2023 Synopsys ARC AIoT Design Contest

Project Proposal

應用於傳統工廠的智慧儀表讀數器

Smart Analog Gauge Reader Applied in Traditional Factory

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July 9, 2023

NCTU
OASIS Lab

Agenda

- Abstracts
- Challenge and Innovation
- Design and Reliability
- Test Result
- Overall Summary
- Reference

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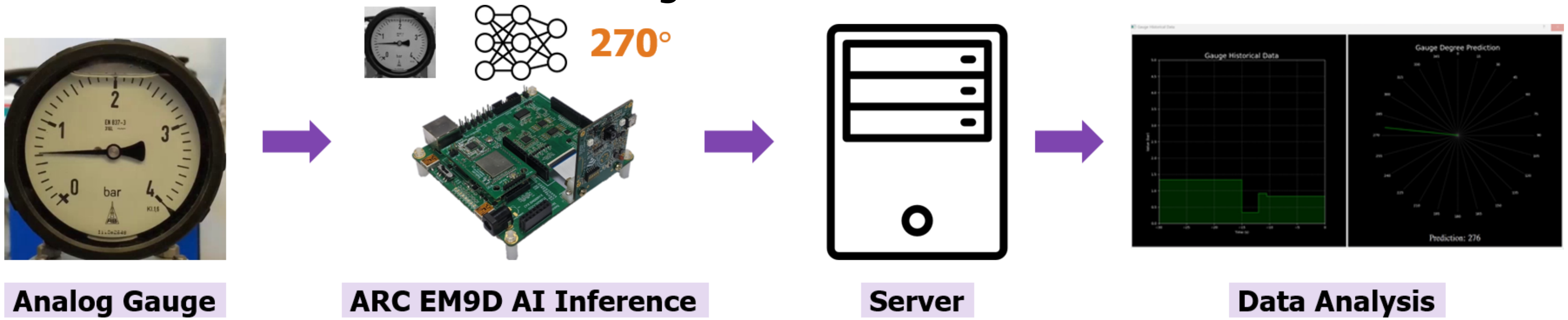
Abstract

- **Motivation**
  - Many traditional factories are still using analog gauges (e.g. pressure gauge, volt meter, …)
  - Replace the new machine with a digital reader → **large-scale update, expensive**
  - Record gauge data and monitor by human inspectors → **time-consuming, extra costs**

- **Our Proposal**
  - Digitize the analog gauge without having to replace it
  - Use **ARC EM9D** real-time monitor analog gauge
  - Reduce labor costs and enhance management automation



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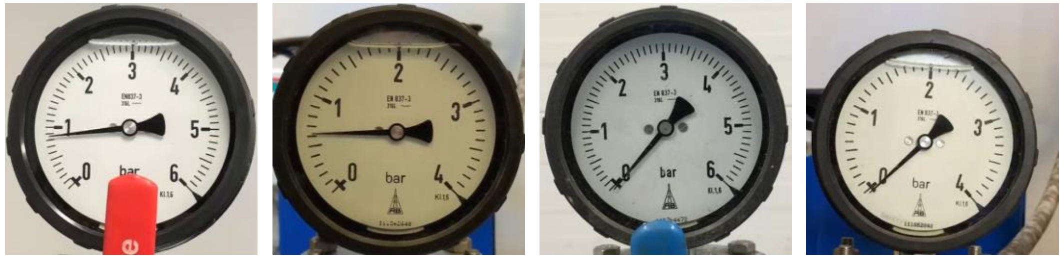
Challenge

- **Data Collection and Model Selection**
  - **Dataset Collection**
    - Collect and annotate a sufficient number of data
    - Different gauge styles and appearances
    - Influence of lighting and noise



▲ Different Types of Analog Gauges

  - **Model Selection**
    - Extraction and recognition of numbers → **Large-scale detection** and **classification** model
    - Angle prediction for gauge pointer → **Regression** or <u>**multi-class classification**</u> problem

- **Computation and Storage Limitations**
  - **Model Deployment**
    - Deploy on the device with limited computational and memory resources → **Model compression**
    - Maintain the model performance (e.g. **accuracy**, **inference time**, model size)

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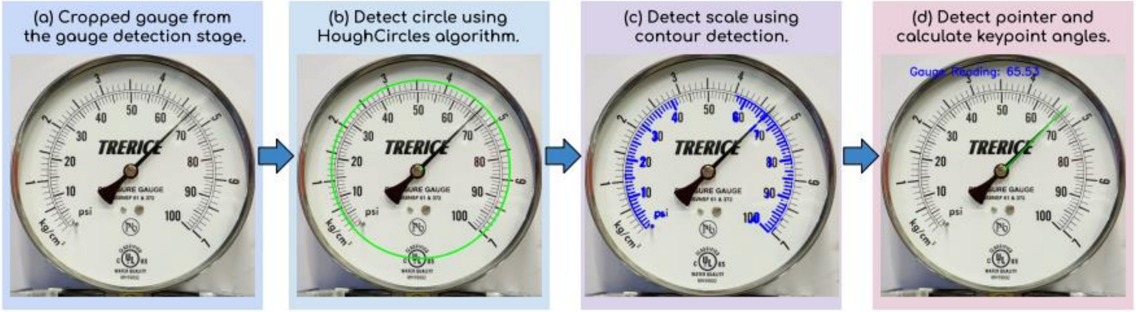
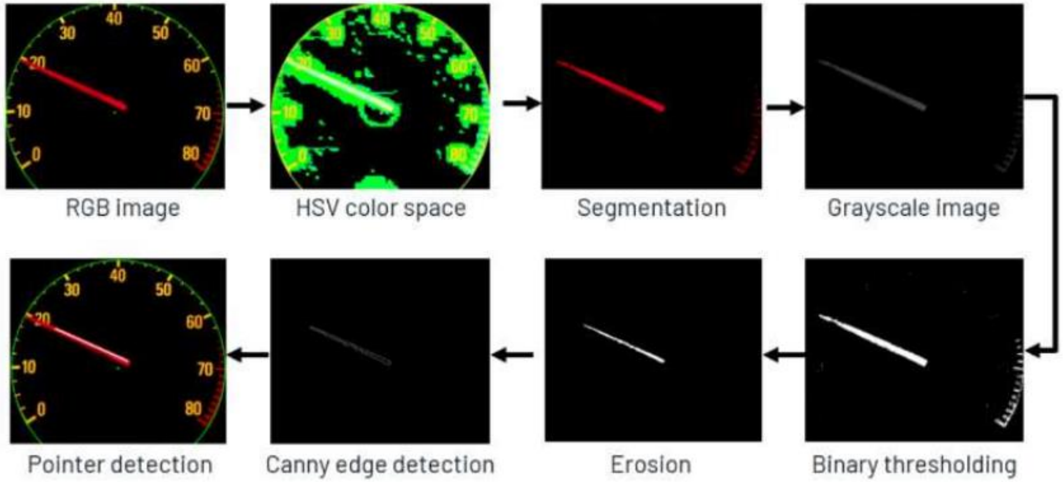
Challenge

