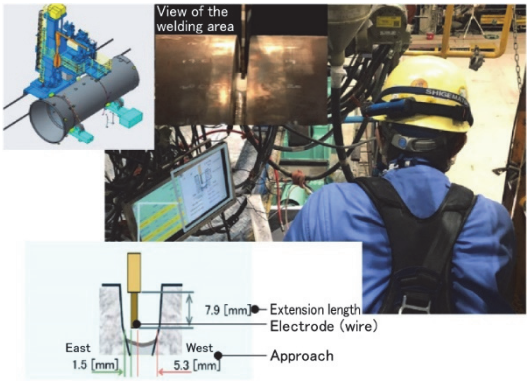
# Development of Welding Technology with Artificial Intelligence




MASAYUKI YASUDA*1 KENICHI NAGAO*1
YOSHIYUKI NAKASHIMA*1 MAYU KUBO*2
HISASHI NISHIKI*3 NAOKI SUDA*1

*High reliability is required for welding of nuclear equipment, and even in mechanized welding, skilled welding operators are operating. On the other hand, the number of workers in the manufacturing industry is decreasing, and it is necessary to develop technology to reduce the degree of skill dependence. In order to solve this problem, two welding techniques which enable high quality welding equivalent to that of skilled welding operators even if the experience is small were developed by incorporating AI technology which is remarkable in recent progress into the automatic welding which has been developed until now, and applied to the actual work. Since this technology contributes to productivity improvement as well as reliability improvement, further development and application expansion of this technology will be promoted.*

## 1. Introduction

In the welding of nuclear equipment, even in the mechanized welding, conditions of the welding area are visually checked to correct the welding parameters in order to achieve high-quality welding, thus skilled techniques are required.

At this time, models to determine correction using AI (machine learning/deep learning) technology based on the welding parameters and image information of the welding area acquired by various sensors were established. By incorporating these models into welding machines, systems that can perform welding operations at the same level as those performed by skilled welding operators were developed.

Two examples of the development are introduced in the following chapters.

## 2. AI welding support system with abnormality detection model

### 2.1 Overview

The AI welding support system is a system for the purpose of sensing each welding parameter during welding so that the control equal to that of the expert welder is possible, and instructing the welder to the right operation judged by AI in process.

Although this technology is useful for all welding process, the system was first developed for submerged arc welding (hereinafter referred to as SAW), which is the main welding process for large nuclear pressure vessels. The welding method of a large pressure vessel in which SAW is commonly used is shown in **Figure 1**. SAW is performed in the downward direction while rotating the vessel barrel.

Weld zone of SAW is covered with dispersed flux (powder) to protect it from the atmosphere. Before welding (before covered by the flux), the welding operator sets the appropriate key parameters such as the wire extension and the aiming position (approach). Since these welding parameters cannot be visually observed during welding, skilled welding operators make corrections based on the surface condition of the flux and the appearance of the weld after welding. Therefore, a system that uses sensors to acquire welding parameters that cannot be visually observed was developed. When a

*1 Nuclear Manufacturing Department, Nuclear System
*2 Manufacturing Technology Research Department, Research & Innovation Center
*3 Engineering Manager, Nuclear Manufacturing Department, Nuclear System

parameter is detected to be in an abnormal condition, the system instructs the welding operator to make corrections to achieve the standard values. As a result, even inexperienced welding operators can easily correct.

