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Advanced Digital Technology (The second part)

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Changes for the Better

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ADVANCE

Advanced Digital Technology (The second part)

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Technical Reports

Precis

Our aim in the Mitsubishi Electric Group is to be a "Circular Digital-Engineering" company, and we are working to solve increasingly severe and diverse social problems through innovation based on advanced digital technology. In this way, we hope to contribute to the realization of a dynamic, yet relaxed and fulfilling society. For this special feature, we will present specific initiatives in the area of advanced digital technology across two issues: a first part (the preceding issue, ADVANCE Vol. 188, December 2024) and a second part (this issue, Vol. 189, March 2025).

Security and Privacy Technologies for Safe and Secure Artificial Intelligence

Authors: *Yoshihiro Koseki*, Tsunato Nakai**

**Information Technology R&D Center*

Abstract

Efforts to use AI for business have become increasingly active in recent years due to the development of deep learning, and Mitsubishi Electric too is considering use in various fields. On the other hand, as systems incorporating AI come into wider use, there are more opportunities for malicious attackers to carry out attacks exploiting the vulnerabilities of AI. At Mitsubishi Electric, our efforts go beyond just improving performance of AI and considering how to use it. We are conducting R&D on security technology and privacy technology to enable safe and secure use, even in environments where AI is exposed to malicious attack. As part of these efforts, we have developed technology allowing object detection AI to output correct results even when its input is tampered with, and technology to prevent leakage of information relating to training data from AI models.

1. Introduction

Deep learning in neural networks garnered renewed interest in the early 2010s and since then has revolutionized AI in various fields—such as images/video, language, audio, and time series data—due to its overwhelming accuracy. In recent years, conversational AI using large language models and generative AI such as image generation AI using diffusion models have become more than just a subject of research. They have become the focus of a major boom, including applications to business, and it is anticipated that use of AI in real-world society will continue to advance at an accelerating pace in the future. On the other hand, as the scope of AI utilization expands, opportunities grow for attacking systems using AI. For such systems, we must consider not only conventional cyberattack techniques exploiting vulnerabilities of OS and applications to target IT systems, but also attack techniques exploiting vulnerabilities specific to AI. This paper describes Mitsubishi Electric's R&D efforts on security technology and privacy technology for realizing safe and secure use of AI.

2. AI Privacy and Security

Deep learning—a subject of active research in recent years—is one type of an AI technology called machine learning. When using machine learning, there are two phases, as shown in Fig. 1: the training phase where a model is generated using training data as input, and the inference phase where tasks such as object detection or translation are performed on images, text, or other inputs using the generated model. Attacks on AI in this training phase or inference phase include causing it to output an unintended result by tampering with data input to the model, or causing unintentional leakage of personal information or other data contained in training data by observing data output by the model. Intensive research has been conducted in recent years regarding attacks on AI, and even if, for example, we limit the scope to adversarial examples attacks—one type of attack technique—over 8,000 papers have been published as of March 2024(1).

The AI Security Information Portal(2) of the Ministry of Internal Affairs and Communications provides an AI Security Matrix summarizing techniques for attacking AI. Five attack categories are defined in the AI Security Matrix: data poisoning, model poisoning, adversarial examples, data theft, and model theft. Figure 1 and Table 1 show the concept and overview of each category.

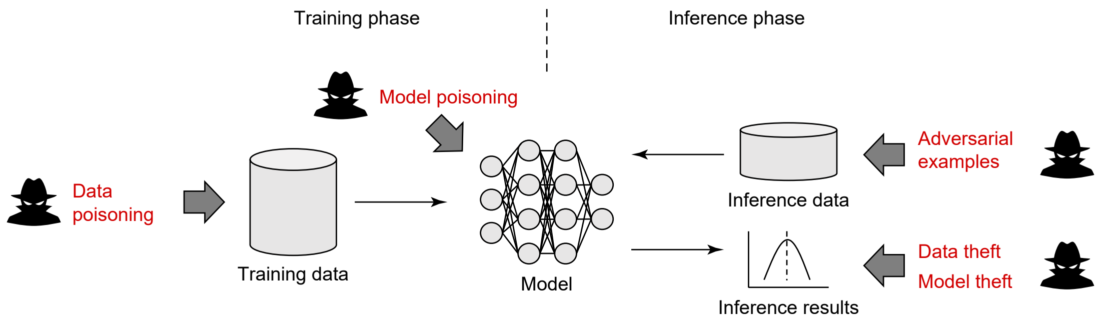

Fig. 1 Overview of attacks on AI

Table 1 Taxonomy of attacks on AI (excerpt from the AI Security Matrix(2))

Category	Overview
Data poisoning	By injecting special data called poisoned data into training data, attackers can install backdoors that cause the model to behave as intended by the attacker in response to specific input data, or can cause degradation of model accuracy
Model poisoning	By tampering with a trained model, backdoors that cause the model to behave as intended by the attacker in response to specific input data are installed in a model distributed to users as a pre-trained model
Adversarial examples	By adding modifications called perturbations to the model's input data, attackers change results such as image classifications and speech recognition to produce incorrect outputs
Data theft	By inputting multiple data items to a model and observing the output, attackers steal information on the data used for training
Model theft	By inputting multiple data items to a model and observing the output, attackers steal internal information such as model structure and parameters

Among these categories, three types of attacks (data poisoning, model poisoning, and adversarial examples) primarily relate to correct operation of the model, while data theft and model theft relate to privacy of the training data and model. From among Mitsubishi Electric's R&D efforts on security technology and privacy technology for countering these attack techniques on AI, section 3 of this paper describes technology to counter adversarial patch attacks, a type of adversarial examples attack, and section 4 describes technology to counter membership inference attacks, a type of data theft attack.

3. Defense Technology for Adversarial Patch Attacks

Object detection is a technology for outputting bounding box coordinates indicating object position, and a label indicating object type, for each object captured in an input image. It is used in areas such as detection of pedestrians by self-driving vehicles, and detection of suspicious persons by surveillance cameras. An adversarial patch attack on object detection hinders object detection by placing a patch image created using a special method near an object captured in an input image. This is a threat to systems using object detection. Figure 2 shows an example of an adversarial patch attack from previous research(3). For the person on the left, the system displays a bounding box and a label indicating that the object is a person. Detection is done correctly. For the person on the right, on the other hand, no bounding box or label is displayed, and it is evident that correct detection has not been performed due to placement of the patch image. This patch image is not digitally placed on the input image. It is exerting an effect even though a printed image of the patch is used by placing it near the person captured by a camera. This sort of adversarial patch attack is called a physical adversarial patch attack, and it is recognized as a particularly important threat.

Fig. 2 Adversarial patch attack (excerpt from previous research[3])

We have developed a defense technology for correctly detecting objects, even when there is an adversarial patch attack[4]. With this technology, ordinary object detection is performed first on the input image. The outputs of object detection at this time are the coordinates of the bounding boxes indicating the positions of the objects in the input image, and objectness scores, which indicate the probabilities that objects are present at their locations. An object is detected at a location if the objectness score is at or above a threshold. On the other hand, the adversarial patch has the effect of lowering the objectness score of an object nearby. It hinders object detection by decreasing the objectness score of the nearby object below the threshold. This defense technology focuses on bounding boxes whose objectness scores have dropped below the threshold. In Fig. 3 on the left, the bounding boxes indicated by the dotted lines have objectness scores below the threshold, and with this technology, multiple black-out images are generated in which those boxes are respectively blacked out. Object detection is performed again for each of the generated black-out images. In images in which part or whole of the adversarial patch is blacked out, the effect of lowering the objectness score is lost, so that the objectness score of the object where the patch is placed is higher than the threshold, and detection as an object can be achieved correctly. The final output for object detection is obtained by performing final integration processing on the detection results output for the multiple black-out images, and the detection results for the images prior to blacking out.

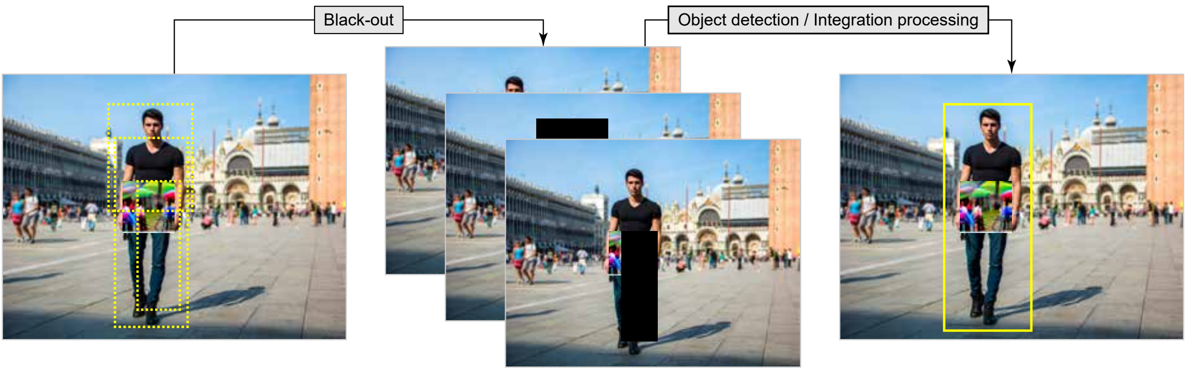

Fig. 3 Mechanism of defense method

4. Defense Technology for Membership Inference Attacks

A membership inference attack identifies whether sample data was used for model training. An attacker can determine whether the owner of a certain data set was a provider of training data based on AI inference results in response to the sample data. Figure 4 shows an overview of a membership inference attack. Membership inference attacks themselves represent relatively insignificant information leakage regarding training data, but training models resistant to membership inference attacks are also resistant to other attacks pertaining to information leakage of training data. Therefore, technologies for countering