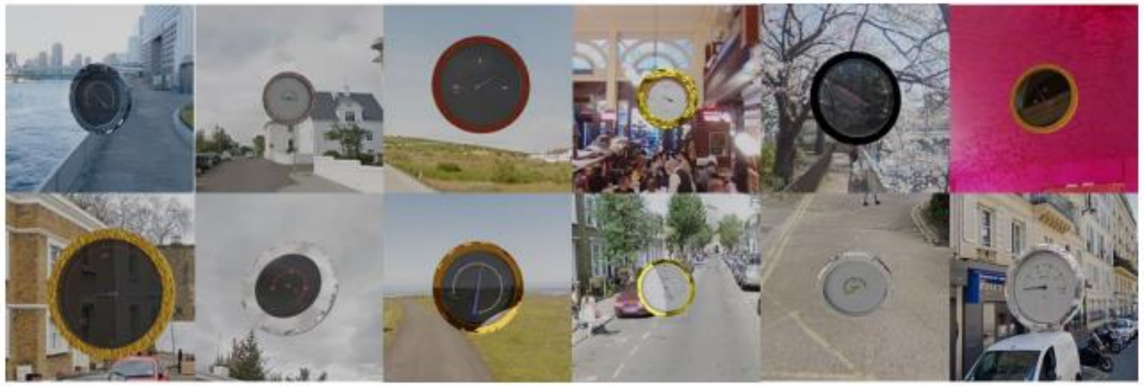
- **Traditional Computer Vision Methods Are Sensitive**
  - **Variations in lighting, background clutter, particular types of gauges**
- **Existing Dataset Lacks Realism**
  - **Inaccurate background representation**
  - **Without considering image distortion**



Real-time Multiple Analog Gauge Reader for an Autonomous Robot Application [2]
(2022 International Joint Symposium on Artificial Intelligence and Nature Language Processing)



High Precision Analog Gauge Reader Using Optical Flow and Computer Vision [1]
(2022 IEEE International Conference on Electro Information Technology)



Real-time Analogue Gauge Transcription on Mobile Phone [3]
2021 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)

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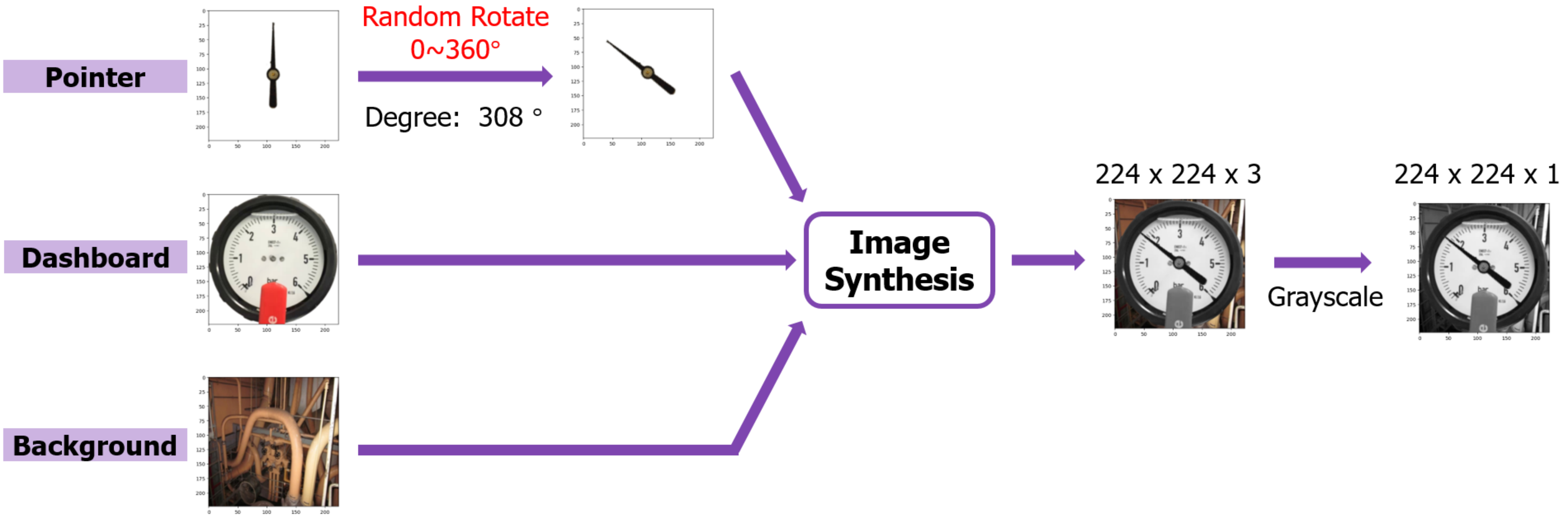
Innovation - Analog Gauge Image Data Generator (1/4)

- **Automatic Image Synthesis and Annotation**
  - **Gauge Images & Videos:** ***Pressure Gauge Dataset*** **(Source: Kaggle)**
  - **Background Images:** ***Places Dataset – engine_room*** **(Source: MIT)**
    - #Samples: 1009



