented a packet loss-tolerant image compression technique that can run on very limited memory platforms. The results from the tests showed that an image data of about 2.4 KBytes could be transmitted up to 1.8 km. Although in this work, it is difficult to be used for external surroundings with continuously variation of brightness.

Chen et. al. [5] proposed a light trustworthy communication protocol called MPLR for image data transmission in LoRa. It facilitates image monitoring in an agricultural IoT platform. The MPLR protocol groups information packet transmissions. By returning one ACK for each group, the time required for ACK is reduced. The test results showed that MPLR protocol during the image data transmission procedure decrease the time by 24%. This method is effective when there are few data transmission errors. Therefore, it is not suitable for large size data.

Ji et al [6], proposed a method in which doesn't transmit full images in order to reduced data rate and bandwidth. Full images are not needed to be transmitted, and by this way bandwidth usage on LoRa can be reduced. The scheme took advantage of the static feature of various areas and especially in farming by suggesting a new monitoring plan that splits every image into tiny grid patches. But this method observed that most points in an image must be static, and significant changes are not allowed.

In order to solve the problem of the conventional method, we propose a new method to divide the photo into the part that the producers want to see and the part that is not so important, and transfer the not important part with reduced image accuracy. The proposal system uses the object detection with deep learning to discover important points. This makes it possible to increase the rate of image data compression. By reducing the image data size, the load and time required for transmission can be reduced, and a practical system can be constructed.

LoRa is expected to be used in various systems because it is license-free and does not require communication costs. However, it has been unsuitable because the amount of data that can be transmitted is small and it takes time to transmit images. We propose a method to reduce the transmission time by extracting and transmitting only the necessary portion of the image. In this paper, we explain the image data compression method and the communication infrastructure using a private LoRa that is the basis of the remote monitoring system. Also, we explain a protocol and a frame data set for the system. In addition, we explain the result of the conduct a demonstration experiment.

2 SYSTEM COMFIGURATION

2.1 Remote Monitoring System

LoRa is a communication standard using spread-spectrum modulation techniques developed by Semtech Corporation. 20mW LoRa is widely used in Japan because it can be used in specified low power radio stations that do not require a license. In recent years, efforts have begun to utilize 250mW LoRa in the disaster prevention systems and the bus location systems [7 - 8]. It is also being used in mountainous areas by taking advantage of long-distance transmission [9]. There is a report that 160km transmission is possible in mountainous areas [9]. 250mW LoRa is more difficult to use than 20mW LoRa because it requires a registration license, but considering its transmittable distance, it is effective as a means to solve the situation where there is no communication environment in the mountains. We decided to use 250mW LoRa.

The system configuration of the remote monitoring system for Nototemari will be described. Since mobile phone networks are often unavailable, it is assumed that in the greenhouse, in addition to temperature and humidity, a photo will be taken once a day and sent from a private LoRa to the management office. Due to the distance between the greenhouse and the management office, there are several repeaters in the proposed configuration where the data is sent to the management office via the repeaters. The 250mW LoRa has a long transmission distance even in the line of sight, but there are undulations in the mountainous areas, and there are parts where the transmission distance is short depending on the location. Therefore, repeaters are indispensable. Figure 2 shows the overall image of the remote monitoring system for Nototemari.

Since the management office is located in Satoyama, only telephone lines can be used in many cases, so the system configuration allows data to be uploaded to the cloud using telephone lines. Greenhouses often do not have a power source, so it may be necessary to obtain electricity from solar power. Therefore, the power is turned off except for acquiring data once a day and transmitting it.

The repeater holds two LoRa modules. One is for reception and the other is for transmission. When the receiving LoRa receives a packet, the packet data is registered in the buffer folder. This process is repeated until all the data is received. The sending LoRa checks if there is data in the buffer folder, and if there is data, sends it in the order of the oldest generation time. Also, it will check if there is data on a regular basis. With these two LoRa modules, data can be sent to the next node without stagnation. Depending on the distance between the management office and the greenhouse, multiple repeaters may be placed.