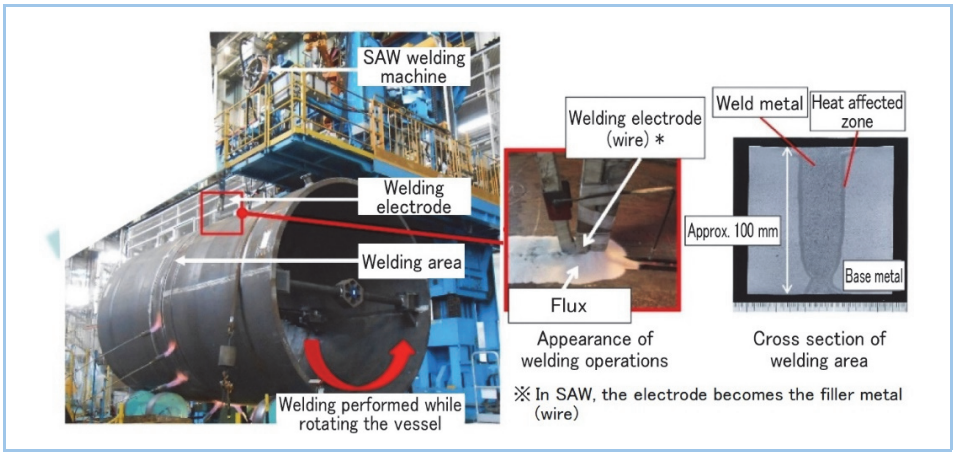



**Figure 1 Example of welding a large pressure vessel**

## 2.2 Details of developed technology

### 2.2.1 Selection of welding parameters

Many welding parameters affect the welding quality of SAW. Therefore, a number of sensors were installed on a mockup and on a welding machine to evaluate the effect on welding quality. As a result, many parameters such as welding current, welding voltage, welding speed, wire feed speed, wire extension length, and wire approach to the groove could be selected as parameters that should be handled by machine learning.

### 2.2.2 Machine learning method

A model to detect abnormalities was established by performing machine learning using the acquired welding parameters. The concept of the abnormality detection model is shown in **Figure 2**. Although the figure is illustrated in a simplified two-dimensional plane, the actual abnormality detection model was established multi-dimensionally, including the acquired data and physical data obtained from the parameters. Regarding machine learning, data from sound welds without defects were used. **Figure 3** shows a color map which evaluated the weld of mock-up vessels actually multi-layer welded using the established abnormality detection model. The horizontal axis indicates the welding angle in the rotational direction of the barrel, and each line on the vertical axis indicates the welding layers. When viewed chronologically, the first layer is shown as the bottom line, with the welding progressing from left to right. The next layer is one line up, with welding progressing from left to right. Red indicates the highest abnormality (abnormal) and blue indicates the lowest abnormality (stable). As shown in Figure 3, weld defects were detected in areas with high abnormality, confirming validity of the model as an abnormality detection model.

