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Automatic Check System for Worker's Protective Equipment at Entrance of Radiation Controlled Area

Masato Watanabe[1], Osamu Segawa[2], and Yoshio Kimura[3]

[1] Research Engineer, Nuclear Safety Research & Development Center, Chubu Electric Power Co., Omaezaki-shi, Shizuoka-ken, Japan (Watanabe.Masato@chuden.co.jp)
[2] Research Engineer, Advanced Research & Innovation Center, Chubu Electric Power Co., Nagoya-shi, Aichi-ken, Japan
[3] Manager, Chuden CTI Co., Ltd., Nagoya-shi, Aichi-ken, Japan

1. INTRODUCTION

When entering the radiation-controlled area of a nuclear power plant, workers should be equipped with prescribed protective equipment to prevent their bodies from being contaminated with radioactivity. The verification procedures of all equipment are performed by self-check in which workers at themselves with a mirror by pointing and calling. To reducing the number of people forgetting the equipment to zero, we have developed an automatic check system to make sure whether all protective equipment is equipped.

The system called "AI-GATE" (Figure 1) uses object detection technology based on deep learning to identify safety protective equipment for workers. An initial prototype of the AI-GATE was installed at the Hamaoka Nuclear Power Plant in May 2021.[1],[2] However, due to limitations in object detection algorithm, the system captured a single worker to avoid misidentifying the protective equipment of the worker behind. In this study, a method was developed to accurately identify the safety protective equipment of the worker in the front, even when the recognition camera captures multiple individuals.

Figure 1. Exterior view of AI-GATE

The improved method was successfully implemented in the AI-GATE in March 2023 [3], and we confirmed the effectiveness the proposed system. This article describes the detail of the AI-GATE and its evaluation results.

2. OVERVIEW OF AI-GATE

2.1 System Concept

In a daily work, the equipment is checked through a self-check, where workers examine their own reflection in a mirror and confirm that they are wearing the necessary gear by pointing and calling out. However, there have been instances where workers have unintentionally forgotten to equip themselves with the protective equipment due to human error. To minimize such occurrences, preventive measures such as displaying posters and using life-size mannequins are implemented. However, it is not possible to completely eliminate the possibility of workers forgetting to wear the protective equipment.

One potential solution to address the issue of workers forgetting to wear protective equipment is to always have a supervisor present, ensuring compliance. However, there are apprehensions regarding the associated costs and the potential for human error on the part of the supervisor, leading to oversight. Consequently, we are actively engaged in the development of an artificial intelligence (AI) function that can accurately determine whether the required protective equipment is properly installed. This AI-based solution aims to provide a reliable and efficient means of ensuring compliance without the limitations and potential drawbacks associated with human supervision.

Figure 2. GUI of the AI-GATE confirming safety protective equipment

2.2 Prototype of **AI-GATE**

The AI-GATE prototype employed a regression-based object detection algorithm SSD (Single Shot Multi-Box Detector) [4] for the purpose of inspecting the presence of protective equipment. Through the utilization of this algorithm, we successfully developed a functionality that can identify and determine the existence or absence of specific items within an image of a worker. The designated check objects include protective clothing (either blue or work clothes), caps, gloves, socks, and dosimeters, as illustrated in **Figure 2**. This implementation allows for efficient and accurate assessment of whether the necessary protective equipment is being worn by the worker.

The AI-GATE incorporates artificial intelligence technology to inspect the presence of all necessary protective equipment, including dosimeters, and autonomously controls the opening and closing of the gate accordingly.

However, we do not use object detection to confirm possession of a dosimeter but use the QR code reading function built into the AI-GATE to scan the QR code affixed to the dosimeter to confirm possession of the dosimeter.

Before introducing the AI-GATE, we used a manual gate that only checked the possession of a dosimeter. By holding the dosimeter over the manual gate, the gate will be unlocked and you can pass through by lifting the gate with your hands.

When the AI-GATE was introduced, the automatic opening/closing gate was equipped with a function that only confirmed the possession of the dosimeter in the event of an AI malfunction, including a malfunction of the built-in PC. In normal times, dosimeters are held up to the gate to confirm possession, which is the traditional procedure, to ensure smooth operation during the initial stage of AI-GATE introduction and in the event of a malfunction.