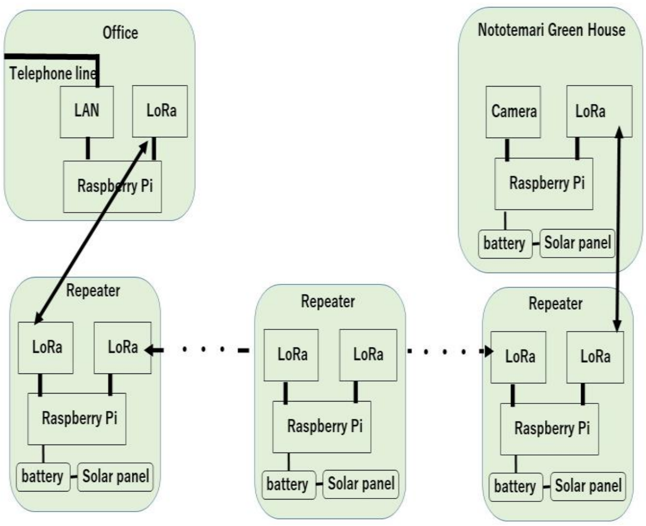


Figure 2: System configuration of remote monitoring system for "Nototemari"

Temperature and humidity are important factors for the growth of Nototemari [10]. Humidity is especially important. In addition, there are many items that should be visually confirmed, such as how the umbrella is wrapped, and images are important for growth management [10 - 11]. For these reasons, a temperature / humidity sensor and cameras were installed in the greenhouse, and these data was transmitted to the management office using a private LoRa network so that it could be confirmed at the management office. Since LoRa has a narrow band, it is difficult to send image data as it is. Therefore, we needed to reduce the size of the data. We decided to use the object detection based on deep learning to extract only the necessary parts and send them.

2.2 Image Data Compression Method

Data compression is important for transferring data within the time limit. In order to compress the data, it is common to reduce the resolution of the data. However, this method is not suitable for careful observation of growth. Therefore, we decided to extract and send only the important parts. We succeeded in compressing the amount of data while maintaining the image quality required for growth management. Figure 3 shows an example of image data compression. The left is the data before compression, and the right is the data after compression. In this example, unnecessary parts are filled with white. If it is better to understand the appearance of the log from the outline alone, reduce the resolution of the unnecessary part or extract the outline to make only the outline. The compression level can be specified. The items that should be observed carefully are first learned, and the learning results are used for recognition. Items that perform object detection can also be controlled. It's important to be able to control, as each growth process has different items to check.

Figure 4 shows the processing flow for acquiring image data and sending it with a private LoRa. First, a picture is taken. Second, the object detection with deep learning is performed. In order to recognize the important part, acquire the training image data in advance, train these, and create a library. This library is used to recognize important parts, maintain the image quality of those parts, and compress the image data size by transmitting the other parts with reduced image quality. Next, the image data is changed to the video data, and the video data is performed compression in H.265 [12], it transmits and receive data at a private LoRa.

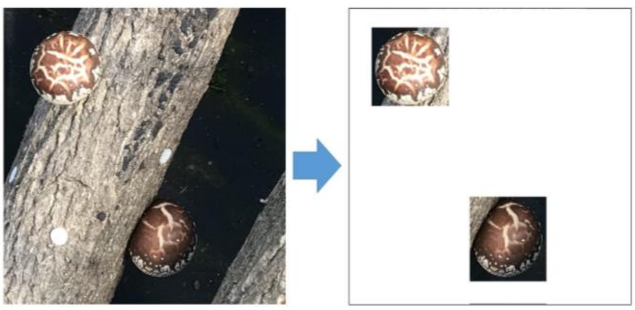


Figure 3: An example of image data compression (Left: before compression, Right: after compression)