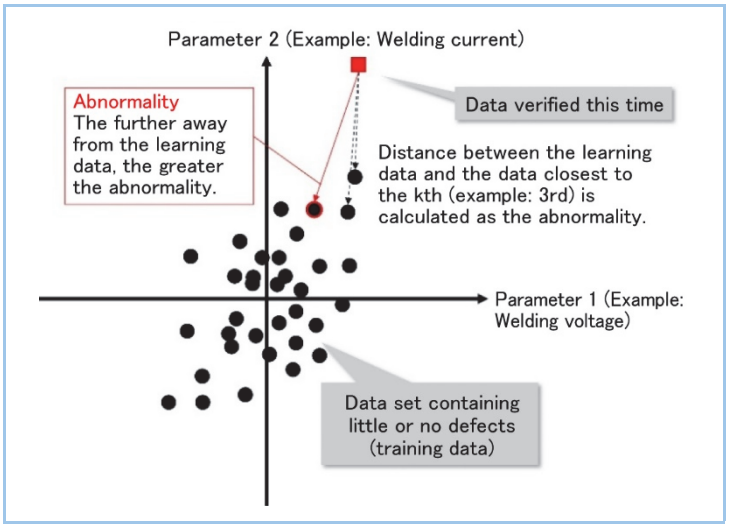



**Figure 2 Concept of abnormality detection model**

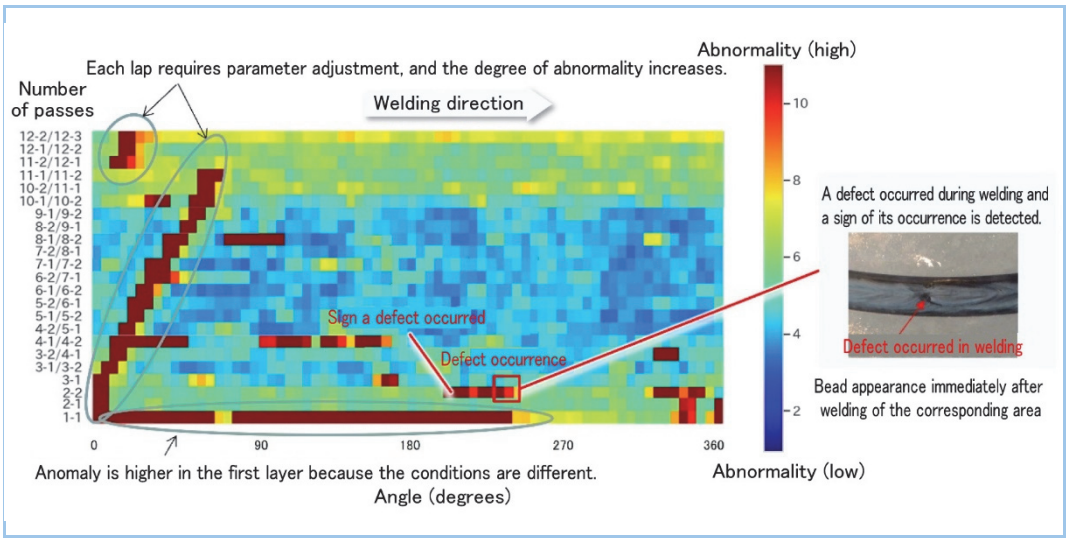



**Figure 3 Evaluation of abnormality detection model in welding of mockup**

2.2.3 System development

A system that measures and displays various parameters in process during welding, alerts the welding operator of the abnormalities detected by the abnormality detection model, and then instructs the welding operator to correct such parameters. An example of the system display screen is shown in **Figure 4**. The system visualizes values that cannot be monitored during welding, such as wire extension length and approach. When an abnormality increases, it is possible to instruct the welding operator to correct various causative parameters.

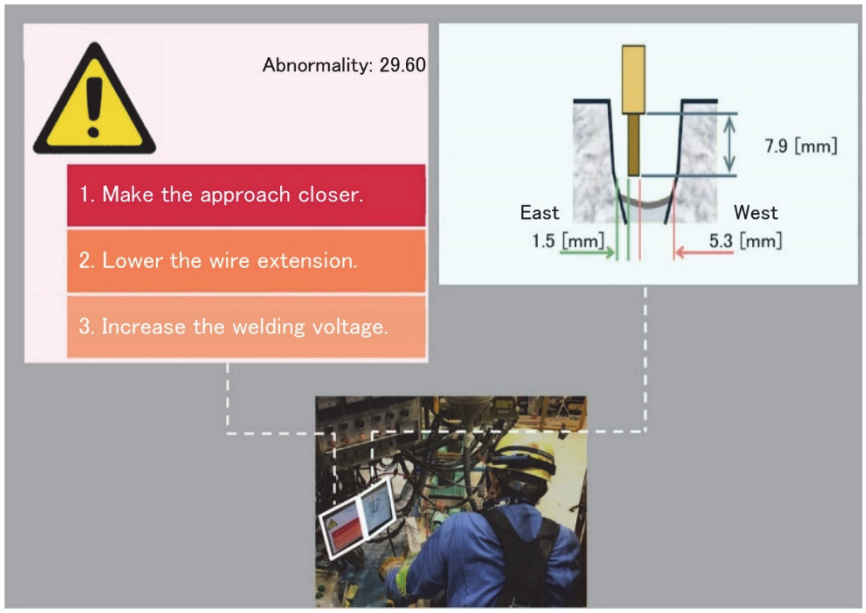



**Figure 4 Screen of welding support system**

## 2.3 Benefits of development

A model for sensing various welding parameters and detecting abnormality by AI (machine learning) was established. This AI welding support system that uses the abnormality detection model has been applied to the circumferential welding of large pressure vessels in nuclear power plants. By detecting welding parameters that could not be constantly monitored until now, and issuing correction instructions using the anomaly detection model, it was possible to achieve stable welding quality independent of welding operator's experience.

# 3. AI automatic welding control system using weld image information

## 3.1 Overview

The automated welding system is designed to combine image processing and AI technologies to automatically perform control at the same correction level as that performed by skilled welding operators while watching a welding monitor.