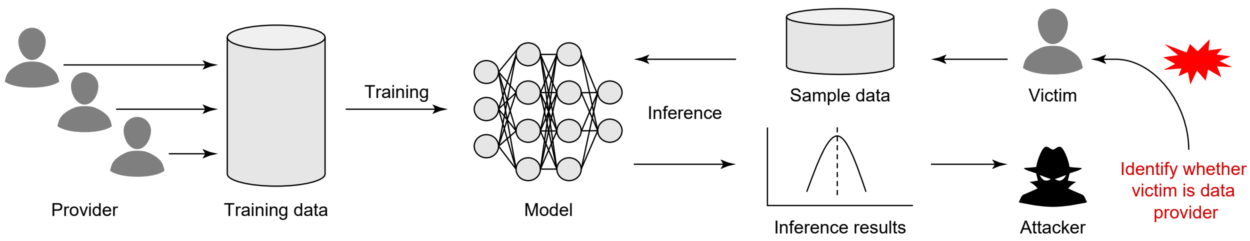

Fig. 4 Membership inference attack

membership inference attacks are important for achieving model privacy.

The reason that membership inference attacks succeed is thought to be overfitting where a model exhibits a strong reaction to data included in its training data, such as outputting a score higher than other data. Mitsubishi Electric has developed SElf-Distillation with Model Aggregation for Membership Privacy (SEDMA), a training method which suppresses overfitting, as a technology for countering membership inference attacks(5). Figure 5 shows an overview of SEDMA. With SEDMA, the labels in training data are replaced with inference results of a model which has not used that training data for training (i.e., soft labels), and new training data with soft labels is generated. A model generated using training data with soft labels is resistant to membership inference attack because it is less prone to overfitting with respect to the original training data. Aggregated models necessary for generating soft labels are generated by splitting the training data into multiple data sets, using these data sets to train different models, and then aggregating these models (by weighted average of parameters between models). Each aggregated model provides soft labels for training data not contained in the training data of the aggregated model. The distinguishing feature of SEDMA lies in this model aggregation, and compared with existing defense methods, this achieves outstanding trade-off performance, at low computation cost, between degradation of model accuracy due to defense measures and defense measure strength.

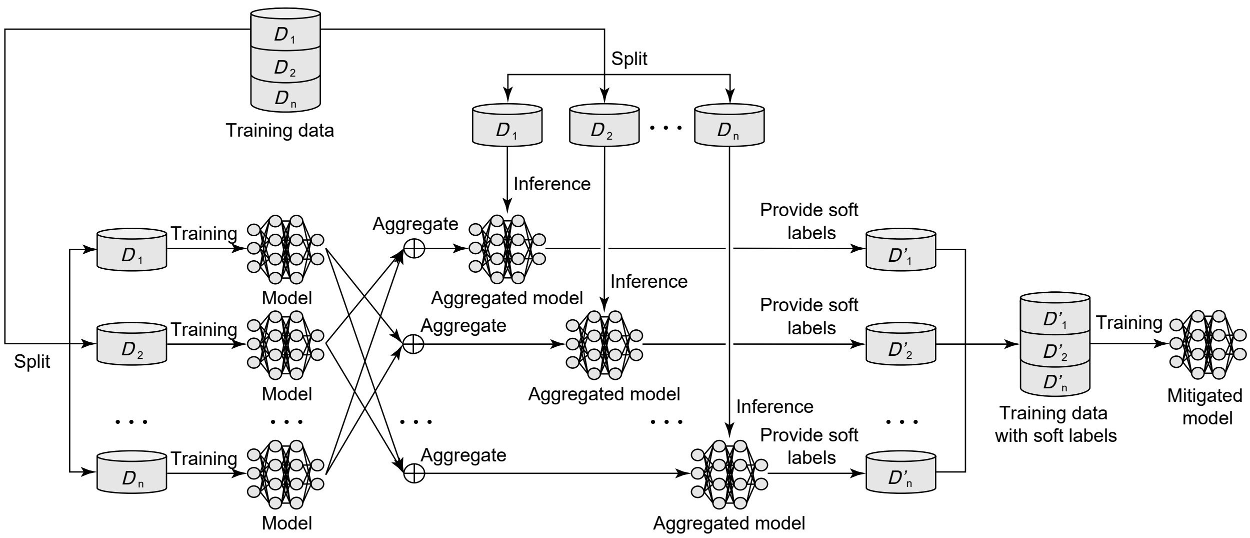

Fig. 5 Overview of SEDMA

Recently, concerns have arisen regarding the risk of information leakage relating to training data in the context of training large language models that require a huge volume of training data. In the area of large language models too, Mitsubishi Electric is moving forward with evaluation of the risk of information leakage from training models due to membership inference attack, verification of the effectiveness of existing defense measures (e.g., differential privacy), and examination of new defense methods(6)(7).

5. Conclusion

This paper has described the efforts of Mitsubishi Electric regarding defense technologies for attacks on AI, in particular defense technology for adversarial patch attacks in object detection, and defense technology for membership inference attacks. Going forward, we will contribute to the promotion of AI and its safe and secure use, by further advancing R&D on security technology and privacy technology. Our focus will be on areas such as large language models that are garnering attention as generative AI, and multi-modal large language models which simultaneously handle images, audio, and other modalities.

References

(1) Carlini, N.: A Complete List of All (arXiv) Adversarial Example Papers (2019) https://nicholas.carlini.com/writing/2019/all-adversarial-example-papers.html
(2) Ministry of Internal Affairs and Communications, et al.: AI Security Information Portal https://www.mbsd.jp/aisec_portal/
(3) Thys, S., et al.: Fooling Automated Surveillance Cameras: Adversarial Patches to Attack Person Detection, 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops, 49-55 (2019)
(4) Koseki, Y.: Defending Against Adversarial Patch Attacks in Object Detection Through Bounding Box Filling, IEEE 13th Global Conference on Consumer Electronics, 868-869 (2024)
(5) Nakai, T., et al.: SEDMA: Self-Distillation with Model Aggregation for Membership Privacy, Proceedings on Privacy Enhancing Technologies, 494-508 (2024)
(6) Nakai, T., et al.: Does Prompt-tuning Enhance Privacy in Large Language Models?, Workshop on Recent Advances in Resilient and Trustworthy Machine Learning-driven Systems (2024)
(7) Higashi, T., et al.: Evaluation of Membership Inference Attacks on LoRA with Differential Privacy, the 9th IEEE European Symposium on Security and Privacy Poster Session (2024)

Digitization of Palpation for Remote Inspection

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Abstract

There are growing concerns over worker shortages in the machinery and equipment maintenance sector, and remote inspection and checking work is being considered as a means of overcoming such concerns. Yet there have been almost no cases of remote inspection and checking work performed using tactile information. In light of this, we are proposing a remote sensing technique tailored to checking looseness of equipment, where tactile information acquired by junior Field Engineers (FEs) at work sites is digitized, and then determined by senior FEs at a remote location. We developed a prototype sensor glove for use by junior FEs at work sites, and a preliminary assessment algorithm to make it easier for senior FEs to determine conditions—evaluation experiments revealed that these delivered ample performance for preliminary assessments. In addition to being used for remote inspection and checking work, this technology is also anticipated to be applied for a range of applications such as remote medical procedures via palpation.

1. Introduction

Appropriate maintenance is essential for the various types of machinery and equipment underpinning our day-to-day lives. Annual inspections conducted by skilled workers are mandated for machinery and equipment that are particularly important, which are checked to ensure that maintenance is being performed under the conditions stipulated by law. Concerns over worker shortages in the maintenance sector have led to calls to implement remote operations based on digital technology as a way of boosting the efficiency of inspections.

Compared to methods based on visual or aural information, there have not been any methods of remote technology established for inspection items based on the use of workers' tactile information (palpation). Given that the travel time to work sites for conducting annual inspections cannot be reduced unless all inspection items can be performed remotely, we decided to focus on digitalizing palpation. Note that there have been cases of remote palpation being considered from the perspective of remote medical procedures.(1)

We turned our attention to inspections that check the state of looseness of equipment using tactile information, and examined the feasibility of a system based on sensors that acquire the force and movement of hands when vibrating equipment located at work sites—this data is then delivered to senior FEs stationed at a remote location. Given that numerous items need to be inspected in a continuous process to acquire data, we opted for an approach where unskilled junior FEs wear sensor gloves and vibrate the equipment, instead of attaching sensors to the equipment. To assess the feasibility of this system, we developed and tested a prototype sensor glove for use by junior FEs at work sites, and an algorithm for preliminary assessments conducted at work sites. After a preliminary assessment, senior FEs stationed at a remote location are able to check the sensor data and make a final determination based on their overall viewpoint leveraging their past experience—we thought that we would be able to achieve efficient and reliable inspection work by taking this approach (Fig. 1).