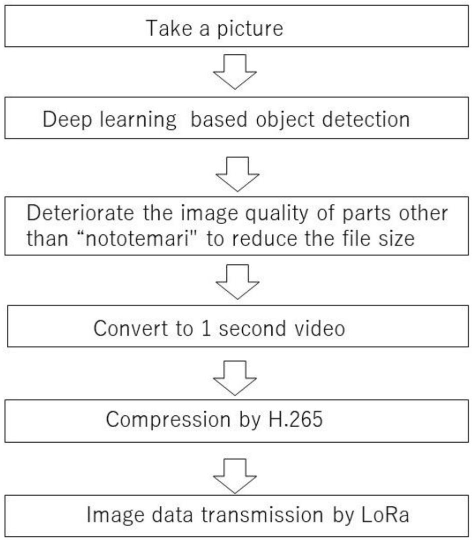


Figure 4: Greenhouse side system flow of remote monitoring system for Nototemari

H.265 is a video compression standard and can achieve equivalent image quality at half the file size and bit rate of H.264. Therefore, the file size has been reduced by converting H.264 files to H.265. H.265 optimizes the block according to the amount of change. In H.265, a block with few changes and a simple block change to a large block, and a block with complex changes change to a small block. This reduces the total amount of information. The larger the block size can be made, the fewer the number of blocks. As a result, the file size can be reduced.

H.265 is a video standard, but it also define about still images as a subset. However, there are restrictions on still images, such as restrictions on the supported bit depth [13]. In order to use the H.265 standard effectively, it is desirable to use as video. Therefore we decided to change the still image to a video. A 1 second video was used because 1 second was easy to handle due to the system construction.

Image compression is performed by lowering the image resolution or filtered for feature extraction except for the part that farmers want to focus on. In extreme cases, the areas that are not in focus are painted white. The data size by filling the unnecessary parts with white is reduce, and by keeping the position of the Nototemari, it is possible to imagine the whole. If the image data size is large, it will take time to send. In addition, the possibility of transmission errors increases, which is not desirable for the system. Therefore, we decided to send the high accuracy only the parts that the producer must confirm with high accuracy. This makes it possible to send in a few minutes, which is practical.

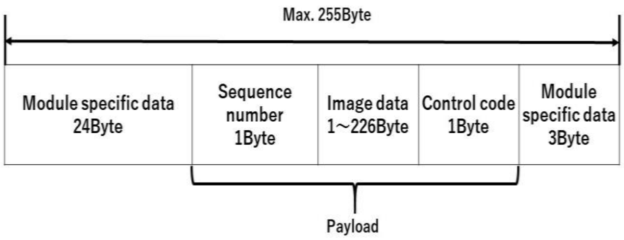
3 COMMUNICATION PROTOCOL AND FRAME STRCTURE

3.1 Frame Structure

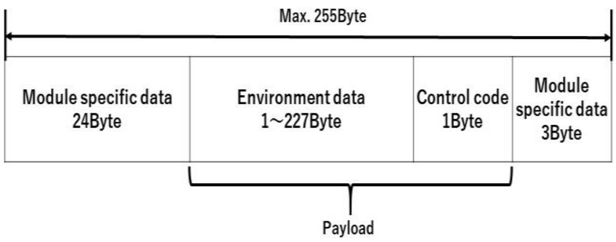
Multiple frames such as an image data transmission frame and an environment data transmission frame are prepared to be able to extend to monitoring functions of agricultural workers such as emergency communication. Here, the image data transmission frame and the environment data transmission frame will be described.

Figure 5 (a) shows an image data transmission frame structure. With LoRa, a maximum of 255 Bytes can be transmitted with one transmission. The first 24 Bytes is the module-specific usage area we are using. Next, the payload comes, and the image data is put in this area and transmitted. As shown in Fig. 6, the image data is divided into 225 Bytes and transmitted, and the receiving side connects the received data into one file. The first Byte of the payload is the data number. The next divided image data 225 Bytes is stored. The next 1 Byte is the control code. In the case of image data, “Null” indicates that the data has a continuation. “\ n” indicates the end of the data. This 1 Byte indicates what purpose the frame is used for. In the case of image data, the data is transmitted using multiple frames, but in the case of environment transmission data, it is completed in the one frame. The last 3 Bytes are space for the module.

Figure 5 (b) shows an environments data transmission frame structure. The first 24 Bytes is the module-specific usage area we are using. Next, the payload comes, and the environment data is put in this area and transmitted. We can put a control code in the next 1 Byte. The character code written in the control code determines what data is contained. The last area is the area where the LoRa module we are using is used.



