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Evaluation System for Recognition Accuracy of Gauge Reading in Nuclear Facility

Yongho Cho [a, b], Wonseo Lee [a], Hocheol Shin [a], Dongseok Ryu [a, b*]
[a] *Korea Atomic Energy Research Institute (KAERI), 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea, 34057*
[b] *Department of Artificial Intelligence, University of Science & Technology (UST), 217, Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea, 34113*
[*] *Corresponding author: sayryu@kaeri.re.kr*

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1. Introduction

Analog gauges remain widely used in nuclear facilities to measure key operational variables such as pressure, flow rate, and temperature, and regular patrols and verification of these readings are essential. As mobile robots and autonomous surveillance technologies have advanced, the adoption of robot-based automated surveillance systems has expanded, increasing the importance of vision-based automatic analog gauge reading methods that can be deployed on robotic platforms.

However, building a reliable AI-based gauge reading system requires a large-scale dataset that covers diverse measurement values and imaging conditions, along with accurate ground-truth labels. In practice, data collection in nuclear facilities is limited due to physical and safety constraints, making it difficult to systematically obtain a wide range of readings from the same gauge. In addition, manual labeling is labor-intensive and time-consuming, and it inherently carries the risk of errors. It is also challenging to adequately reflect environmental variations such as changes in illumination and viewing angle.

Internationally, deep learning–based gauge reading studies have been reported [1], [2]. In Korea, the Korea Atomic Energy Research Institute (KAERI) has investigated both traditional computer vision–based approaches [3] and Chain-of-Thought (CoT)–based reasoning methods using multimodal large language models (MLLMs) [4]. Nonetheless, securing training and evaluation datasets that systematically incorporate diverse conditions remains a key challenge.

To address this issue, our preliminary study proposed the concept of a dataset construction system that reproduces arbitrary gauge readings and automatically generates ground-truth labels by combining a real gauge panel with a 3D-printed structure and a motor-driven mechanism [5]. Building upon this concept, we develop a dataset acquisition device for the evaluation of gauge-reading accuracy in nuclear facilities. The device enables precise and repeatable control of both pointer position and viewpoint, providing a systematic framework for data acquisition and label generation.

2. Design of Dataset Acquisition Device

In this section, we describe the configuration and operating concept of the dataset acquisition device developed to obtain analog gauge image datasets in a repeatable and systematic manner.

The proposed device was designed to precisely control both the pointer position and the observation viewpoint while preserving the texture and reflective characteristics of a real gauge dial. Through this design, it is possible to stably acquire images under diverse shooting conditions. Furthermore, the system is configured to automatically record the information required for label generation at the time of image capture. This integrated structure aims to ensure both reproducibility under identical conditions and consistency in data management.

As illustrated in Fig. 1, the device consists of three main components: a motor control unit, a gauge simulation unit, and an image acquisition unit.

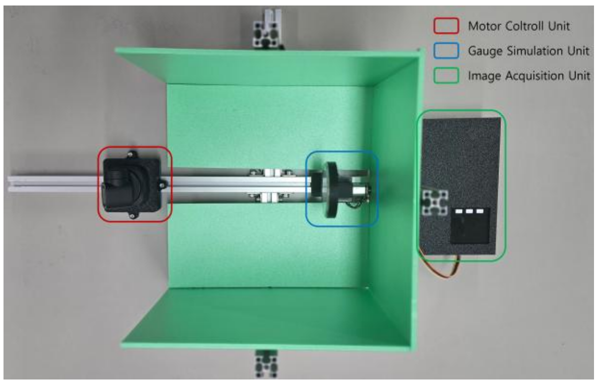

Fig. 1. Overall configuration of the dataset acquisition device.

2.1. Motor Control Unit

As shown in Fig. 2, the motor control unit comprises a battery power supply and a motor driver. The motor driver controls the motor mounted in the gauge simulation unit to set the pointer position.

The motor driver is connected to a PC via a USB cable and operates based on serial communication. When the automation control program transmits a command specifying the target pointer angle, the motor rotates accordingly and the pointer moves to the designated angle. This configuration enables precise and repeatable control of the pointer position.