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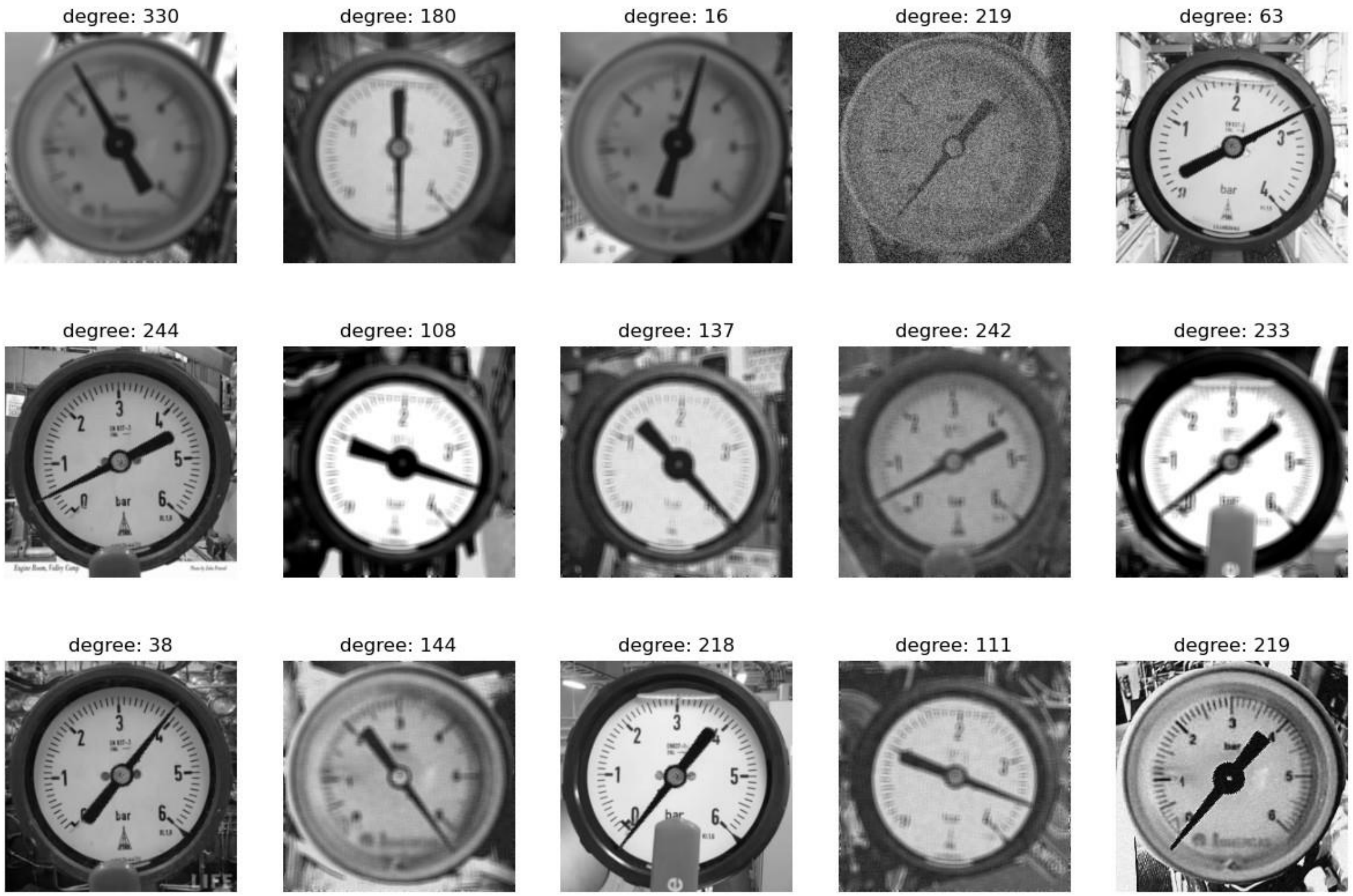
Innovation - Analog Gauge Image Data Generator (2/4)

- **Data Augmentation**
  - **Random Enhancement**
    - Saturation
    - Brightness
    - Contrast
    - Sharpness
  - **Random Noise**
    - Gaussian Noise
  - **Random Blur**
    - Gaussian Blur



▲ Synthesis Images with Data Augmentation

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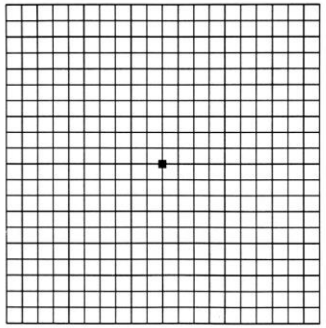
Innovation - Analog Gauge Image Data Generator (3/4)

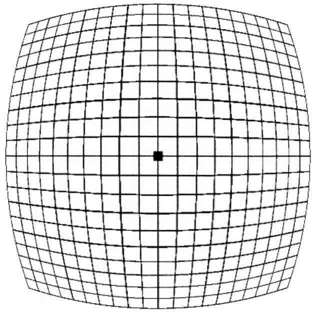
- **Fisheye Transform**
  - **Simulate the effects of image distortion**

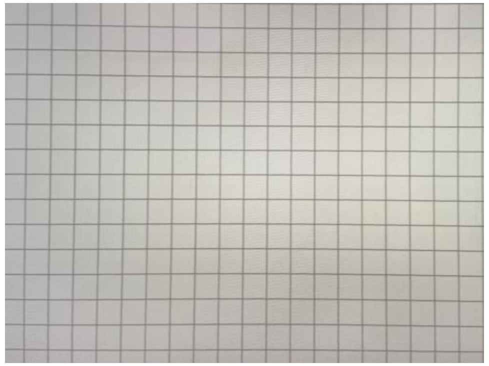
1. Normalize pixel in the interval of [-1,1]
2. Cartesian to polar: $r = \sqrt{x^2 + y^2}$
3. Distortion: $x_d = \frac{x}{(1-dr^2)}, y_d = \frac{y}{(1-dr^2)}$

   where d is the distortion coefficient
4. Polar to Cartesian: $x_u = \frac{w(x_d+1)}{2}, y_u = \frac{h(y_d+1)}{2}$

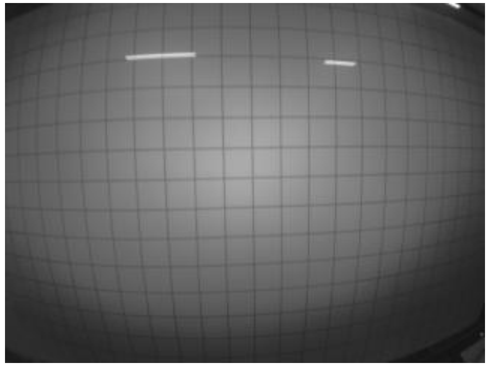
▲ Captured by HM0360 AoSTM VGA camera







▲ Captured by iPhone11 camera



▲ Captured by HM0360 AoSTM VGA camera (Distorted Image)

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Innovation - Analog Gauge Image Data Generator (4/4)

- **Fisheye Transform for AoSTM VGA Camera**

▲ **W/o** Fisheye Transform, Random Crop, and Padding

▲ **W/** Fisheye Transform, Random Crop, and Padding

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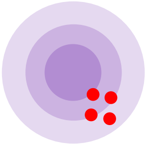
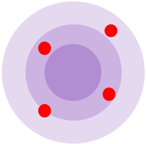
Innovation - Analog Gauge Calibration

- **How to determine the number of output classes?**
  - Limited by int8 quantization from 0~255 (unable to predict 0~360°)
  - Number of classes impacts the size of the output FC layer