(a) Image data transmission frame structure



(b) Environments data transmission frame structure

Figure 5: Frame Structure

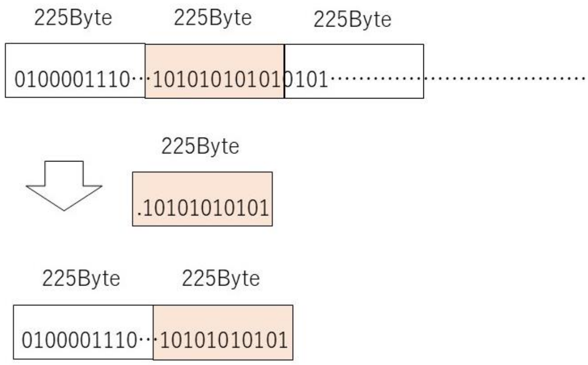


Figure 6: Image data transfer image

3.2 Communication Protocol

The communication protocol is the stop-and-wait scheme [5]. That is, after sending the data, change to the receive mode and receive an ACK indicating that the data has been received. If the ACK is not received even after waiting for 15 seconds, the data will be sent again. This process is repeated until an ACK is received. Since temperature and humidity send one piece of data in one frame, data is sent using this protocol.

The communication protocol for image data transmission is shown in Fig. 7. The communication protocol used in the image data transmission is also the stop-and-wait scheme. The procedure will be explained. The first 225 Bytes of untransmitted data are taken out and sent from the LoRa device in the greenhouse to the Gateway. When the Gateway receives the data, it returns an ACK indicating that it has received it. This process is continued until all the data has been transmitted. If the transmission fails and the ACK cannot be received, resend will wait 15 seconds and the data will be retransmitted.

The problem in implementing the stop-and-wait scheme is that it cannot determine the duplication of packets. If an Ack sent from the receiving side to the sending side is lost or corrupted, the sending side times out and retransmits the frame. In this case, the receiving side will have two frames with the same content, and the data will not be consistent. To solve this problem, a sequence number is defined in the first Byte of the frame, and 0 and 1 are entered alternately for each transmission. This allows the receiving side to detect duplicate frames by checking if the sequence number is entered alternately.

When there is no more data to send, the sender sends an exit character. The receiver receive the exit character, completes the reception and sends an Ack to the sender. This completes the sending and receiving process. After that, the receiver continues to wait for data to be received.