Upon verifying the presence of all required equipment, the red "X" lamp on the gate changes to a blue arrow symbol (<=), indicating access permission. The gate automatically opens when a dosimeter is presented within the designated timeframe (**Figure 3**).

During the initial implementation of the system at the power plant, an assistant was assigned during the morning and afternoon peak entry periods for the first week. Their role was to provide guidance and support to users as they familiarized themselves with the new system. However, as time progressed, the users became proficient in the operating procedures, and subsequently, the system was operated smoothly without the need for additional assistance.

Figure 3 Automatic check procedure with the AI-GATE at Hamaoka Unit 3

2. 3 Issue of Prototype **AI-GATE**

The AI-GATE prototype has certain limitations in its AI functionality, which restricts the camera's capability to capture only one worker. Consequently, to ensure that individuals positioned behind the worker are not visible, the preparation of a screen was deemed necessary. As a result, a relatively spacious area was required for the installation of the system.

Additionally, the recognition speed was approximately 5 persons per minute, leading to congestion during peak entry times when a large number of workers rushed in. Therefore, an enhancement in processing speed was necessary.

3. AI-GATE IMPROVEMENTS

3.1 Algorithm for Object Detection

The AI-GATE prototype initially utilized SSD for object detection. Since the performance of SSD was not enough, we adopted YOLO v5 [5] in the new system implementation. To fine-tune the pre-trained model, around 3,000 labeled images were prepared. Additionally, the threshold value for detecting the raising of both hands was optimized to enhance the decision speed of object detection. Consequently, the decision speed for object detection improved by approximately 2 times, reducing the time from approximately 3.5 seconds to 1.5 seconds.

Figure 4 shows confusion matrix of the evaluation results (mAP: mean average precision) using YOLO v5, with an overall average of 94%.

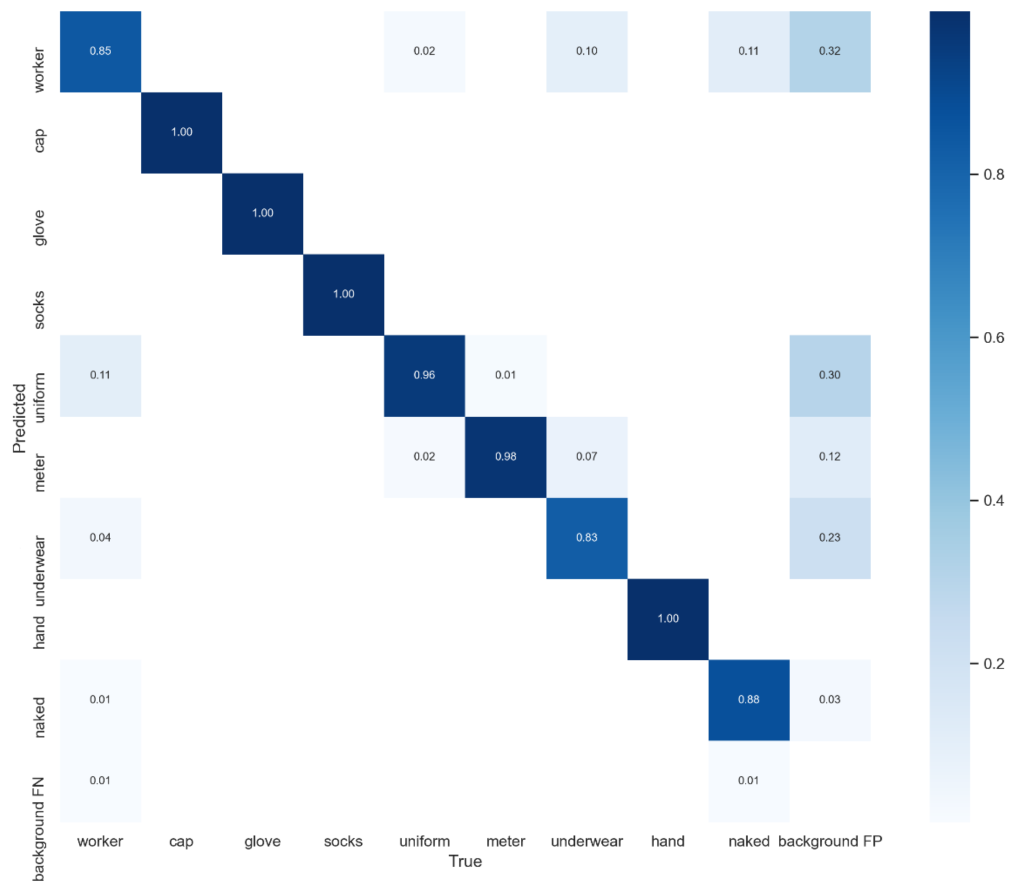

Figure 4 Confusion matrix of evaluation results (mAP with YOLO v5)