Poor accuracy
Good precision

- **Trade-off Between Accuracy, Precision & Model Size**



Poor accuracy
Poor precision

Scaling (degree)	#Classes (output size)	FC Size (input size = 1024)	Output FC Weight Reduce (%)
1	360	369 K	0.00
2	180	185 K	49.87
3	120	123 K	66.67
4	90	92 K	75.07
5	72	74 K	79.44
6	60	62 K	79.95

Scaling = 4

Better Precision

Scaling = 8

Poor Precision

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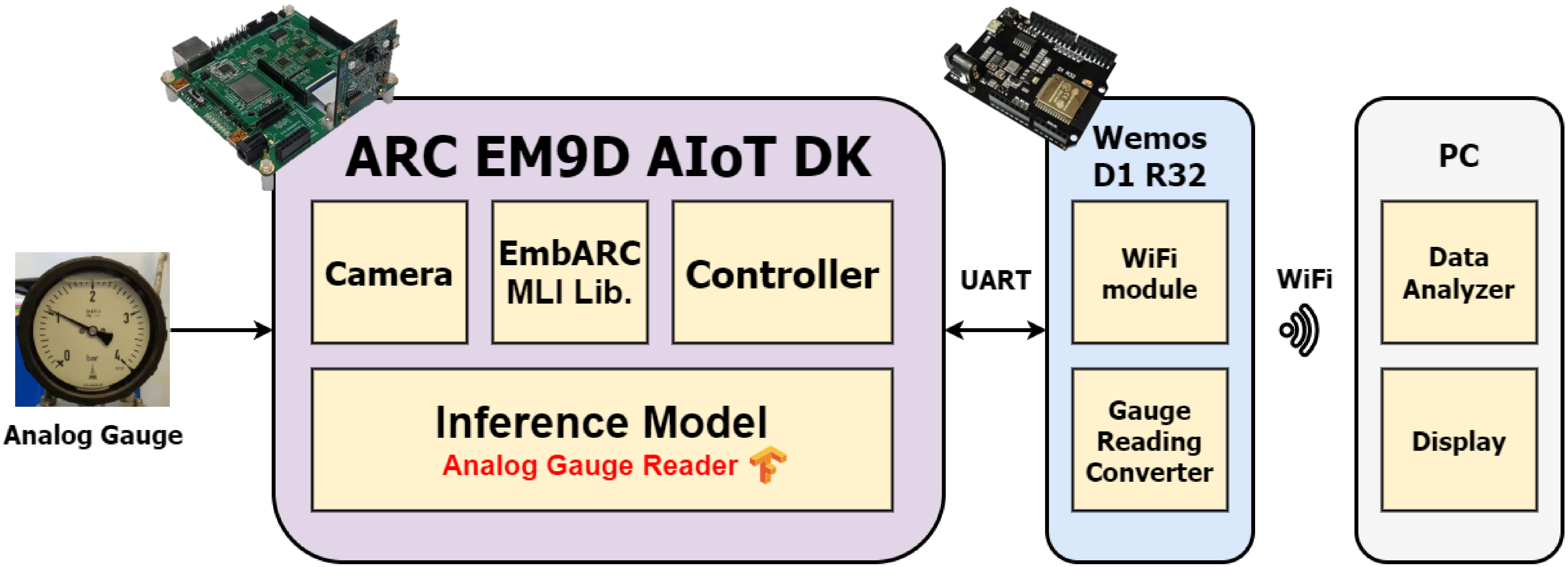
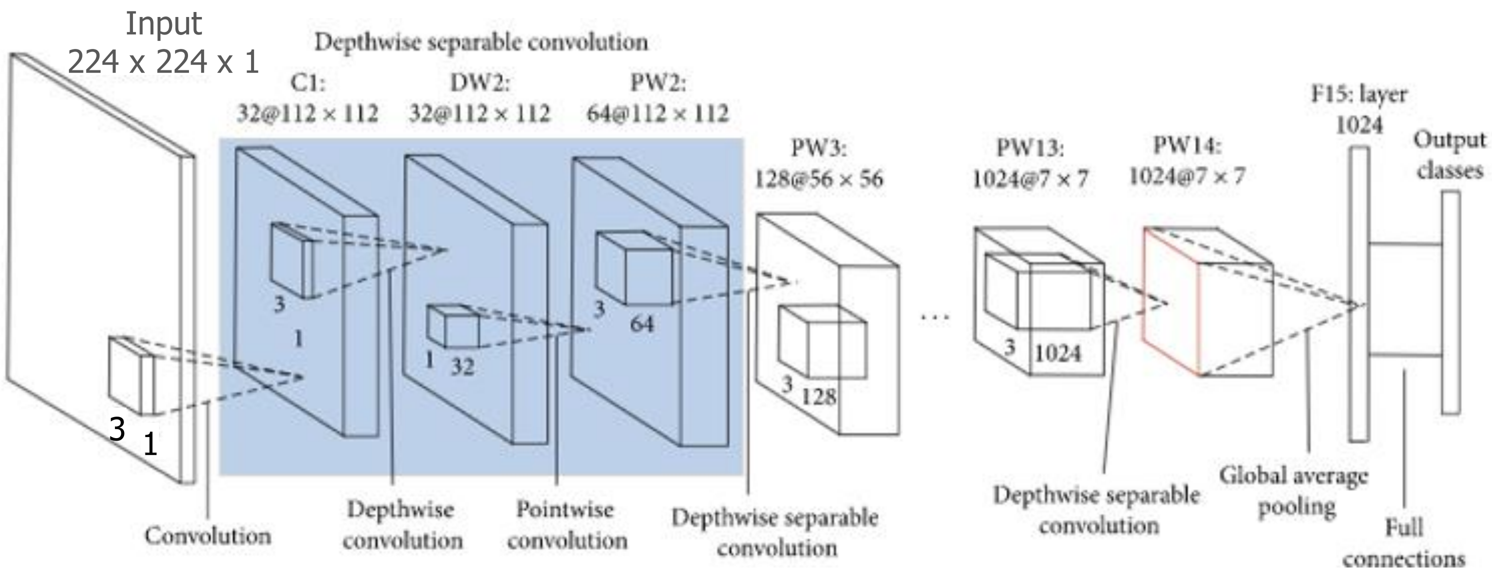
System Architecture



Analog Gauge Reader

- **MobileNet V2**



Model	#Param (M)
MobileNetV2-base	2.34
MobileNetV2-small	0.80
MobileNetV2-tiny	0.35
MobileNetV2-micro	0.21

Memory region	Used Size	Region Size	%age Used
ICCM0:	0 GB	64 KB	0.00%
ICCM1:	307684 B	320 KB	93.90%
SYSTEM0:	917932 B	957168 B	95.90%
DCCM:	104 KB	256 KB	40.62%
XCCM:	32 KB	32 KB	100.00%
YCCM:	32 KB	32 KB	100.00%

```
ReorderXML
GenWholeImage
Total image size= 782 KB( 0xc38b0 )
```