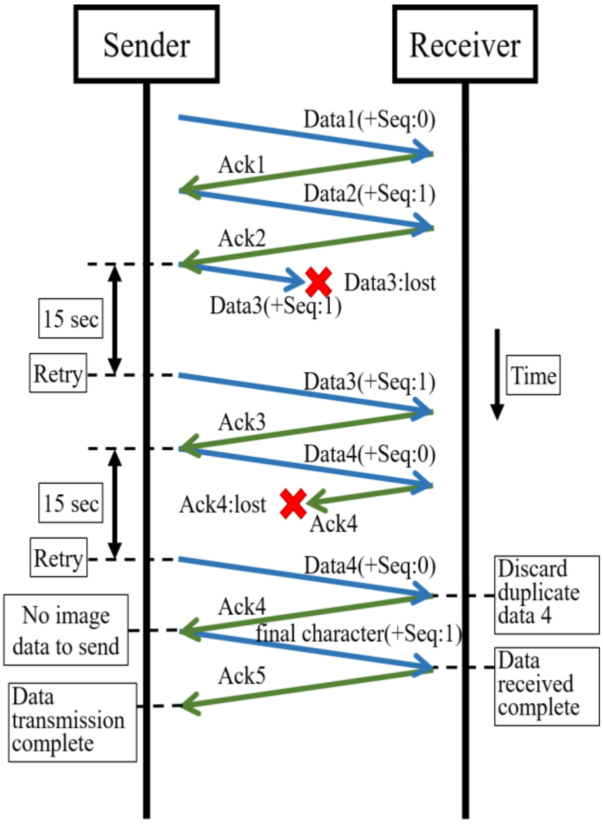


Figure 7: Communication Protocol

Figure 8: Camera installed in the Nototemari greenhouse

Figure 9: An example of image data which is extracted object detection

4 EXPERIMENTAL RESULTS

In this chapter, we will evaluate the proposed image data compression method to enable transmission and reception of images using LoRa. In addition, the result of visual verification that there is no problem in the image accuracy for the observation target even if the image data compression is performed is shown. In addition, it shows that the compressed image data can be transmitted using LoRa in a reasonable time. Figure 8 shows an example of a camera installed in the Nototemari greenhouse. In this experiment, four cameras were installed in one greenhouse at different heights and locations. Since the camera is installed in the frame of the greenhouse, it is difficult to shoot from a short distance.

4.1 Object Detection Experiment

We will explain the experiment of image data degeneracy using the object detection based on deep learning. We collect photos of what we want to check in advance and we let learn. The work of collecting photos was done with the cooperation of the Ishikawa Agricultural Experiment Station. Yolov5 was used for the learning and the object detection [14].

Learning of yolov5 is very time consuming. However, once we can make a library, we can continue to use it. Therefore we make it in advance. The learning process was done on a homebrew PC (CPU is Intel CPU BX8070110900K Core i9-10900K processor 3.7GHz 20MB cache 10 cores. The graphics board is the MSI GeForce RTX 3070 VENTUS 2X OC graphics board VD7419.). We spent several days for learning. When the training was completed, the trained library is installed in the Raspberry Pi 3b of the sender device.

The object detection was performed on the Raspberry Pi 3b using the trained library. Figure 9 is an example of the result of object detection by yolov5. Nine Nototemaris were detected. This data was used to reduce the image quality of the parts other than Nototemari. The program of the image quality reduction used OpenCV library [15]. In this experiment, other area of not interest were painted white. Table 1 shows the difference in data size. We confirmed the data is reduced to about 1/10. We can see that deleting unnecessary parts helps to reduce the image data size.

Table 1: Comparison of data size between original image data and extracted data

	Data size
Original image data	4,164,000 Bytes
Extracted data by object detection	352,907 Bytes

4.2 Image Data Compression Experiment

We will explain the experiment of image data size reduction to H.265 using ffmpeg [16]. The result of degeneracy using the object detection based on deep learning is shown for the photograph taken at Nototemari greenhouse. Figure 10 is after reduction by the object detection based on deep learning and reduction of the image quality of the parts other than Nototemari. In this example, the part other than the part recognized by the object detection based on deep learning is painted white. Figure 11 shows the reduction results of the file size reduction using H.265. As can be seen from the Fig. 10 and Fig. 11, compression does not have a significant im

Table 2 shows the data size of after conversion to H.265. When compressed with H.265, the data size was 1/5 of that before compression. Table 3 shows the conversion time to H.265. The experiment was done with a Raspberry Pi 3b. The processing time is about 31 seconds and about 21 seconds, which is practical.

Compression using the object detection based on deep learning is different from the conventional method of reducing the image quality of the entire image, and it is possible to acquire high-quality data for the part we want to see. In addition, our system can support for the rotation of logs of Nototemari by producers. That is, there is no problem even if the position of the Nototemari changes in the camera image. Also, if we register a disease etc. in the object detection library, the data will be sent with a clear image of that