This technology was developed for automatic TIG welding, which is widely used for piping in nuclear power plants. A conventional mechanized TIG welding process is shown in **Figure 5** and a schematic diagram of conventional welding operator operation in **Figure 6**. This mechanized welding is performed while oscillating the arc to the left and right according to the direction welding progresses. Normally, a welding operator welds while checking the image of the welding area obtained from a weld monitoring camera. To prevent weld defects such as poor fusion, the welding operator recognizes subtle changes in the boundary between the base metal (groove) and the molten part (molten pool) and wire misalignment, and corrects the electrode position, wire position, and oscillation width to appropriate values.

Therefore, by learning the image of the welded part and the correction operation of the skilled welding operator by associating them with each other and constructing the judgment model, a welding system which automatically corrects electrode position, wire position, and oscillation width was established.

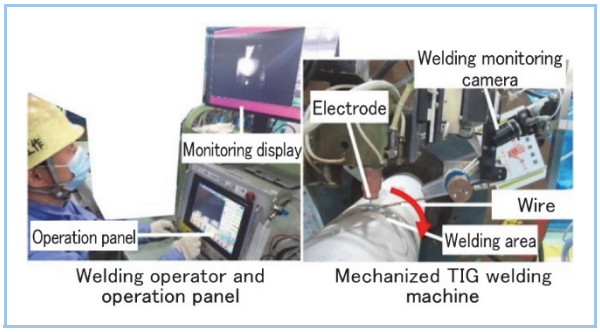



**Figure 5 Operation of automatic TIG welding**

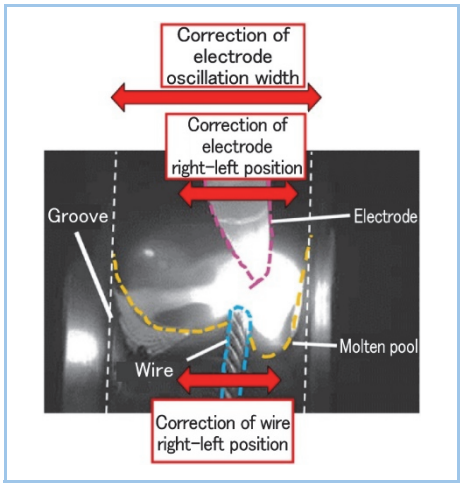



**Figure 6 Welding area image and schematic diagram of welding operator operations**

## 3.2 Details of developed technology

### 3.2.1 Collection of welding images

To conduct accurate analysis by AI, clear images are needed. To achieve this, image acquisition technology was developed that can clearly identify weld features (molten pool, groove, electrode, and wire) by performing exposure control processing and digital image correction on weld monitoring images that are affected by high-intensity arc light reflected in the groove.

### 3.2.2 Deep learning method

The mock-up for welding was welded under two conditions of proper welding condition and condition in which correction operation of electrode and wire position was necessary, and the welding image was acquired. For each welding image, the correction operation information of the welding operator was linked, and the learning data set was made. Examples of the created dataset are shown in **Figure 7**. Furthermore, by adding data such as parallel movements and rotations to this learning data set, it was made to be a learning data set which increases the robustness against the variation of camera setting in welding, etc.

By deep learning of this learning data set, a model that automatically determines the correction of the left-right position of the electrode, the left-right position of the wire, and the oscillation width was established.