- **Gauge Reader Converter**

$$angle = (360° + pred \times scaling - initial\ angle)\ \%\ 360°$$

$$value = \left(\frac{angle}{angle\ per\ scale}\right) \times value\ per\ scale$$

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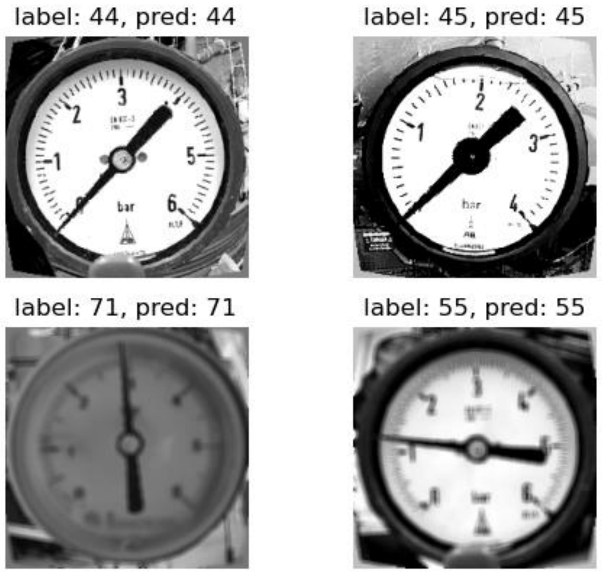
Post-Training Quantization

- **Reduce Memory Storage & Computational Resources**
  - **Model Weights:** fp32 → int8
  - **Steps:**
    1. Train fp32 TF model (model.pb)
    2. Evaluation fp32 model on GPU
    3. Quantize the model weight
    4. Convert the fp32 model to int8 TFLM model (model.tflite)
    5. Evaluation int8 model on GPU
    6. Convert the TFLM model to C file (model.h)
    7. Inference on ARC EM9D



▲ Inference using int8 TFLM model

fp32 TF model @ NVIDIA GTX 2080 Ti → **int8 TFLM model** @ Intel(R) Xeopn(R) CPU E5-2660 v4 → **TFmicro model** @ ARC EM9D AIoT DK

Test Accuracy: 83.70%

Test Accuracy: 82.75%

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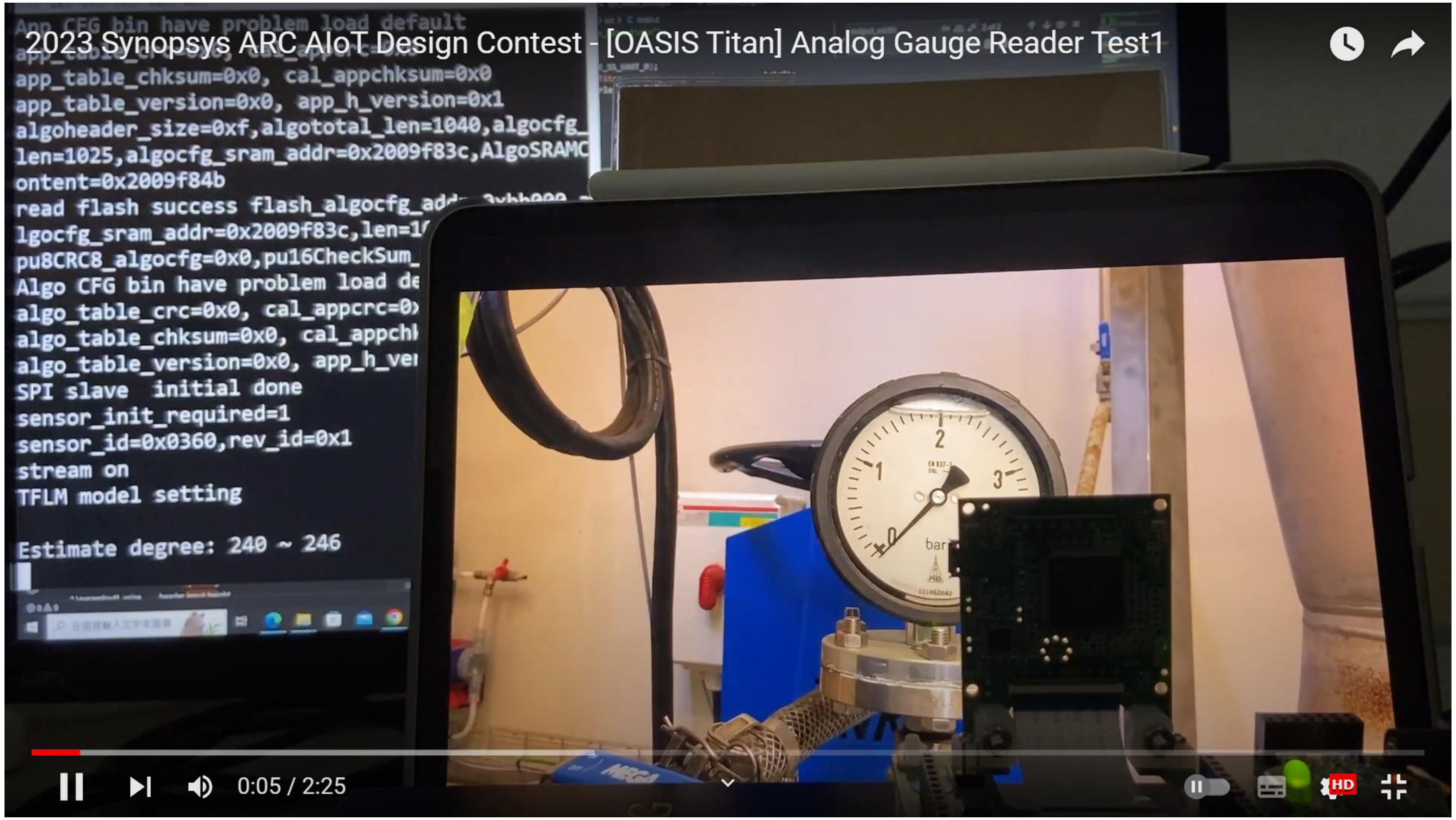
Demo Video – Analog Gauge Reader Inference Test1