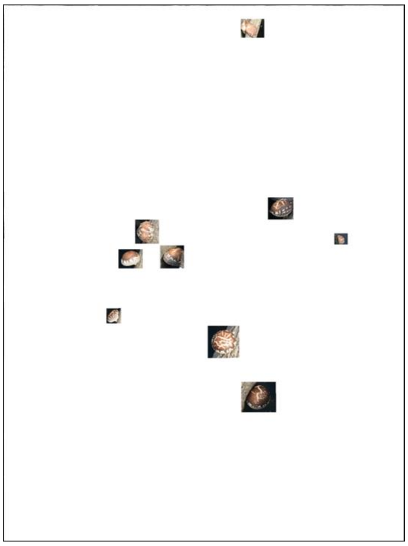


Figure 10: An example of extraction by object detection

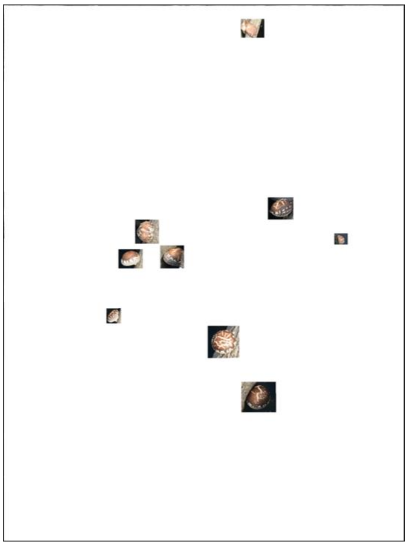


Figure 11: An example of after compression with H.265

Table 2: Data size after reduction

	Data size
Extraction data by object detection	352,907 Bytes
After compression with H.265	69,955 Bytes

Table 3: Processing time of image data compression

	Processing Time(s)
Extraction by object detection	31.477
Compression with H.265	21.338

part, so we will not overlook it.

H.265 also has the disadvantage of enormous calculation costs for encoding time. In fact, the compression process to H.265 took about 21 seconds on a Raspberry Pi 3b. However, considering the transmission time in LoRa, we thought that data should be compressed by an edge computing even if it takes time.

4.3 Data Transmission Experiment

In this chapter, we explain the LoRa transmission test experiment. We tested how long it takes to transmit a compressed image data. Figure 12 shows the experimental environment. The experiment was conducted indoors. The experiment was done with a Raspberry Pi 3b. This is a communication experiment between gateway and a sender unit. A sender unit takes a picture, detects an object, compresses data, and transmits with LoRa. In this experiment, the image data to be transmitted was prepared in advance, and only the image data transmission was tested.

Under the restriction of a law in Japan, when LoRa communication is used, the time that can be continuously transmitted is set to 4 seconds. Therefore, the size of data that can be transmitted at a time varies depending on parameters such as SF and BW. In order to improve the efficiency of communication, we need to change the size of data that can be sent at a time depending on the SF and BW. Table 4 shows the correspondence between the parameters and the communication speed. SF9, BW 125MHz can send data to the farthest distance, but the amount of data that can be sent is the least.

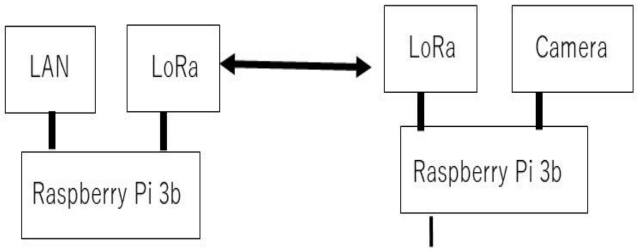


Figure 12: LoRa transmission test environment

Table 4: Correspondence table between parameters and communication speed (bps) [17]

	BW 125 kHz	BW 250 kHz	BW 500 kHz
SF7	5469	10938	21875
SF8	3125	6250	12500
SF9	1758	3514	7031

Table 5: Transmission of extracted data by object detection

		BW 125 kHz	BW 250 kHz	BW 500 kHz
SF7	Send time	39m 20s	22m 31s	17m 31s
	Resend count	27	3	4
SF8	Send time	47m 53s	29m 41s	20m 36s
	Resend count	0	1	1
SF9	Send time	1h 28m 14s	43m 12s	32m 15s
	Resend count	51	0	20

Table 6: Transmission of image data compressed with H.265

		BW 125 kHz	BW 250 kHz	BW 500 kHz
SF7	Send time	6m 57s	4m 34s	3m 16s
	Resend count	2	1	0
SF8	Send time	9m 45s	6m 5s	4m 2s
	Resend count	1	1	0
SF9	Send time	18m 28s	8m 49s	6m 39s
	Resend count	14	1	5

We conducted a communication experiment using the image in Fig. 10 and the image in Fig. 11. The results of that experiment are shown in Table 5 and Table 6.