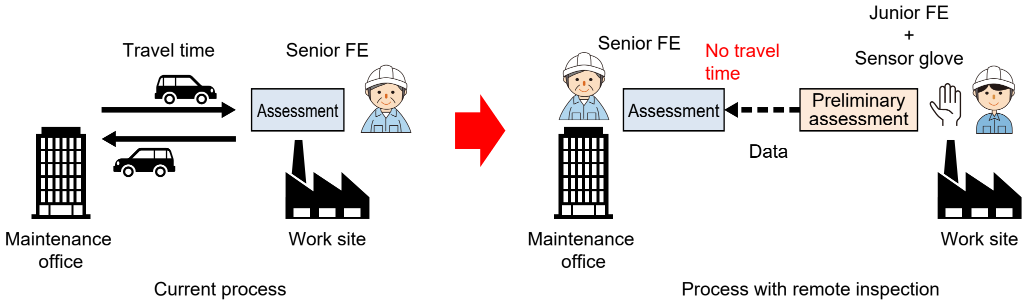


Fig. 1 Operational improvements through the introduction of remote inspection

2. Prototype Sensor Glove for Acquiring Work Site Data

To verify the feasibility of the proposed method, the first step was to develop a prototype sensor glove worn by junior FEs at work sites.(2)

2.1 Examples of target inspection items

Before developing the prototype sensor glove, we studied the specific items being targeted. Given that items being inspected with the use of tactile information often include sensors and covers, we assessed an inspection method of holding target inspection items secured with bolts by grasping them with the thumb and index finger, and vibrating them as shown in Fig. 2.

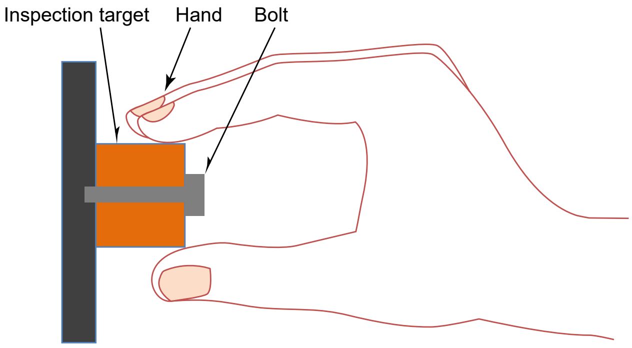


Fig. 2 Examples of target inspection items

2.2 Selection of sensors and development of prototype sensor glove

A prototype sensor glove was then developed to be used for collecting data during vibration.

Sensor data required for determining looseness include movement while vibrating the vibration target as well as the strength and direction of the force from the finger causing that movement. We decided to use sensors mounted on FE's hands, based on the perspective of the ease of installing and mounting the sensors. Given that only the FE's fingertips maintain contact with inspection target during vibration, we decided to focus on acquiring "contact force" and "acceleration" information at their fingertips. After taking these mounting restrictions and the ease of making the system into consideration, we decided to mount pressure sensors (1) and (2) at the tips of the FE's thumb and index fingers that form the contact surfaces with the target inspection item, and acceleration sensor (3) at the tip of the FE's index finger (Fig. 3).

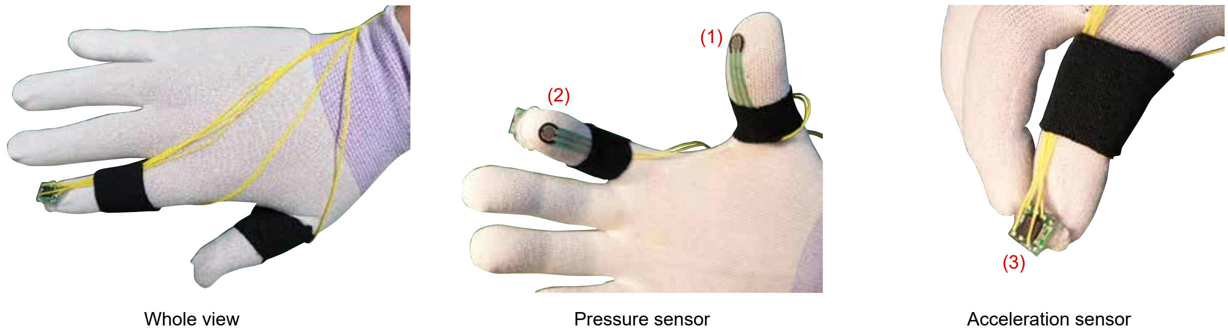


Fig. 3 3 Sensors on prototype glove

We thought that mounting these sensors into the FE's work gloves would help alleviate the impact of wearing them without affecting operations, so we developed the prototype shown in Fig. 3. To prevent wiring from restricting the movement of FEs, we also made use of Bluetooth*1 for connecting to PCs and other devices.

*1 Bluetooth is a registered trademark of Bluetooth SIG, Inc.

3. Preliminary Assessment Algorithm

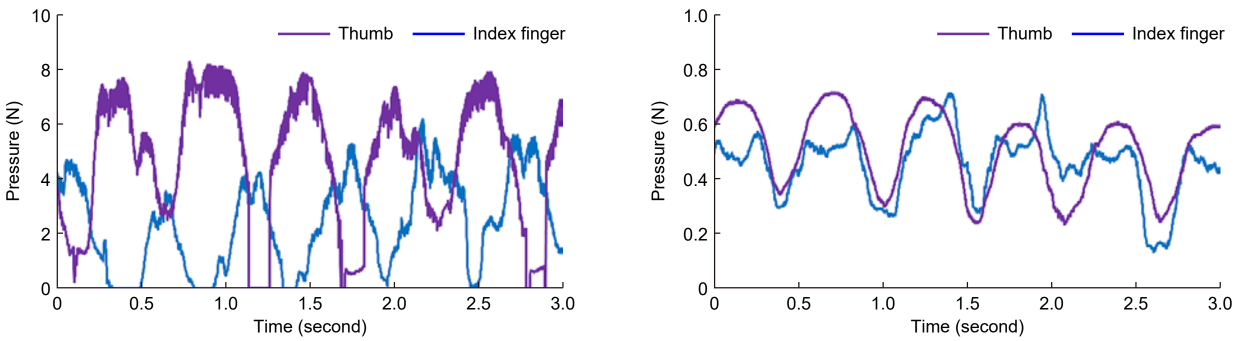
Together with the prototype sensor glove, a prototype algorithm for preliminary assessment of looseness conditions was also developed. This algorithm comprises two stages: determining vibration quality (Section 3.1) and determining looseness conditions (Section 3.2), with looseness conditions only determined after vibrations are determined to be appropriate. The final determination after the preliminary assessment is conducted by senior FEs from their overall viewpoint based on their experience.

3.1 Determining vibration quality

Vibration quality is determined in two ways: whether or not the item is being "grasped" appropriately, and whether or not the direction and strength of the force "applying vibration" are appropriate.

The evaluation of "grasping" uses pressure sensor values at the tip of the thumb and index finger, and determines it to be appropriate if they both exceed the threshold values.

The evaluation of "applying vibration" uses the phase difference between changes in the pressure sensors of those two fingers, and is determined to be an appropriate vibration if it exceeds a preset phase difference threshold. This is based on the fact that the two waveforms are in the opposite phase when applying vibration is applied at the appropriate time and direction, but are not in the opposite phase when the direction of vibration is different or grasping is not tight enough. Figure 4 shows the waveforms when the opposite phase is present, and when only the fingers are being opened or closed. The phase difference is calculated by applying a bandpass filter (1 to 5 Hz) to the two waveforms to extract the AC component, then fitting a single-frequency sinusoidal wave to identify the frequency.



(a) Appropriate vibration

(b) Inappropriate vibration

Fig. 4 Relationship between vibration quality and pressure sensor waveforms

If either the "grasping" or "applying vibration" is determined to be inappropriate, an instruction is shown to apply vibration again.(3)

3.2 Determining looseness conditions

Looseness conditions are determined for data that has been determined to have appropriate vibrations when evaluating vibration quality. Looseness conditions are determined using the maximum amplitude from the acceleration waveform at the fingertips. This method uses the fact that there is play between the bolts and the bolt holes of the metal block as shown in Fig. 5, and when it is loose, the block moves with vibrations, thereby generating a pulsating acceleration waveform caused by impacts at the edge of play. More specifically, the measurement period was divided into one-second intervals, with the maximum amplitude of acceleration changes for each interval used as the feature value. The average value of this feature value over the measurement period (10 points) was compared with threshold value (0.5) set experimentally, and when the value exceeded the threshold value, it was determined that there was looseness.

Fig. 5 Pulse generation depending on the presence of looseness

4. Evaluation Experiment

To verify the effectiveness of the sensor glove and preliminary assessment algorithm, a jig was made up to trial the data collection and determination.

4.1 Evaluation experiment conditions

For the evaluation experiment, a jig was made by securing a metal block matching the size of the target inspection item with two bolts (Fig. 6). A coil spring was mounted to each bolt, and the bolts were tightened with a torque wrench to set conditions with and without loosening such that the tightening torque could be reproduced.