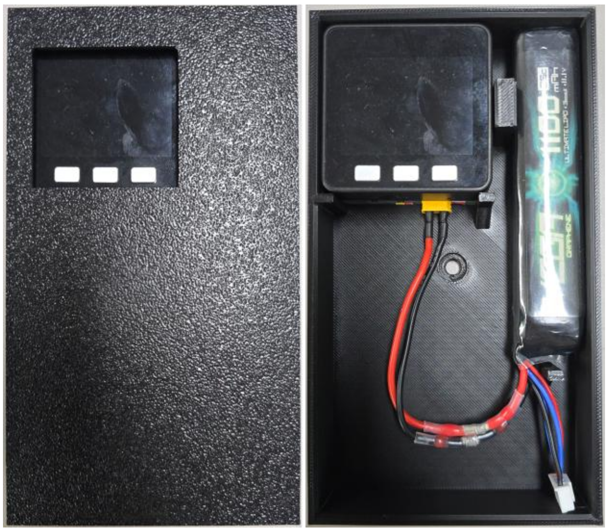

Fig. 2. Motor control unit

2.2. Gauge Simulation Unit

The gauge simulation unit is presented in Fig. 3. It incorporates a dial plate extracted from a commercial analog gauge to preserve realistic visual characteristics, including texture, scale printing quality, and reflective properties observed in actual industrial environments.

The pointer is mechanically coupled to a DC motor located at the rear of the device. By driving the motor, the pointer angle can be accurately set to a desired value, allowing controlled reproduction of gauge readings with high repeatability.

To incorporate viewpoint variation, the gauge structure is designed to rotate horizontally from −60° to +60° in 10° increments. This enables systematic acquisition of gauge images from multiple observation angles.

Fig. 3. Gauge simulation unit

2.3. Image Acquisition Unit

The image acquisition unit consists of a camera installed to capture gauge images. A reflective panel is positioned within the setup to minimize the influence of external lighting variations and to provide uniform illumination across the gauge surface.

This configuration improves the consistency of the acquired image data and supports stable dataset construction under controlled environmental conditions.

3. Data Acquisition and Labeling Procedure

The operation of the experimental device and the data acquisition process were performed using an automated control program.

First, a serial command was transmitted from the PC to the motor driver to rotate the DC motor and position the gauge pointer at a predefined target angle. After the pointer motion stabilized, an image of the gauge was captured using the camera. This procedure was sequentially repeated for multiple predefined pointer angles at a fixed observation viewpoint.

After completing image acquisition for all designated pointer positions at a given viewpoint, the observation angle of the gauge was adjusted, and the same process was repeated. By systematically combining controlled pointer positions and discrete observation angles, the proposed procedure enables reproducible and structured acquisition of gauge image data under varying geometric conditions.

At the moment of image capture, quantitative information describing the gauge configuration was automatically generated and stored as label data. The recorded parameters include the minimum gauge value $V_{\min}$, the corresponding minimum scale angle $\theta_{\min}$, the maximum gauge value $V_{\max}$, the corresponding maximum scale angle $\theta_{\max}$, the current pointer angle θ, the observation viewpoint angle, and the gauge identifier.

Based on the recorded pointer angle and predefined scale information, the corresponding gauge value, V, can be calculated using linear interpolation as follows:

$$V = V_{\min} + \frac{\theta - \theta_{\min}}{\theta_{\max} - \theta_{\min}} (V_{\max} - V_{\min}) \qquad (1)$$

This formulation ensures a consistent mapping between pointer angle and gauge value under the assumption of a linear scale distribution. All label data were stored together with the corresponding image file to maintain one-to-one image–label correspondence, thereby ensuring dataset consistency and facilitating efficient use for AI model training and evaluation.

4. Conclusions

In this study, a dataset acquisition device for analog gauge image collection was developed to support AI-based gauge reading research in nuclear facility surveillance environments. The proposed system enables precise control of pointer position and observation viewpoint while preserving the visual characteristics of real commercial gauges.

The device consists of a motor control unit, a gauge simulation unit, and an image acquisition unit. By integrating motor-driven pointer control with systematic viewpoint adjustment and automated image capture, the system allows reproducible and structured acquisition of gauge images under controlled geometric conditions. In addition, the automatic generation and storage of label information ensure consistent image–label correspondence and reduce the need for manual annotation.

The proposed device addresses practical limitations associated with collecting real-world gauge data in nuclear facilities and provides a foundation for constructing reliable training and evaluation datasets. Future work will focus on expanding the variety of gauge types, incorporating diverse illumination conditions, and enhancing the level of automation to better reflect realistic field environments.

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