The definition of terms are as follows:

Worker: Search for people (Worker) to recognize the person in front.
Uniform: Uniform refers to protective clothing, but it is not used in the system.
Underwear: Although this refers to underwear, it is a negative example of not wearing protective clothing.
Naked: This means nudity without protective clothing, which is a negative example.
Background FP (False Positive): Percentage of situations in which background objects that do not belong to any class are incorrectly classified into some class.
Background FN (False Negative): Percentage of situations in which an object that should have been correctly detected was mistaken for the background.

3.2 Algorithm to detect a person in the front

In the AI-GATE prototype, the AI function had limitations that prevented it from detecting and recognizing multiple people in the camera's field of view. To address this limitation, a screen was used to block the view of any other people behind the camera subject. This screen ensured that only one worker was captured by the AI system. As a result, the installation of the AI-GATE required a relatively large space and a designated path for the worker to move, which restricted the possible locations for installation.

Therefore, in order to distinguish the equipment of the worker in the front row from multiple people on the camera, we developed a method based on the size and positional relationship of the object detection bounding box. The judgment flow, which outlines the steps of this method, is presented below.

(1) The system consistently scans for both the worker and the equipment.
(2) Once the system detects a glove in the hands-up position on the screen, it initiates the process of determining the equipment.
(3) To determine the equipment, the system selects a specified number of objects within the largest bounding box of the worker, prioritizing them based on the size of the bounding box.
(4) Examples of the specified number for each piece of protective equipment are as follows: cap: 1, gloves: 2, dosimeter: 1, socks:2.
(5) Simultaneously, the system ensures that no negative examples such as bare hands, naked body, or underwear are detected.
(6) For all equipment, within the designated judgment time, the system analyzes up to the specified number of frames. If the percentage of frames with equipment exceeds the acceptance criteria, it is determined that all protective equipment is present.

In the initial AI-GATE prototype, the identification of protective equipment was not accurate when the person positioned at the back (**Figure 5**). However, with the modified algorithm described above, significant improvements have been made to address this limitation. The current system has the capability to accurately recognize and identify the protective equipment worn by the individual situated at the foremost position, even in scenarios where multiple people are present within the camera's field of view. This enhancement ensures that the AI-GATE system focuses solely on the person in the front and avoids any potential misjudgments caused by the presence of other individuals in the background.

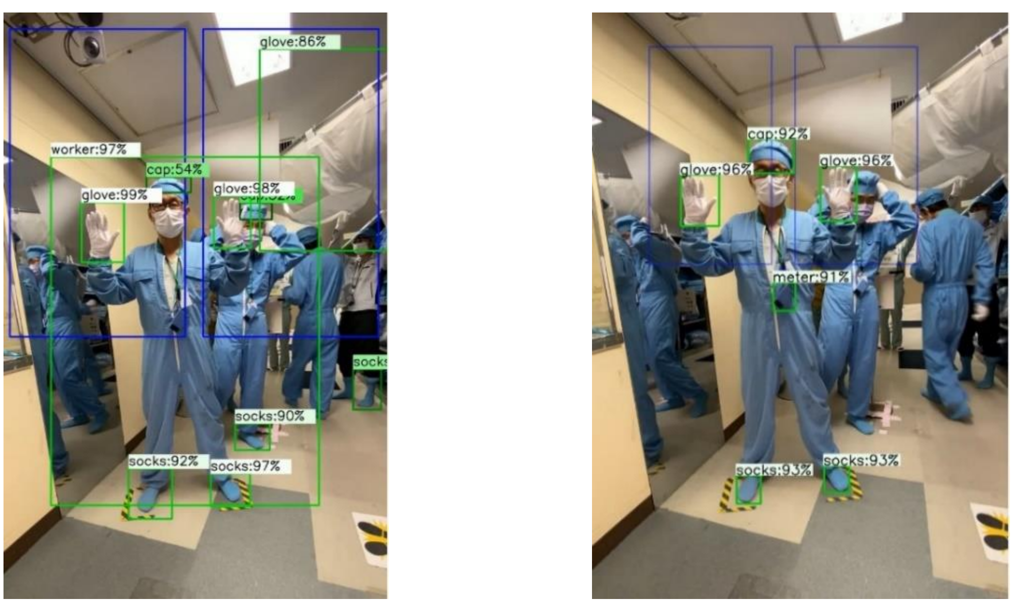

Figure 5. Comparison of recognition results Left : Prototype, Right : Improved machine