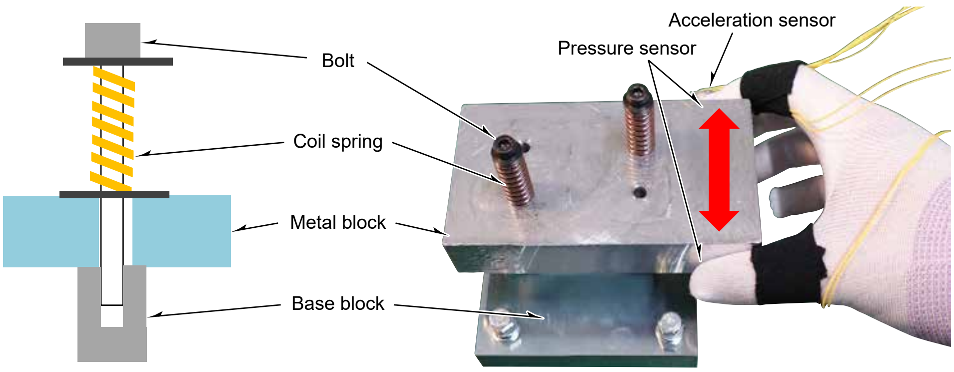


Fig. 6 Fixture for evaluation data acquisition

In the evaluation experiment, a tester wearing a sensor glove applied vibrations to the jig for more than 10 seconds, and only data that was determined to be of an appropriate vibrationquality was collected. Using this method, data for 61 conditions with looseness and 61 conditions without looseness were collected for evaluation.

4.2 Experiment results

The acquired evaluation data were used to assess the determination performance of the preliminary assessment algorithm. As shown in Fig. 7, the evaluation data revealed a tendency for peak acceleration to be larger under looseness conditions, and to be smaller under rigid conditions. Moreover, when calculating the determination feature values for each data, the determination results of all data perfectly matched with the jig settings (100% accuracy), as shown in Fig. 8. If a high level of accuracy is acquired with the preliminary assessment, final determinations made by senior FEs are able to focus on difficult cases, such as those with a low level of looseness. From these results, the preliminary assessment algorithm that we developed was verified as being effective for achieving remote inspections of equipment looseness with greater efficiency.

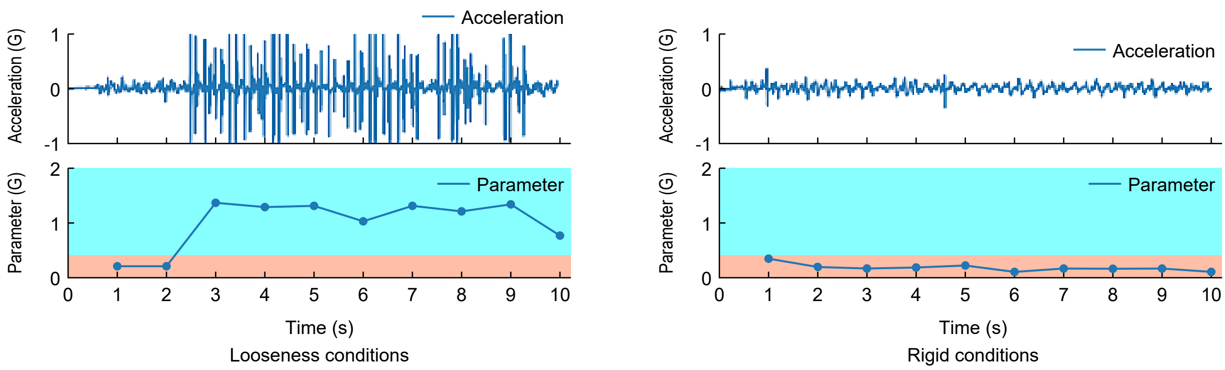


Fig. 7 Waveform data under looseness condition and rigid condition

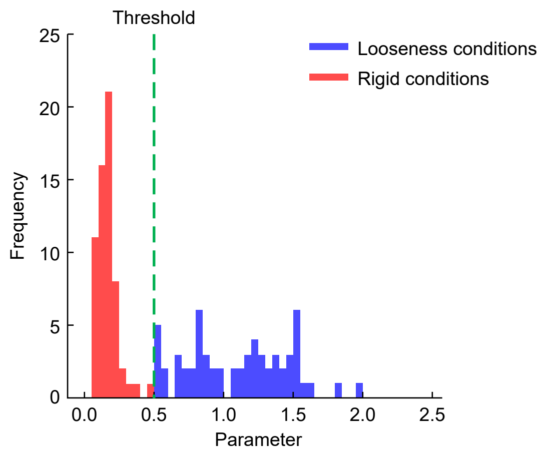


Fig. 8 Extracted parameters from evaluation data (acceleration waveforms during vibration)

5. Conclusion

We developed a prototype sensor glove and preliminary assessment algorithm for digitizing tactile information of junior FEs at work sites for conducting remote inspections utilizing tactile information, which we verified as delivering sufficient performance. Moving forward, we will continue verifying the effectiveness of the system for various target inspection items, ensuring robustness for FEs and the environment, and looking into development of a system for data protection and management. With the development of technology for remote work that involves tactile information, we are seeking to achieve a future where highly reliable services by senior FEs are readily available around the world for the maintenance of machinery and equipment.

References

(1) Tanaka, Y.: Trends in Haptic Research, Systems, Control and Information, 64, No. 4, 119-120 (2020)

(2) Fukui, K., et al.: Study of Remote Inspection System using Sensor Gloves, 40th Annual Conference of the Robotics Society of Japan, 2C3-06 (2022)

(3) Kobayashi, S., et al.: Development of Automatic Detection Method for Fastening Condition Inspections, 2023 Annual Conference on Electronics, IEEJ, GS10-5 (2023)

A Low-Code Development Method for Manufacturing Facilities

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Abstract

The distinguishing feature of the low-code development method for manufacturing facility control programs is that control programs for realizing cycle operation are generated from flowcharts widely used as a design technique for cycle operation. Since the generation of control programs can be done without changing the conventional design technique, the method enables reduction of implementation man-hours needed for the control program, without increasing design man-hours. In the future, we will move forward with development aimed at commercialization by applying this method prototype to development of in-house facilities, and confirming its effectiveness.

1. Introduction

In recent years, demand has been steadily rising for factory automation due to social problems such as the shrinking working population. However, development of facilities for factory automation requires many man-hours, and thus there is a need for greater efficiency in facility development. Among facility development tasks, the task of implementing a control program for controlling facilities is in particular need of greater efficiency. This control program implementation work includes many simple tasks where implementation is done by repeatedly writing similar types of processing based on facility design. Therefore, there is a need for technology to generate control programs from facility designs in order to make this kind of work more efficient. This paper examines a low-code development method enabling generation of control programs from facility designs.

2. Low-Code Development Method for Control Programs

2.1 Control programs to be generated and their design technique

Manufacturing facilities perform automatic production based on cycle operation in which a certain series of actions is repeatedly executed. Therefore, control programs must implement cycle operation by coding the operation sequences and operation conditions of each machine provided in the facility. This cycle operation program is a crucial program that directly affects the facility's production capacity because it determines the movements of the facility in automatic production. Also, this program is implemented by repeatedly writing similar processing, so there is a need for greater efficiency in implementation. The correspondence relationship between design content and implementation content for cycle operation programs has previously never been sorted out, and no efficient techniques have been provided for generating programs from designs. Thus, this paper examines a low-code development method for generating programs for this cycle operation. This section describes an implementation technique that is widely used in cycle operation programs, and the associated design technique.

Control programs for facilities in Japan are frequently implemented using ladder language, one of the languages specified by the IEC 61131-3 standard for PLCs. Figure 1 shows an example ("Control program" section on the right half of the figure). In ladder language, a control program is implemented by describing relay circuit type processing called circuit blocks, and combining multiple circuit blocks. In ladder language, a notation method called state transition format is well known as an implementation technique for cycle operation[1]. This notation is composed of two parts, a state transition section and an output section. The state transition section describes circuit blocks that sequentially advance the states of the facility's cycle operation based on values such as sensor signals. More specifically, as shown in the state transition section in Fig. 1, it describes a circuit block which sequentially turns ON state variables (M0 to M2) each time a condition such as a sensor signal (X1) (yellow box in Fig. 1) going ON is satisfied, and then turns OFF all state variables when the final state variable goes ON. The result of this is a program for cycle operation

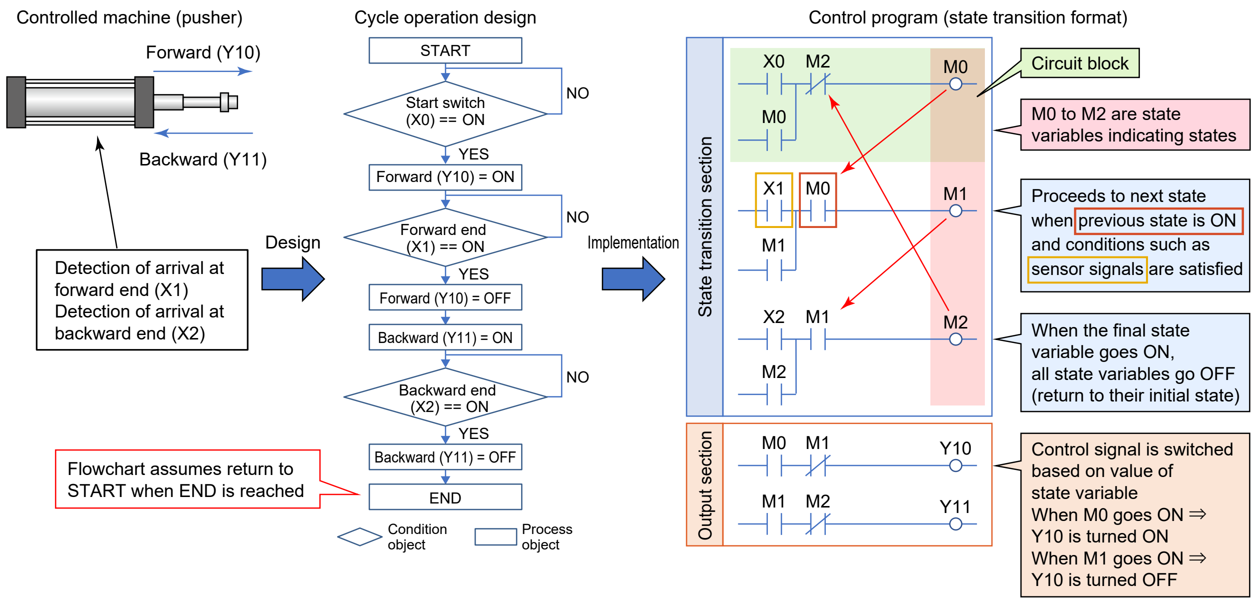

Fig. 1 An example of a cycle operation design and program

which returns to the initial state after the state transitions, and repeats state transitions from the initial state.