Table 5 shows the results when the image data shown in Figure 10 is transmitted using LoRa. SF has changed SF7, SF8, and SF9. BW was changed to 125 kHz, 250 kHz, and 500 kHz. With SF7 and BW125 kHz, the transmission time is the longest and the number of retransmissions is also large. The larger the BW, the shorter the time to transfer the data. If we change from SF7 to SF8 or SF9, the transmission time will be slower. If the transmission time is long, the number of retransmissions tends to increase. It takes tens of minutes to transfer the data, which is not practical.

Table 6 shows the results when the image data shown in Fig. 11 is transmitted using LoRa. SF has changed SF7, SF8, and SF9. BW was changed to 125 kHz, 250 kHz, and 500 kHz. With SF7 and BW125 kHz, the transmission time is the longest and the number of retransmissions is also large. The larger the BW, the shorter the time to transfer the data. If we change from SF7 to SF8 or SF9, the transmission time will be slower. If the transmission time is long, the number of retransmissions tends to increase. In the case of SF7 and BW 500 kHz, it takes only few minutes to transfer the data, which is practical.

When compressed with H.265, the data size will be about 1/5. We can see that the transmission speed is also about one-fifth. That is, it can be said that using H.265 is effective in reducing the LoRa transmission time and the number of retransmissions. As can be seen from Table 5, it takes a lot of time without data compression. Especially with SF9, some parameters took more than an hour. In contrast, the compressed image data can be transmitted and received in less time even in SF9. The fact that they can be transmitted and received in less time in SF9 leads to a reduction in the number of repeaters installed, thus we can realize a sustainable system.

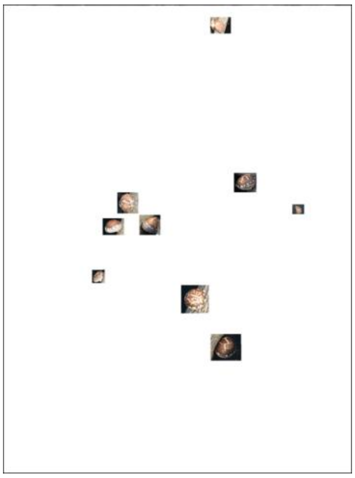


Figure 13: Received image data

Figure 13 is an image acquired by the gateway. We can see that there is no image deterioration of the Nototemari parts compared to the transmitted data. In addition, since the parts that users want to observe with the image quality taken by the camera are retained, it can be said that it is sufficiently practical for growth management of Nototemari. About 4 cameras will be installed in the greenhouse, but if the time required to transfer the data of one image is about 10 minutes, even if all the data is sent, it will be within 1 hour. Thus the system can send the data once a day. Then, it can withstand the operation with the solar panel and battery. It is of great significance for agricultural workers to be able to see the state of the Nototemari in a greenhouse in the Noto's Satoyama at home or in the workplace with clear images. Picture quality was adequate for them in experiment. This eliminates the need to check the status on a regular basis and makes it possible to reduce management costs.

5 CONCLUSION

Nototemari is a representative agricultural product of Ishikawa Prefecture. It is cultivated in a greenhouse in Noto's Satoyama. Noto's Satoyama communication environment is not good. In this paper, we reported the results of a study on the construction of a remote monitoring system for Nototemari cultivation. The Nototemari cultivation greenhouse is far away from the management office where the cultivation is managed, so it is costly to visit the greenhouse to monitor the growth. In addition, many producers are elderly. Therefore, we thought that we could improve the efficiency of cultivation work at low cost by constructing a LoRa network and periodically sending image data of the growth status to the management office. However, due to the slow transmission speed of LoRa communication, it took a long time to send the image data as it was. Therefore, we have built a mechanism to transmit image data in a practical time by recognizing a Nototemari using the object detection based on deep learning, not degrading the image quality of that part, and transmitting the image with degrading the image quality of other parts. In this paper, we show the experimental results of the propose image data sending system, and show its effectiveness. The proposed an image data sending system turned out to be sufficiently practical because one image data can be sent in a short time.

ACKNOWLEDGMENTS

The research is supported by the Telecommunication Advancement Foundation.

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(Received: November 16, 2021)
(Accepted: August 8, 2022)

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