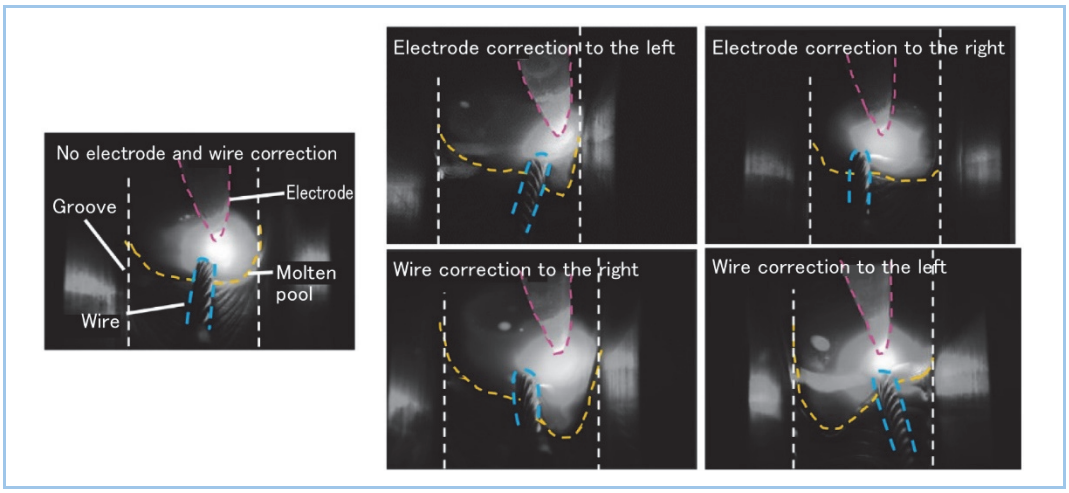



**Figure 7 Examples of created dataset images**

3.2.3 System development

By implementing the optimized model, an automatic welding control system that performs image processing, judgment processing, and automatic correction with the control response time equivalent to that of a welding operator's correction was developed. An example of the display of the developed system is shown in **Figure 8**. Instructions for corrections determined by AI during welding are indicated by arrows on the display, enabling the welding operator to perform welding while monitoring the welding process and confirming the corrective AI instructions.

No welding defects were observed in the mockups fabricated using the developed system, confirming that high-quality welding was achieved.

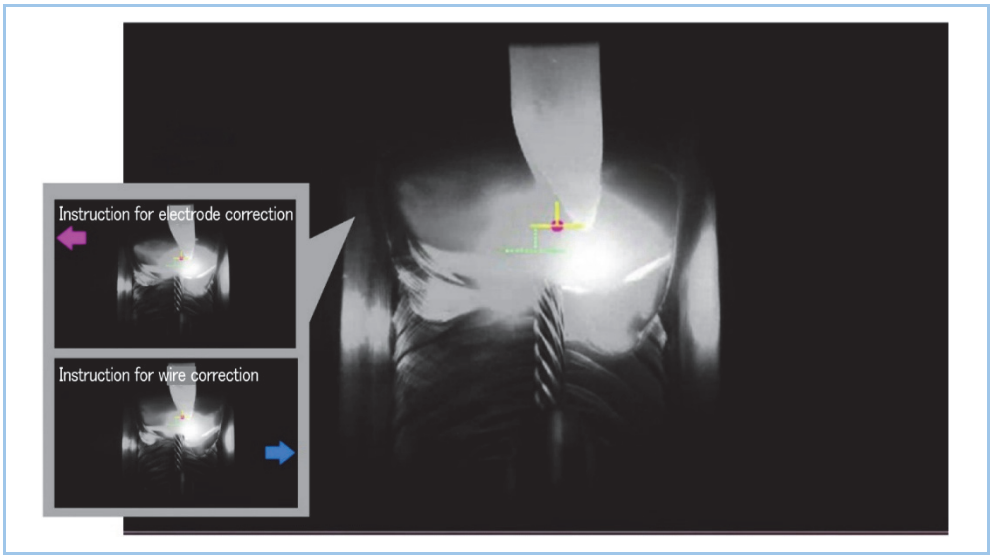



**Figure 8 Image of the AI Automatic Welding Control System**

### 3.3 Benefits of development

An automatic welding control system that implements an automatic judgment model which was established by linking image information of welds with skilled welding operators' correction and analyzed by AI (deep learning) was developed. This system has been used for piping in nuclear power plants, and ensures stable quality due to AI corrections at the same level as those by skilled welding operators. In addition, the system reduces welding operator workload, enabling a single person to handle four welding machines simultaneously.

## 4. Conclusion

This report introduced two welding systems developed using AI.

The AI welding support system uses an abnormality detection model to detect abnormalities in various welding parameters and instruct the welding operator to make corrections to the relevant parameters when such abnormalities increase. The AI automatic welding control system uses an

automatic weld image judgment model to perform automatic welding that simulates corrections of skilled welding operators.

These systems enable even inexperienced welding operators to achieve the same high-quality welding as that by skilled welding operators.

On the other hand, the scope of application of these systems is currently limited. Securing skilled workers for construction of innovative light water reactors is expected to be difficult in the future. Mitsubishi Heavy Industries, Ltd. hopes to accelerate the development of welding technologies based on AI technology to help solve these issues.