SYNOPSYS®

2023 Synopsys ARC AIoT Design Contest

Project Presentation

應用於傳統工廠的智慧儀表讀數器

Smart Analog Gauge Reader Applied in Traditional Factory

指導教授: 張錫嘉 教授

隊員: 陳冠瑋、李家毓、鄭宇皓、蔡易昕

隊名: 綠洲泰坦 OASIS Titans

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NCTU OASIS Lab

Agenda

- **Motivation**
- **Challenge and Innovation**
- **Design and Implementation**
- **Demo Video**
- **Summary**

Motivation

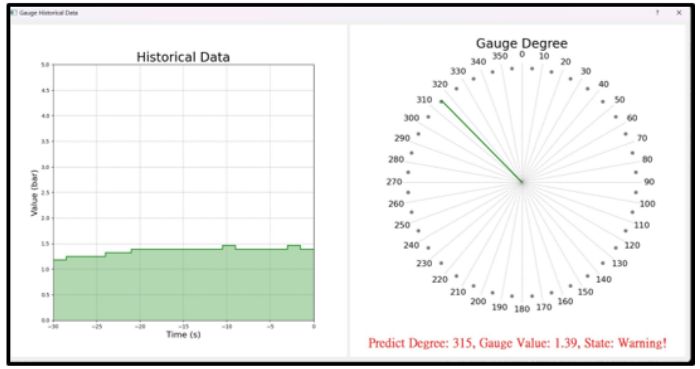
- **Many traditional factories are still using analog gauges**
  - Replace the new machine with a digital reader → **large-scale update**
  - Record gauge data and monitor by human inspectors → **time-consuming**

- **Our Proposal**
  - Use **ARC EM9D** to digitize & monitor the analog gauge
  - Reduce labor costs and enhance management automation