The output section describes circuit blocks that turn ON/OFF control variables corresponding to each machine based on the value of state variables in the state transition section. As shown in Fig. 1, the described circuit block is such that when the state variable M0, which is the ON condition for the control variable Y10, goes ON, Y10 is turned ON, and when the state variable M1, which is the OFF condition for Y10, goes ON, Y10 is turned OFF. Cycle operation of each facility is implemented using state transition format consisting of these state transition sections and output sections.

In many cases, specifications for this cycle operation are designed using a flowchart like that in Fig. 1 (section labeled “Cycle operation design”). This flowchart assumes that the flow of the sequence is repeated by executing sequential processing from START, and then returning to START when END is reached. The flowchart shown in Fig. 1 is an example representing cycle operation of a pusher operated by a pneumatic cylinder.

2.2 Issues with the low-code development method

There are two issues for enabling low-code development of control programs. First, it must be possible to design cycle operation with a flowchart, which is the conventional design technique shown in Fig. 1. If the low-code development method requires a design technique significantly different from that used before, there is a possibility that design man-hours will increase, and efficiency will not be improved. Also, if the design technique is close to the conventional approach, it will be possible to seamlessly shift to development using this method.

Second, it must also be possible to generate control programs in a form close to previously implemented control programs. Source code for control programs is read and expanded by people other than the implementer, such as maintenance staff. Therefore, if the forms of the generated control programs change, it will hinder this work and may interfere with maintenance, etc.

Due to the above considerations, we have devised a method for generating control programs in state transition format from flowcharts, which are the conventional design technique, in order to resolve these two issues.

2.3 Control program generation step

With the low-code development method, the flowchart design content and circuit blocks in state transition format are redefined as combinations of patterns, and a control program in state transition format is generated from a flowchart by mapping the flowchart patterns to the control program patterns based on a correspondence relationship. This section describes that correspondence relationship, and then describes the technique for generating control programs based on that correspondence relationship. To simplify the explanation in this section, the patterns in flowchart design content and the patterns in generated circuit block are limited to those shown in Fig. 1. There will be multiple patterns when applying the method to development of actual facilities. Examples of patterns include: cases where the direction of flow branches at a condition object, and cases where a timer is used as a condition.

First, circuit blocks for state transition sections are generated from condition objects in the flowchart. As noted in section 2.1, the state transition section has the characteristic that the system transitions to the next state when the condition is satisfied. Therefore, a condition object indicating flow to the next object when the condition is satisfied is placed into correspondence with a state transition section in state transition format. Next, a circuit block for the output section is generated from the process object of the flowchart. The output section has the characteristic that it switches a control variable ON/OFF based on the value of state variables in the state transition section. Therefore, the output section in state transition format is placed into correspondence with the process object indicating rewriting of the value of a control variable. The switching of the control variable is done in multiple process objects, so multiple process objects and a single circuit block of the output section are placed into correspondence. With the technique examined here, circuit blocks are generated in the three steps indicated below based on these correspondence relationships (Fig. 2).

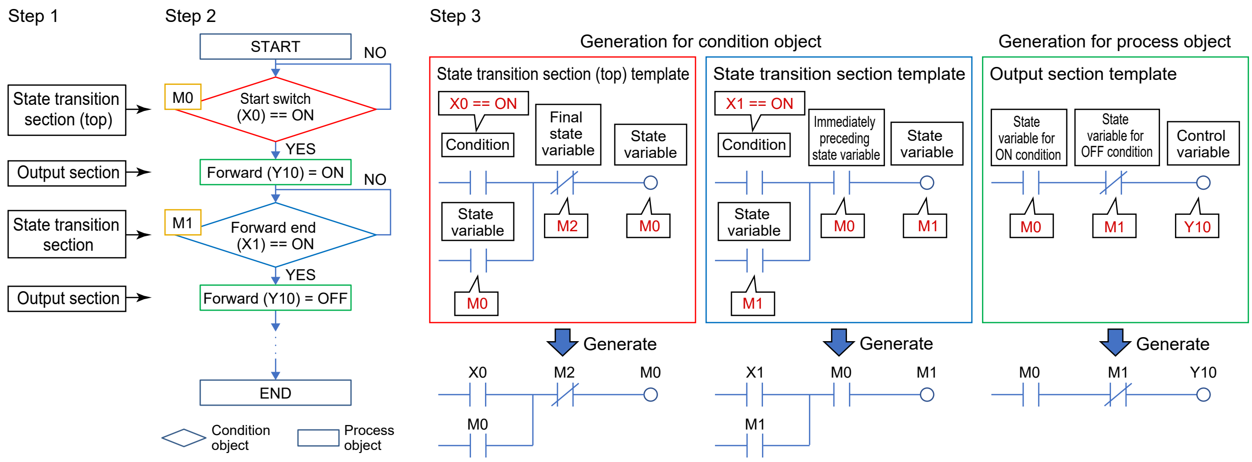

Fig. 2 Control program generation process

(1) Step 1: Flowchart analysis

The flowchart is analyzed, and for each object in the flowchart the circuit block pattern to be generated is determined based on the type of object and the line connection information between objects. As shown in Fig 2, it is determined, based on the type of object, that the pattern to be generated is a circuit block of a state transition section for a condition object, and a circuit block of an output section for a process object. The circuit block at the top of the state transition section includes processing to reset all states, and is different from circuit blocks not at the top. Therefore, of the condition objects, the one at the top of the flowchart is determined from line connection information, and it is determined to be the pattern for "state transition section (top)" as indicated on the left side of Fig. 2.

(2) Step 2: Variable assignment

A single state variable is needed for a single process of a state transition section, and thus a single state variable is assigned to each condition object. State variables are assigned in sequence, starting from M0, to the condition objects in Fig. 2.

(3) Step 3: Generation of circuit blocks corresponding to each object

Based on the flowchart information and allocated state variable information, circuit blocks are generated that reflect the contents of the flowchart from the circuit block templates corresponding to the patterns identified in Step 1. Circuit blocks for condition objects are generated by identifying the variables to be set in the template, based on the conditions indicated in the condition objects, information on line connection between objects, and other factors, and then setting those variables. Circuit blocks for process objects are generated by identifying the necessary variables based on line connection information relating to the multiple process objects for each control variable, and then setting those variables.

In this way, a control program in state transition format is generated by generating circuit blocks corresponding to flowchart design content, and arranging the generated circuit blocks to correspond with the flowchart.

3. Conclusion

This paper has presented a low-code development method for generating control programs for cycle operation from flowcharts. Since generation can be done using this method without changing the conventional design technique, the method enables reduction of implementation man-hours needed for the control program, without increasing design man-hours. Going forward, we will verify the effectiveness of this method, and strive for commercialization.

References

(1) Kumagai, H.: Handbook: Standard Sequence Programs using PLC, Techniques for Creating Ladder Diagrams to Control Equipment, Nikkan Kogyo Shimbun (2021)

Skill Assessment AI Technology for Expert Skill Succession

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Abstract

We have developed an AI technology for assessing skill in mold-surface polishing work in order to transfer the superior skills of experts to non-experts. We developed an AI model which compares fingertip movements extracted from video taken by a camera during polishing work, and learns so that experts have higher assessment values than non-experts. As a result, the model was able to distinguish the movements of experts and non-experts with an accuracy of 96.3%. Furthermore, the assessment values found by the AI model tend to be higher when an area is polished broadly and uniformly, and this result was found to pertain to a polishing technique called "blending" that experts practice in order to minimize distortion. In the future, we plan to verify whether non-experts can master polishing methods that minimize distortion by assessing their ability to perform blending polishing.

1. Introduction

Over 75% of companies in the manufacturing industry need to secure human resources, and securing skilled human resources in particular is essential for continuing their business activities[(1)]. The percentage of companies re-hiring expert skilled workers after retirement age and assigning them as instructors in order to develop skilled human resources has risen as high as 60%[(2)]. Going forward, expert skilled workers will age further, and accelerating transfer of skills is an urgent issue. However, the skills cultivated by experts have been unconsciously optimized based on their own experience, and it is difficult to discover those skills and transmit them to non-experts. To address this, Mitsubishi Electric has been conducting R&D together with Kyoto University and the National Institute of Advanced Industrial Science and Technology (AIST) through the NEDO Project "AI for Extracting and Transferring Experts' Tacit Knowledge." The aim is to achieve early transfer of expert skills.