- **Link**

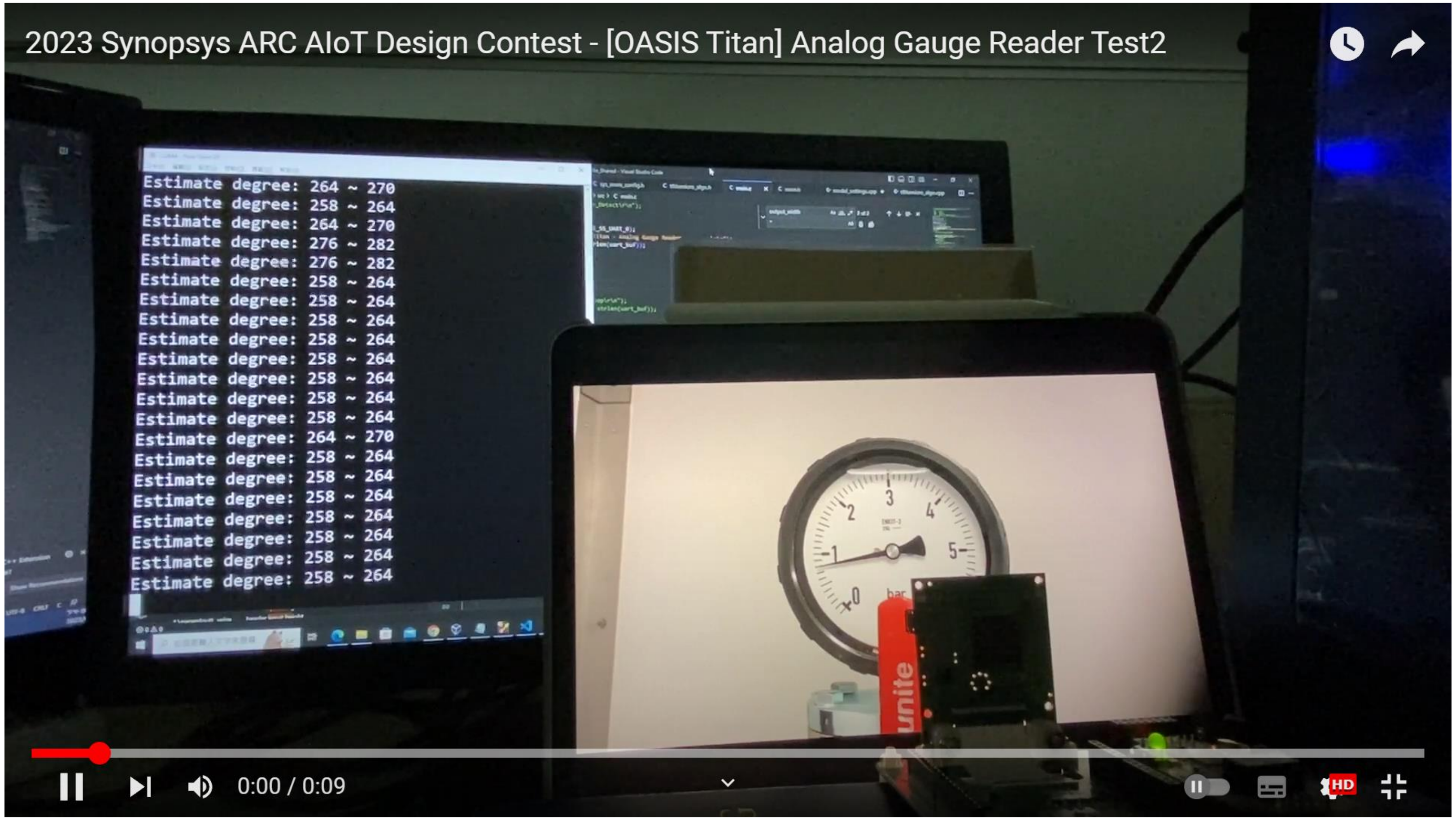
  https://www.youtube.com/watch?v=Uo0q9bvPye8&t=44s&ab_channel=ChenBaker



Demo Video – Analog Gauge Reader Inference Test2

- **Link**

  https://www.youtube.com/watch?v=cPMuLgIlY1I&ab_channel=ChenBaker



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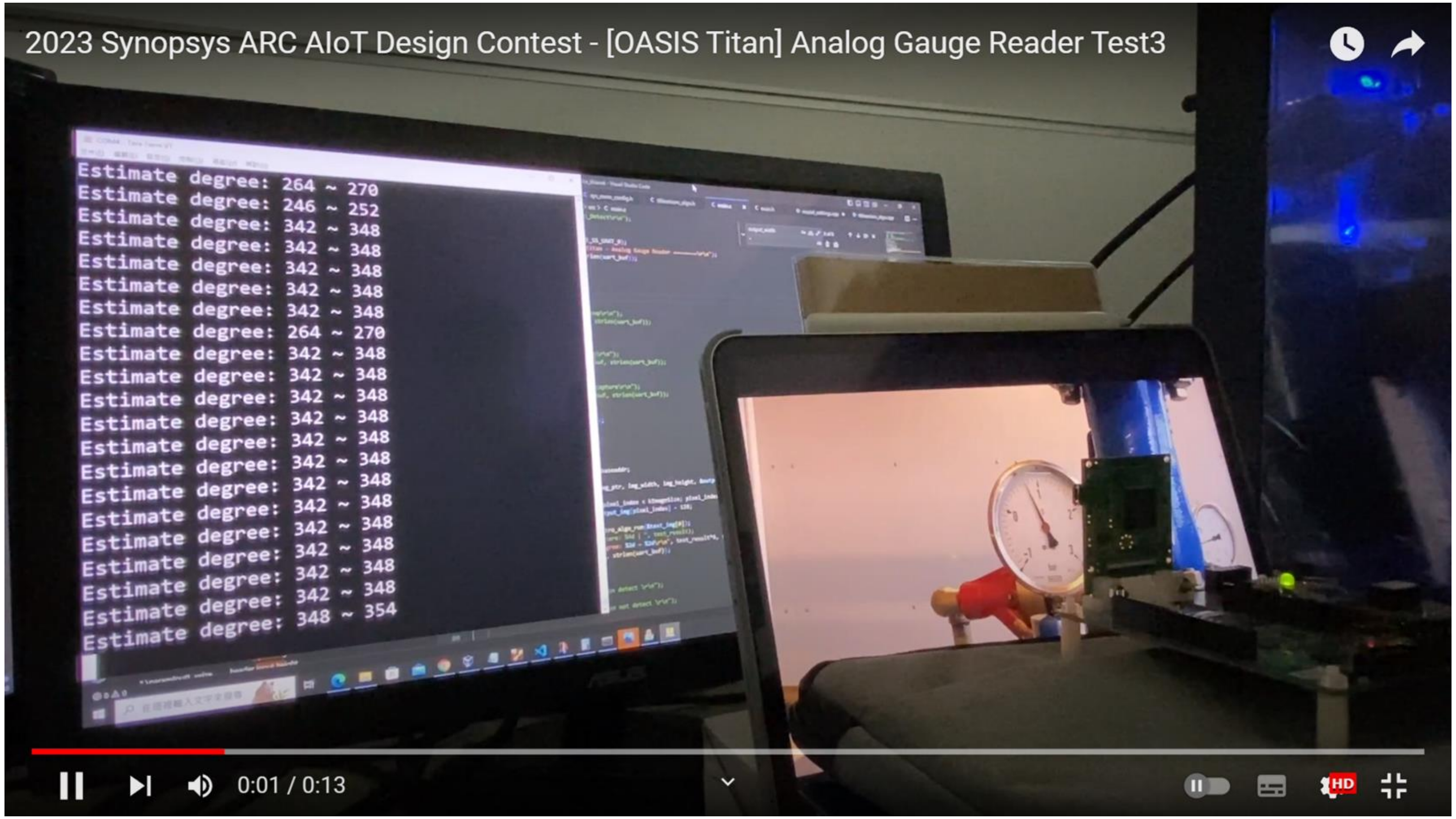
Demo Video – Analog Gauge Reader Inference Test3