Analog Gauge

ARC EM9D AI Inference

Server



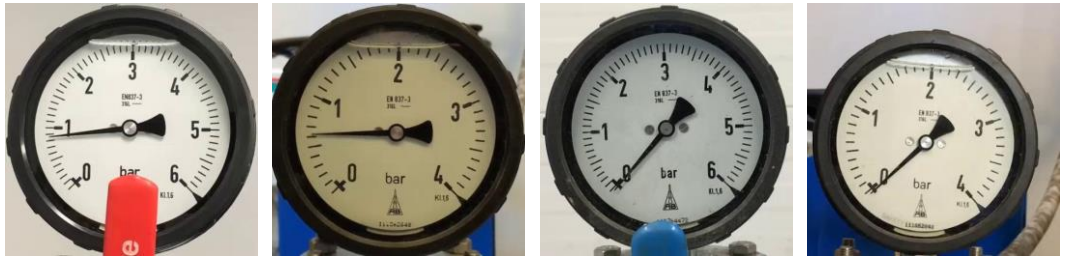
Data Analysis

Challenge

■ Data collection is hard for analog gauges

– Different gauge styles and appearances

– Influence of light and noise



▲ Different Types and Appearance

▲ Influence of light and noise

■ Model deployment is limited by edge device

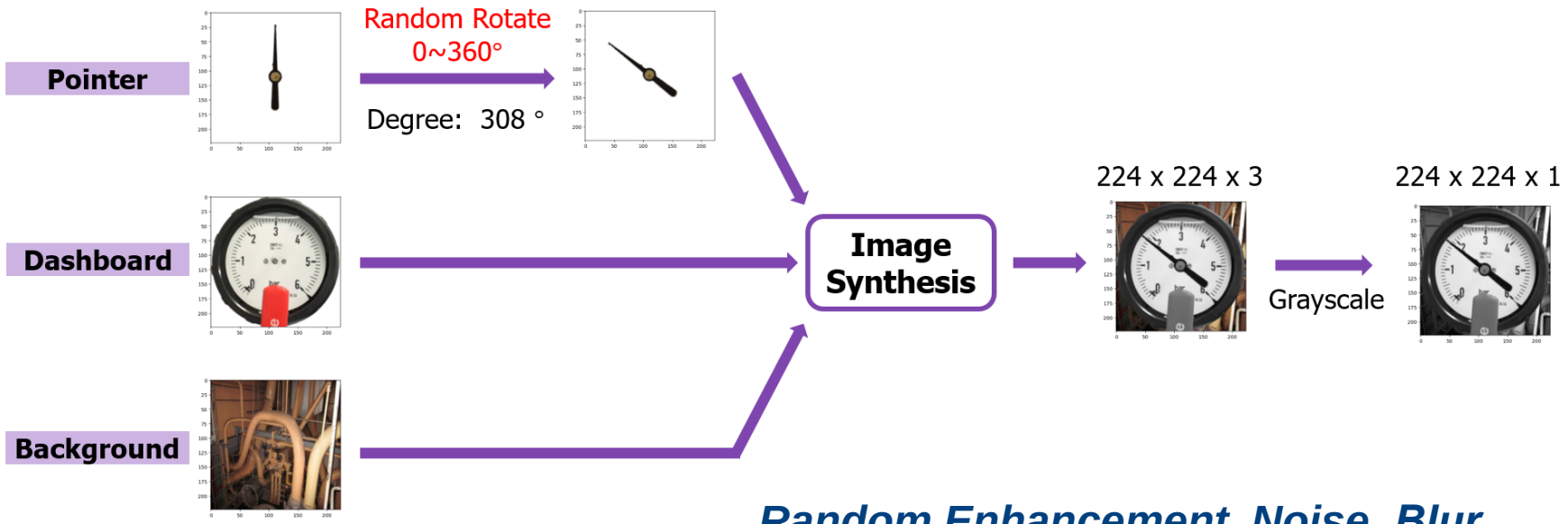
– Limited computational and memory resources

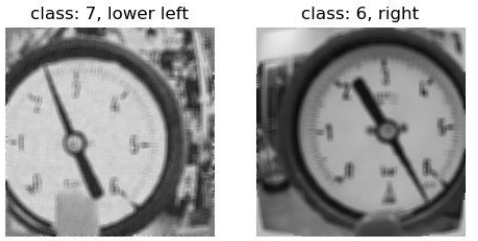
- **Detection model is too large for ARC EM9D (ex: YOLOv7-Tiny has 6M parameters)**

– Compress the model size and sustain the performance (e.g. accuracy, precision)

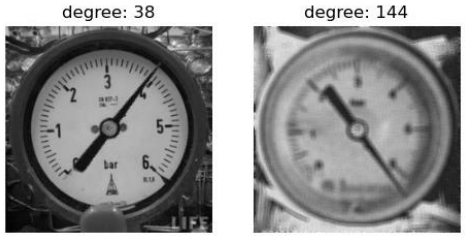
Innovation - Data Synthesis & Annotation (1/2)

■ Automatic Image Generation w/ Augmented Process





▲ For detection model



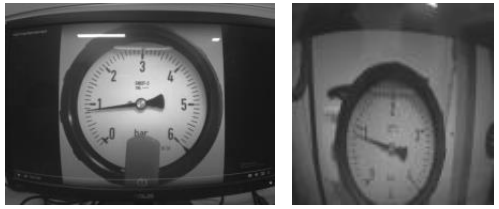
▲ For classification model

- **Gauge Images & Videos:** *Pressure Gauge Dataset* (Source: Kaggle)
- **Background Images:** *Places Dataset – engine_room* (Source: MIT)

Innovation - Data Synthesis & Annotation (2/2)