For this project, Mitsubishi Electric has adopted the theme of mold-surface polishing (mirror polishing) for finishing metal surfaces cut with NC machining into a distortion-free mirror surface, and we have developed AI technology for assessing that skill based on videos taken by a camera during polishing work by experts and non-experts (Fig. 1).

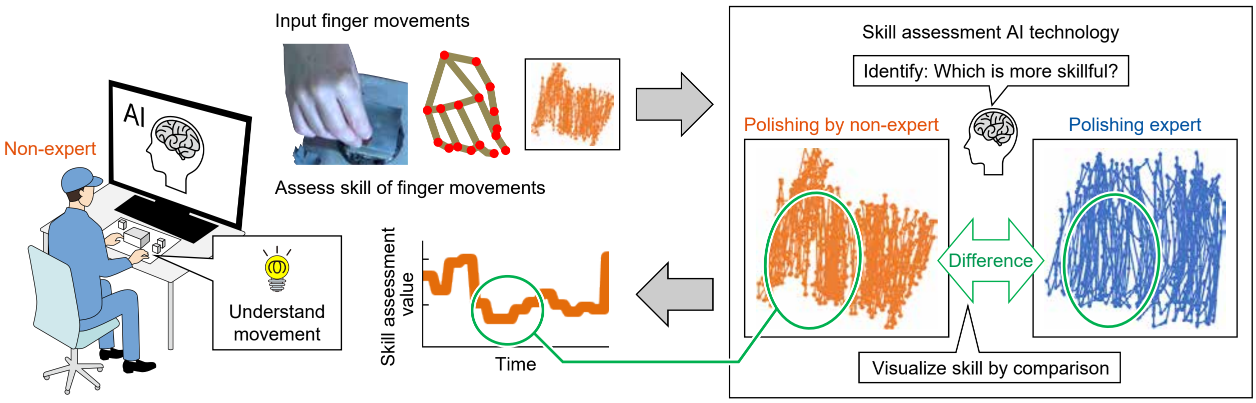


Fig. 1 Reducing the training period of technicians using skill assessment AI technologies

This paper explains the method of the developed skill assessment AI technology. It also evaluates the method and discusses its future outlook.

2. Skill Assessment AI Technology

To discuss the AI technology for assessing skills, we first explain the technical task of mirror polishing which is the theme in this paper. We also discuss the data extraction method and assessment method for assessing skills.

2.1 Technical task of mirror polishing

Mirror polishing is a type of work where the entire surface is smoothed to a mirror finish by applying a grinding stone or sandpaper to the surface of a mold part and polishing it. If mirror polishing skills are inadequate, the surface becomes distorted, and distortions occur in parts formed by the mold. This sort of distortion problem is determined by the motion with which polishing is done, and at what position polishing is done relative to the metal surface, and thus it was decided to assess differences in polishing trajectory between experts and non-experts. To secure input data in sufficient volume for an AI model, we had experts and non-experts perform repeated mirror polishing of mold parts, and took a total of 26 hours of video of this polishing process.

2.2 Extraction of polishing trajectories

To extract polishing trajectories, a video of the skilled worker's hands was taken by a camera during polishing, from a position above the worker. Polishing scenes were excerpted from the video. Hand skeleton information was extracted using MediaPipe(3), and the coordinates of the index finger of the polishing hand were extracted from that.

From the resulting work videos, 497 trajectory data sets were obtained for experts and 173 trajectory data sets were obtained from non-experts. There is more trajectory data for experts because they interrupted polishing at shorter time intervals, and we divided the trajectory in such cases. The reason why we divided the trajectory each time polishing was interrupted is that the position where polishing is resumed after the interruption is not always the same, and there is a high probability that the data will contain noise if the trajectories before and after the interruption are taken to be a series.

2.3 Skill assessment method

The skill assessment AI model developed in this case is based on a method of assessing which one of skill levels in to input videos are superior(4), and it was decided to do the assessment with 128 frames (4.3 seconds) of fixed-length data using a Temporal Convolutional Network (TCN). A TCN or Recurrent Neural Network (RNN) must be used to handle the polishing trajectories, which are time series data. However, experts take less time to polish than non-experts, and to prevent the model from capturing this tendency, we adopted fixed-length data using TCN rather than variable-length data using RNN. This AI model performs metric learning so that experts are assessed higher. This is achieved by taking pairs of trajectories from both experts and non-experts as input, and when the assessments of experts and non-experts are reversed, that difference is provided to the model as a loss. At inference time, if the polishing trajectory of a worker whose skill improvement is to be supported is input, the model can assess the skill level by comparing the input with previously learned trajectory data (Fig. 2).

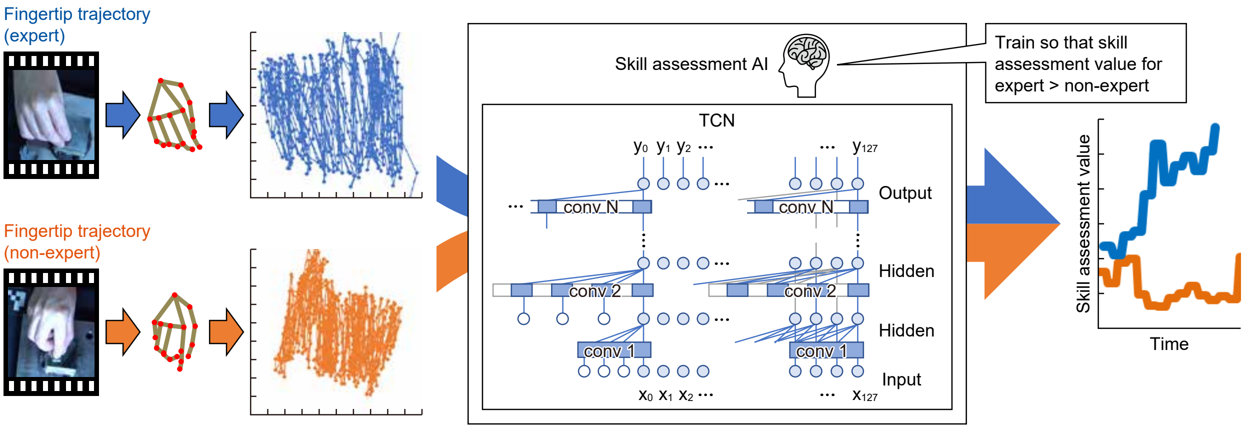
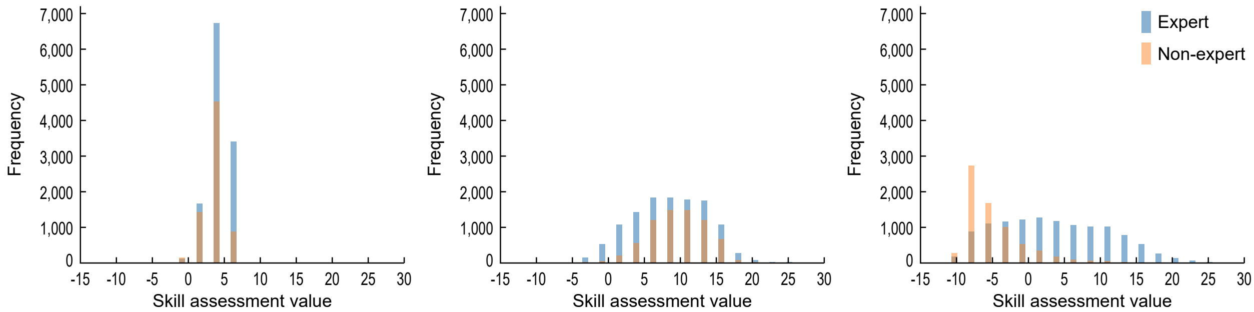


Fig. 2 Skill assessment AI model

3. Assessment

Measurements of surface distortion and other factors revealed that experts were able to perform work with good quality. Therefore, 39,873 trajectory pairs were created as training data from the obtained polishing trajectories, and training was carried out so that the assessment values of experts would always be higher than those of non-experts. As a result, the assessment accuracy marked 96.3%. In measuring the judgment accuracy, we recorded a right judgment when the model gave a higher scored for the expert than that of the non-expert and a wrong judgment in the reverse case, for each of all pairs of an expert and non-expert.