- **Link**

  https://www.youtube.com/watch?v=dGtSQWrOaJU&ab_channel=ChenBaker



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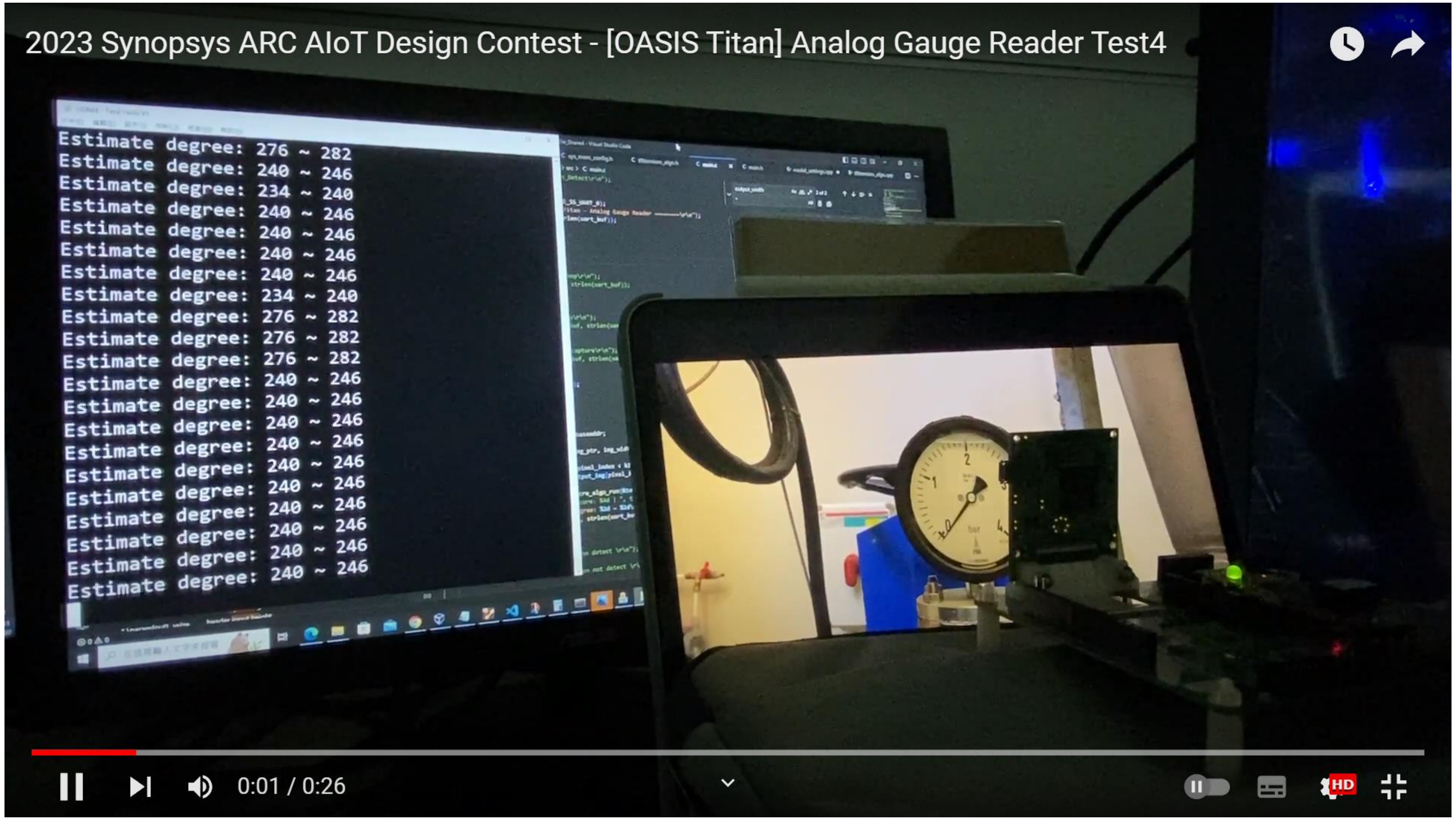
Demo Video – Analog Gauge Reader Inference Test4