3.3 Gate Mechanism Optimization: Reducing Unnecessary Time Delay

The prototype had a mechanism that closed the gate 6 seconds after system confirmation and restarted the process. This duration was intentionally set longer to allow the system to accommodate situations where it took time for the user to touch the dosimeter to the QR-code reader. However, if the touch could be performed quickly, this extended time became unnecessary and resulted in wasted time.

To address this issue, the gate was equipped with a sensor that confirmed the passage of a person and obtained a signal indicating the completion of the passage. This enabled the system to promptly resume the system judging process for the next person. As a result, the overall time per person was reduced by approximately 3-4 seconds.

3.4 Comparison of Prototype and New System: Time and Speed at AI-GATE

We conducted a measurement to determine the duration it took for a worker to raise both hands to initiate the judging process, pass through the gate, and begin judging the next person. The results showed that the prototype took approximately 10 seconds, whereas the new system took slightly over 5 seconds, effectively reducing the total time by approximately half.

Therefore, the new system has nearly doubled the speed of judgment, resulting in a shorter waiting time at the AI-GATE. This improvement has been positively received by the operators.

4. EXTENTION OF THE SYSTEM

4.1 Smartphone based System

Additionally, it is worth noting that AI can be utilized solely with a smartphone, eliminating the necessity of integrating it with an automatic gate. In this scenario, an LCD screen display of the smartphone is employed to indicate the presence of all required equipment. This approach proves to be cost-effective as automatic gates can be expensive. Consequently, smartphones can be installed in locker rooms located at the entrances of controlled areas, serving as a preventive measure against human error in forgetting necessary equipment.

4.2 Domain Adaptation for Various Industries

In the conducted study, it was verified that the system has the capability to identify full harness and insulated boot equipment using a limited amount of supervised data. This was achieved through the application of transfer learning, utilizing a pre-trained AI model for object detection (as depicted in **Figure 6**). This development holds the potential to extend the application of protective equipment inspection beyond nuclear power plants, encompassing various industries. Consequently, our user has a significant anticipation for the implementation of this technology.

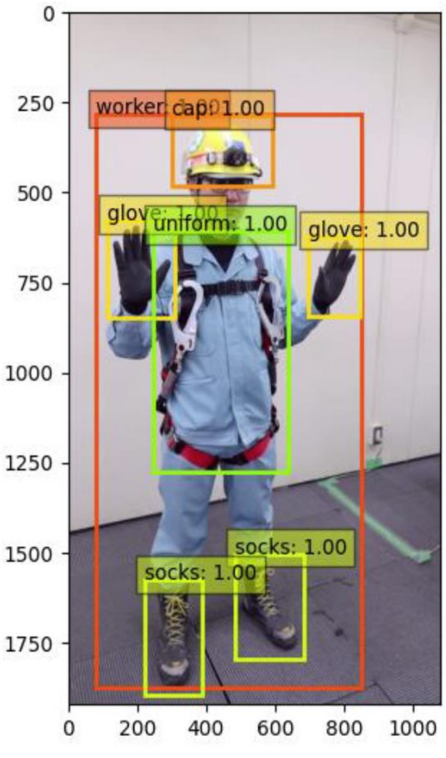

Figure 6. Application to construction sites

5. CONCLUSION

As of May 2021, AI-GATEs have been successfully implemented in Units 1 through 5 at the Hamaoka Nuclear Power Plant. Notably, there have been no reported instances of individuals forgetting to wear their required protective equipment since the installation of the current AI-GATEs. Moreover, in March 2023, the improved method (Section.3) was implemented to enhance the performance of the system, effectively doubling its processing speed.

The utilization of AI technologies, specifically object detection, has proven to be instrumental in meeting the stringent requirements for preventing human errors in Japan's nuclear power plants. Our approach has effectively addressed the critical need for error prevention in these high-risk environments.

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