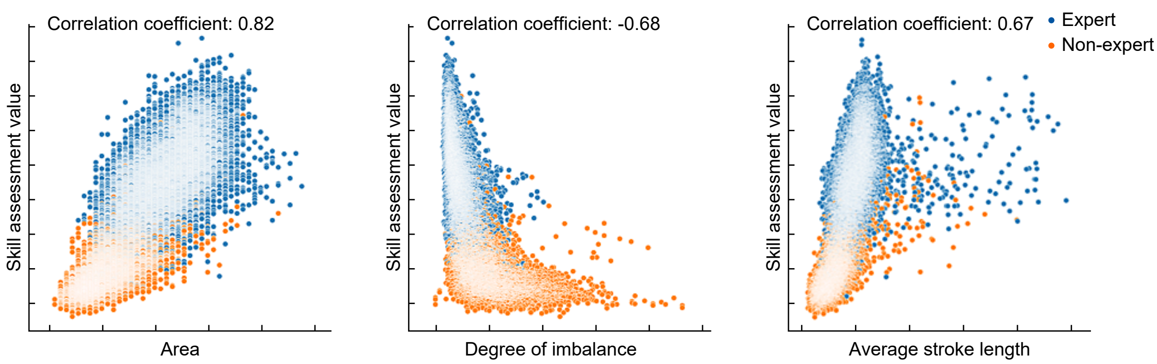
Next, to confirm whether the model has captured movement skills, a frequency graph was created showing how many frames of trajectory are used to assess skills (Fig. 3). Figure 3 shows in (a) and (b) that there is no difference in skill assessment values between experts and non-experts, but differences appear with 128 frames in (c). Therefore, the AI model does not capture the skill by reacting only to a specific position; it captures the skill through movement.



(a) 1-frame portion (b) 14-frame portion (c) 128-frame portion

Fig. 3 Distribution of skill assessment values with respect to the number of frames in the trajectory

To further investigate which types of trajectories the AI model reacts to, we examined the correlation between the skill assessment values found by the AI model and the values of the features listed in Table 1, which we created in advance by observing movements of experts. Figure 4 plots the distribution of all polishing trajectories of experts and non-experts, with features from Table 1 on the horizontal axis and skill assessment values found by the AI model on the vertical axis, and shows the correlation coefficients between each feature and the skill assessment values. In Fig. 4, data indicating expert polishing is given in blue, and data indicating non-expert polishing is given in orange. The figure only shows distributions for the three features in Table 1 that are highly correlated with skill assessment values. From Fig. 4, it is evident that the assessment value tends to be higher if the polishing area is higher, and if polishing is highly imbalanced and locally focused, then the assessment value tends to be low. There is also cross-correlation between average stroke length and broadness of area, and thus average stroke length was found not to be an effective feature that could serve as a substitute for area.



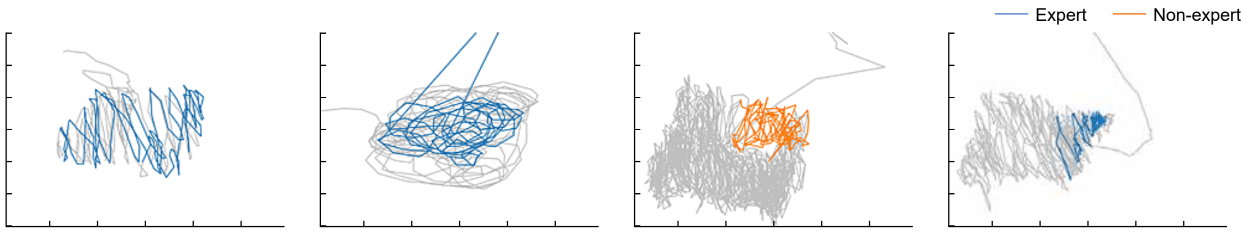
(a) Correlation with area (b) Correlation with degree of imbalance (c) Correlation with average stroke length

Fig. 4 Relationship between feature values and skill assessment values

Table 1 Description and name of hand-made features

Feature name	Explanation
Average X coordinate	Analysis of whether there is a polishing tendency imbalanced to the right or left side
Average Y coordinate	Analysis of whether there is a polishing tendency imbalanced to the near or far side
Total movement distance	Analysis of whether total movement distance of polishing trajectory is long or short
Average angle	Analysis of whether movement direction of polishing trajectory is always the same
Average variance	Analysis of whether movement direction of polishing trajectory has variation
Average stroke length	Analysis of whether round-trip stroke length of polishing trajectory is long or short
Stroke length variance	Analysis of whether round-trip stroke length of polishing trajectory has variation
Area	Analysis of whether area of polishing trajectory is broad
Average speed	Analysis of whether speed of polishing trajectory is high
Average acceleration	Analysis of whether acceleration of polishing trajectory is high
Degree of imbalance	Analysis of whether polishing trajectory is locally imbalanced compared to other points

Figure 5 visualizes trajectories that were ranked at the top and bottom as a result of sorting by assessment values calculated by the AI model. In Fig. 5, the overall trajectory is shown in gray, and 128-frame portions of the overall trajectory are shown in color. The expert's polishing trajectories are shown in blue and the non-expert's polishing trajectory is shown in orange. A trend was confirmed in which trajectories of polishing by an expert over a broader area, as in Fig. 5(a) and (b), were assessed with a high ranking, while trajectories of local polishing by a non-expert, as in Fig. 5(c), were assessed with a low ranking. It was also confirmed that the ranking was low for trajectories polished locally, even if done by an expert, as in Fig. 5(d).



(a) Top rank example 1, Expert
(b) Top rank example 2, Expert
(c) Bottom rank example 1, Non-expert
(d) Bottom rank example 2, Expert

Fig. 5 Polishing trajectory of top and bottom ranking assessed by skill assessment AI model

An expert interviewed beforehand commented, "To avoid distorting the surface, it's good to polish with a 'blending' technique. 'Blending' means that when you polish intensively in one area, you should also polish the surrounding areas and overall surface to maintain uniformity." This comment indicates that one should not intensively polish one area too much, but rather broaden the area by also polishing the surrounding areas and the overall surface. This matches the behavior of the AI model developed here.

4. Conclusion

We were able to capture the features of the "blending" polishing method, which is important for preventing surface distortion, through an AI model that was trained by comparing polishing trajectories of experts and non-experts and determining which had higher assessment values. With the previous method(4), videos containing multiple features distinguishing experts and non-experts were compared, and thus there was the problem that features unrelated to the skill were also extracted. With the developed method, in contrast, comparison is done by focusing on features for capturing the skill of finger movements, so it was possible to extract features relating to the above polishing method. By utilizing this kind of AI model, we can assess the polishing methods of non-experts, and support skill transfer by providing non-experts with examples of highly-assessed experts as models to follow so that non-experts can refer to them as necessary.

In response to the worsening shortage of skilled human resources in the manufacturing industry, we believe that incorporating the developed AI technology for skill assessment will help capture technical skills, promote their transfer, and accelerate the development of skilled personnel. In the future, we plan to develop a Skill Succession Support System using the developed AI technology for skill assessment, and we will verify its effectiveness, with the aim of accelerating the development of skilled personnel.

These results were obtained as result of a project (JPNP20006) commissioned by NEDO.

References

(1) Ministry of Economy, Trade and Industry, Ministry of Health, Labour and Welfare, and Ministry of Education, Culture, Sports, Science and Technology: White Paper on Manufacturing Industries 2019 (2019)

(2) Ministry of Economy, Trade and Industry, Ministry of Health, Labour and Welfare, and Ministry of Education, Culture, Sports, Science and Technology: White Paper on Manufacturing Industries 2022 (2022)

(3) Lugaresi, C., et. al.: MediaPipe: A Framework for Perceiving and Processing Reality, Third Workshop on Computer Vision for AR/VR at IEEE Computer Vision and Pattern Recognition (2019)

(4) Doughty, H., et. al.: Who's better? who's best? Pairwise deep ranking for skill determination, IEEE Conference on Computer Vision and Pattern Recognition (2018)

Case Studies of Extending Open-Source Database Software PostgreSQL and Contributing to Open-Source Communities

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Abstract

Open-Source Software (OSS) has become increasingly important in recent years. In addition to using OSS, Mitsubishi Electric emphasizes contribution to OSS communities to improve their value and achieve sustainability, and we plan to expand those activities. By deepening understanding of internal operation of PostgreSQL[*1], an OSS Relational Database Management System (RDBMS), through efforts toward management of external data with PostgreSQL, we have identified opportunities for accelerating aggregation processing in distributed configurations, and proposed some development results to the OSS community. To advance the dissemination and development of OSS, and we are also contributing to various OSS communities through activities such as patch submissions, documentation translation, and conference presentations.

1. Introduction

To achieve sustainable growth, Mitsubishi Electric has established a management strategy of promoting open innovation based on technical capabilities and creativity. The aim is to design the future and create new value in a timely fashion through fusion of knowledge and co-creation both within and outside the group. One important initiative within this overall strategy is contributing to OSS communities. Use of OSS is growing throughout the world. It is said that 96% of the world's software projects include OSS, and 77% of their source code is OSS[(1)]. OSS is essential to global software development, including at Mitsubishi Electric. We believe it is our social responsibility to participate in and contribute to OSS communities in order to improve the value of OSS and make it sustainable. Mitsubishi Electric has promoted the use of OSS in accordance with its philosophy and licenses, formulating OSS Usage Guidelines in 2014, and establishing an Internal OSS Manager Liaison Committee in 2018.

PostgreSQL, an OSS RDBMS, supports the standard SQL used for database operation and definition, and is highly extendable. In connecting our database products by using PostgreSQL's foreign database management feature, it was necessary to understand PostgreSQL's internal operation in order to overcome limitations due to the interface of our database products. When, as part of this process, we performed parallel aggregation processing in a distributed configuration by connecting PostgreSQL instances using the foreign database management feature, we found there was still room for significant performance improvement, and that led us to create a patch for PostgreSQL core functionality, and propose it to the community.

2. Initiatives for PostgreSQL Feature Extensions

Mitsubishi Electric is engaged in various initiatives relating to PostgreSQL, such as feature extensions. An example is shown in Fig. 1. The feature extensions in the figure are explained in section 2.1 and 2.2 below.