- **Link**

  https://www.youtube.com/watch?v=Z6F6YlwSd7A&ab_channel=ChenBaker



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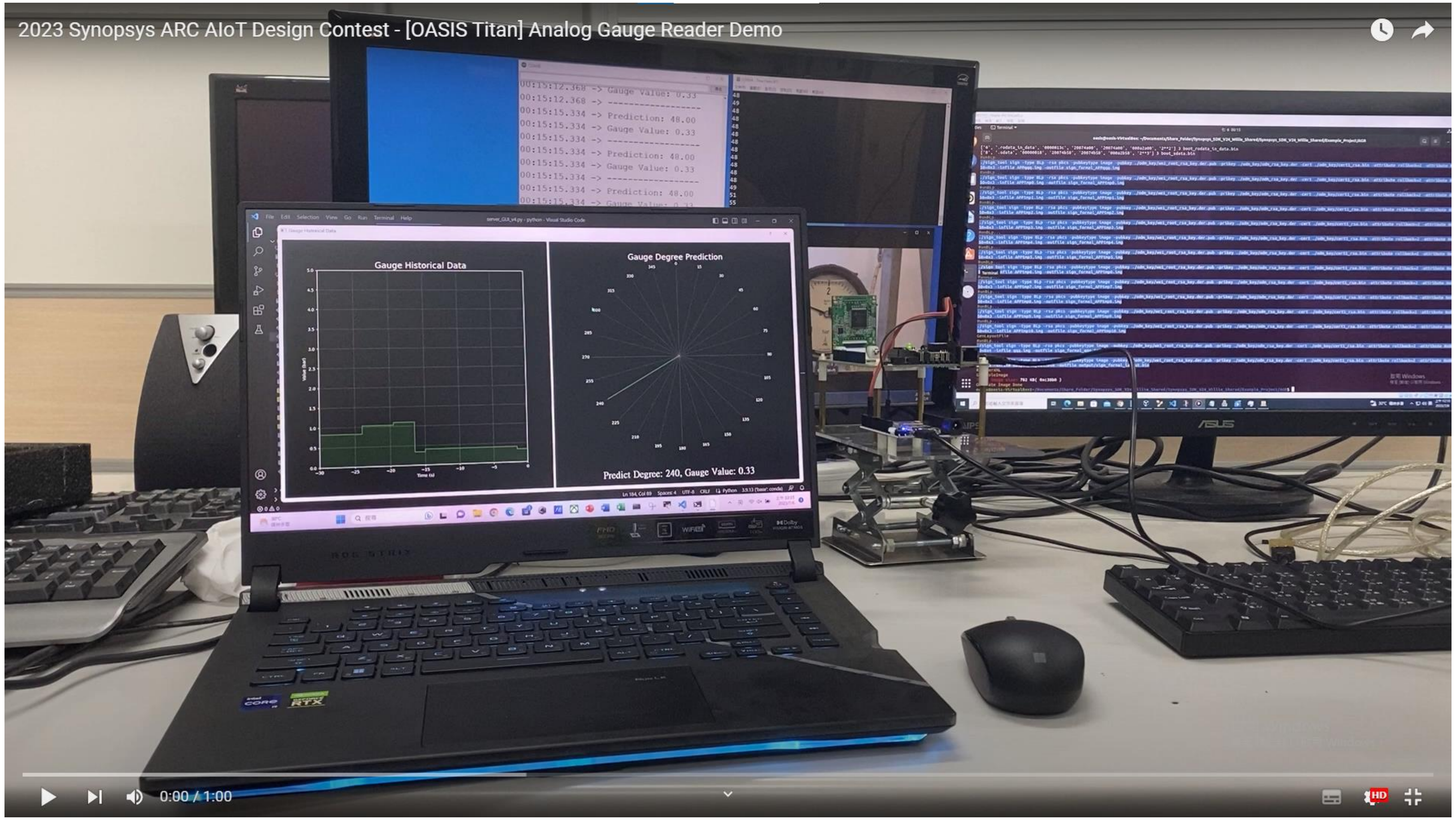
Demo Video – Analog Gauge Reader Inference Demo

- **Link**

  https://www.youtube.com/watch?v=5TH9fBItiWc&ab_channel=ChenBaker



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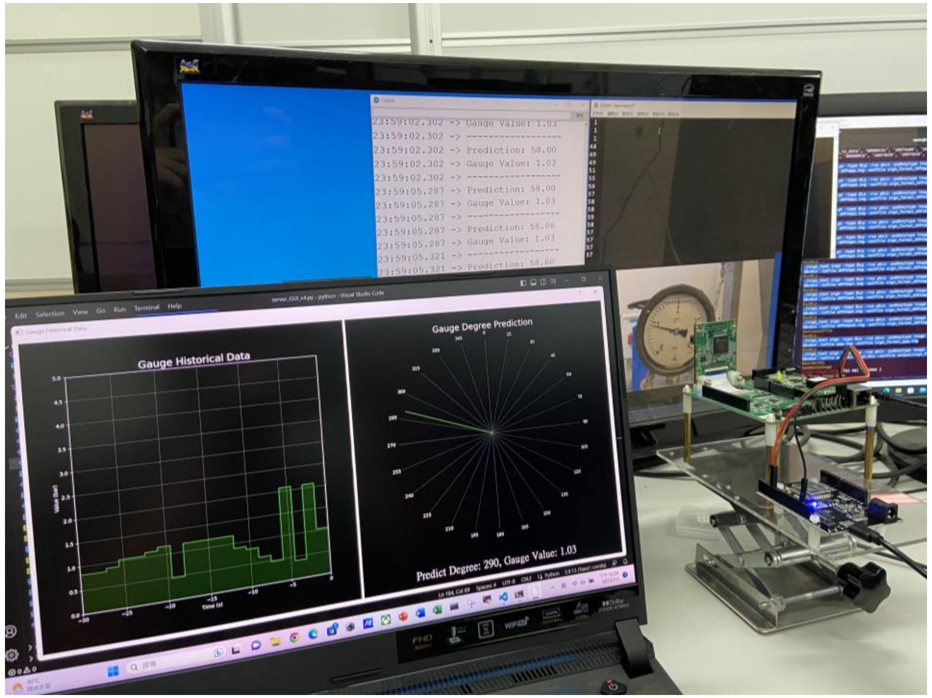
Overall Summary

- **Real-time Analog Gauge Reader**
  - **Data Generator Generate**
    - Automatically generates and labels images to create a training dataset
    - Suitable for the real-world scenario
  - **Analog Gauge Calibration**
    - Decide the number of categories
    - Trade-offs between model size and accuracy
  - **Model Compression**
    - Reduce the size of MobileNetV2
    - Using int8 quantization to compress the model size
  - **UI for Recording and Displaying Analog Gauge**



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Reference

[1] Chavan, S., Yu, X., & Saniie, J. (2022, May). High Precision Analog Gauge Reader Using Optical Flow and Computer Vision. In 2022 IEEE International Conference on Electro Information Technology (eIT) (pp. 171-175). IEEE.

[2] Trairattanapa, V., Phimsiri, S., Utintu, C., Cherdchusakulcha, R., Tosawadi, T., Thamwiwatthana, E., ... & Suttichaya, V. (2022, November). Real-time Multiple Analog Gauges Reader for an Autonomous Robot Application. In 2022 17th International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP) (pp. 1-6). IEEE.

[3] Howells, B., Charles, J., & Cipolla, R. (2021). Real-time analogue gauge transcription on mobile phone. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 2369-2377).

[4] Hinton, G., Vinyals, O., & Dean, J. (2015). Distilling the knowledge in a neural network. arXiv preprint arXiv:1503.02531.

[5] He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep residual learning for image recognition. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 770-778).

[6] Sandler, M., Howard, A., Zhu, M., Zhmoginov, A., & Chen, L. C. (2018). Mobilenetv2: Inverted residuals and linear bottlenecks. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 4510-4520).

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