*1 PostgreSQL is a registered trademark of the PostgreSQL Community Association of Canada.

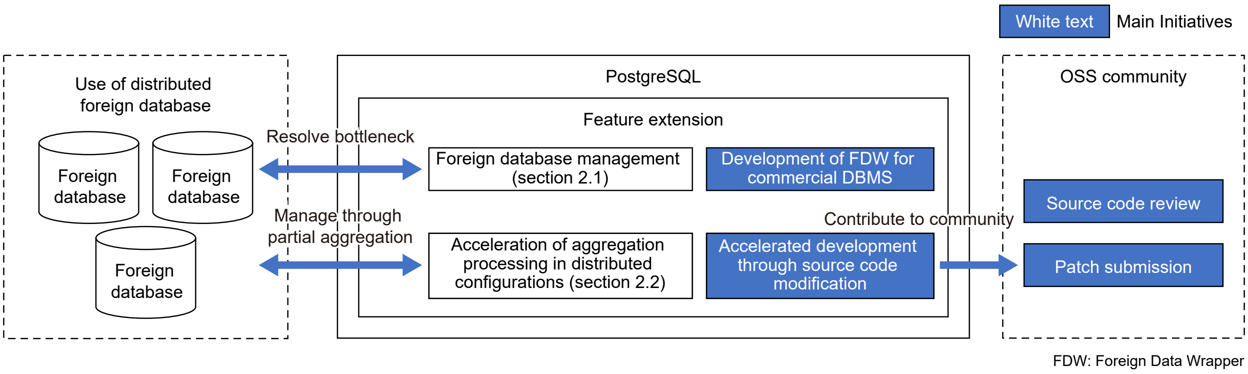

Fig. 1 An example of various initiatives, including PostgreSQL feature extensions

2.1 Foreign database management

Here we present two examples of extension in application of the FDW, the external data management feature of PostgreSQL to a commercial Database Management System (DBMS).

The first is an example which resolved the restriction on the number of connections with foreign databases. FDW needs to maintain the connection to a foreign database until the query is complete. Therefore, when multiple queries are executed simultaneously to a foreign database or when executing queries containing numerous foreign tables, and the number of connections exceeds the limit, a connection-waiting deadlock may occur. In this case, processing of the entire query halts. To solve this issue, we added a connection management feature for foreign databases to FDW, allowing new connections to be initiated while continuing existing query processing when the limit on the number of connections has been exceeded (Fig. 2).

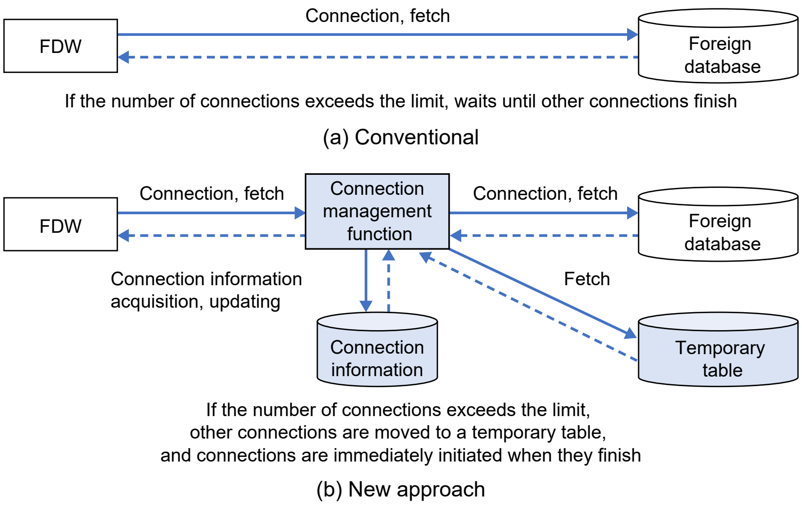

Fig. 2 Removing foreign database connection restrictions

The second example resolves processing bottlenecks of FDW. Since PostgreSQL executes queries with a single process, PostgreSQL and FDW are executed synchronously, resulting in inefficiency because FDW processing cannot be executed during execution of PostgreSQL processing. When there is a discrepancy between PostgreSQL's internal data format and the foreign database's output format, transform processing may take a longer time. To address this issue, we achieved acceleration by executing PostgreSQL processing, fetch processing, and transform processing asynchronously, and parallelizing the transform processing (Fig. 3).

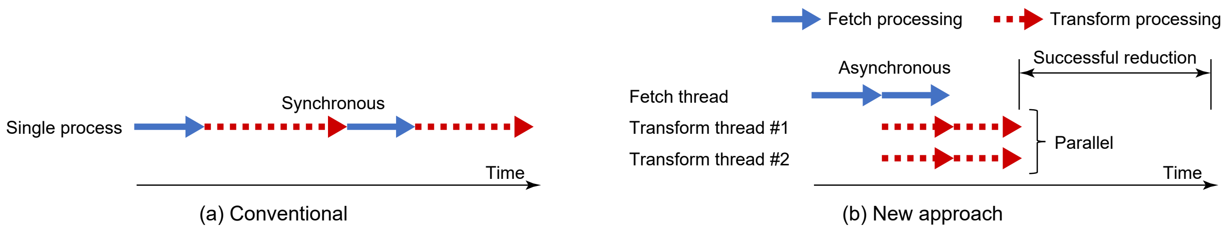

Fig. 3 Acceleration of querying foreign database

2.2 Acceleration of aggregation processing in distributed configurations

The PostgreSQL development community is advancing the development of built-in sharding to achieve scale-out using only standard features such as FDW. In the existing built-in sharding, operations that can be processed in parallel are limited to row selection, joins, and the like, and parallel processing of aggregation operations is not supported. Mitsubishi Electric regards built-in sharding as a collaborative area, and we offer improvement proposals based on know-how in foreign database management that we have accumulated through the development described in Section 2.1.

The premise of built-in sharding is that the coordinator that controls the workers expresses the processing requested by FDW to each worker as SQL statements, issues them to the workers, and generates the final result using the SQL statement results from each worker. To maintain consistency with this premise, the content of the state value generation processing (partial aggregation processing) of the aggregation function that workers pass to the coordinator needs to be expressed using SQL aggregation functions. However, there is a problem that partial aggregation of some existing aggregation functions cannot be expressed by the format of existing aggregation functions. For example, in the case of numerical averaging processing, the state value that a worker passes to the coordinator is an array containing the total and the count of data items, but there is no existing aggregation function that returns such a state value.

For this issue, we submitted a patch to the community that installs aggregation functions (partial aggregation functions) that execute partial aggregation processing in workers, and those functions are then executed by each worker. For all aggregation functions that can be parallelized, we implemented their partial aggregation processing as functions based on existing mechanisms, so that partial aggregation can be installed without coding but only with simple definition statements. Performance was evaluated using TPC-H, an international standard benchmark for analytic queries of large-scale databases, and the results confirmed that the aggregation processing speed increased proportionally with the number of workers. With five workers, it was confirmed that the aggregation processing speed became 12 times faster compared to conventional PostgreSQL due to aggregation parallelization and the elimination of data transfer overhead through partial aggregation.

3. Activities Contributing to Various OSS Communities

Aside from the PostgreSQL described in section 2, Mitsubishi Electric participates in various OSS communities and contributes to the dissemination and development of OSS through activities such as feature enhancement and quality improvement through patch submissions, document translation, and conference presentations. These contribution activities of Mitsubishi Electric have only just started, but we are formulating an “OSS Contribution Policy” and “OSS Contribution Guidelines,” and we plan to broaden our activities in line with those frameworks. In addition to PostgreSQL, we have been contributing to communities by submitting patches for feature enhancements and bug fixes, and reviewing patch submissions, for various types of open source software including PyTorch[*2] (one of the most widely used AI frameworks), Apache TVM[*3] (a compiler that optimizes and accelerates AI processing), and Hummingbird. In Hummingbird, our company’s engineer Masahiro Hiramori ranks No. 3 in number of commits (as of November 2024). He contributes to the development and sustainability of OSS communities as a committer with the authority to integrate source code provided by contributors into the mainline. We were one of the few Japanese companies that made a presentation at TVMCon, a conference on deep learning compilers.

*2 PyTorch and Hyperledger are registered trademarks of the Linux Foundation.
*3 Apache TVM is a registered trademark of the Apache Software Foundation.

In addition to submitting patches, we contribute in the form of translating official documentation from English to Japanese for Hyperledger*2, a blockchain platform. We gave a presentation on this translation work at the Hyperledger Conference.

We are also contributing to the overall OSS ecosystem by participating in the Linux Foundation, a non-profit organization that brings together numerous major OSS communities including PyTorch and Hyperledger mentioned above to promote the development of OSS.

4. Conclusion

This paper has discussed examples of PostgreSQL extension development, our involvement with OSS communities, and our previous efforts to contribute in the fields of AI frameworks and data management. Going forward, we will establish internal OSS contribution policies and OSS contribution guidelines, conduct high-quality and speedy development using OSS, and fulfill our social responsibilities through contributions to OSS communities.

Reference

(1) Black Duck Software, Inc.: 2024 Open Source Security and Risk Analysis Report
https://www.blackduck.com/en-us/resources/analyst-reports/open-source-security-risk-analysis.html

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