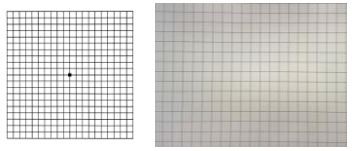
■ Fisheye Transform

– **Simulate the effects of image distortion**

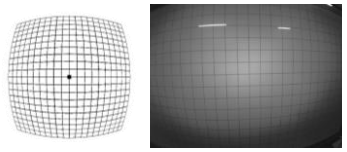


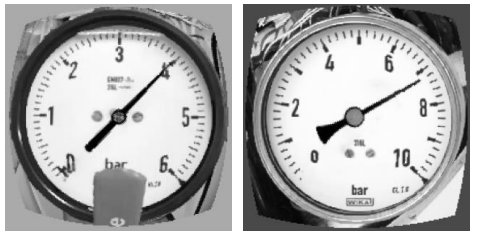
▲ HM0360 AoSTM VGA Camera

iPhone11

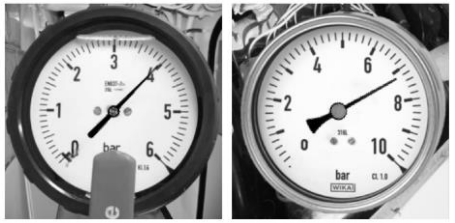


ARC EM9D (Distorted)





▲ **w/** Fisheye Transform

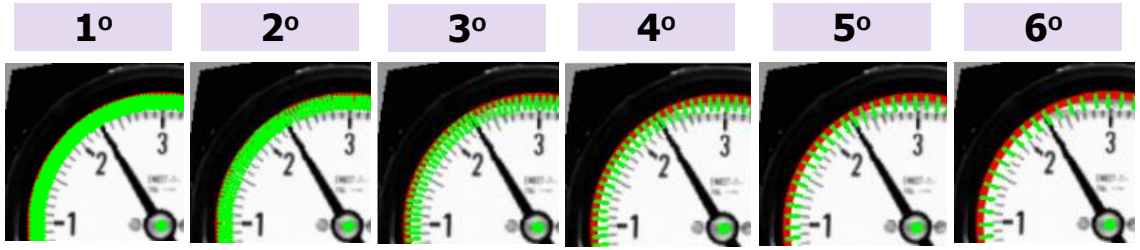


▲ **w/o** Fisheye Transform

■ Trade-off between accuracy, precision & model size

Resolution	#Classes	FC Size (input size = 1024)	Accuracy
1º	360	369 K	75.35%
2º	180	185 K	89.75%
3º	120	123 K	94.65%
4º	90	92 K	94.55%
5º	72	74 K	97.15%
6º	60	62 K	98.35%

Resolution



Innovation – 2-phase Pipelined Models

■ Replace YOLO with 2-phase models for smaller size

– **Model 1: Gauge Detector**
- Detect the relative position of an analog gauge
- **MobileNetV2-pico (#Param: 0.05M)**

– **Model 2: Gauge Reader**
- Classify the angle of the analog gauge
- **MobileNetV2-nano (#Param: 0.11M)**

Model	#Param (M)	Deployable
YOLO		
v4	64.40	No
v7	36.90	No
v4-Tiny	6.10	No
v7-Tiny	6.20	No
MobileNetV2		
base (orig.)	2.35	No
Small	0.80	No
Tiny	0.34	No
Micro	0.19	Yes
Nano	0.11	Yes
Pico	0.05	Yes

■ Redesign MobileNetV2 for Embedded AI

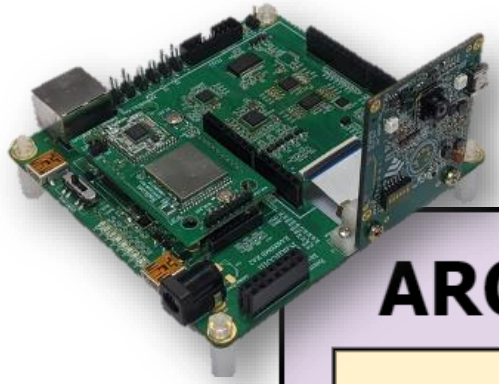
– **Reduce the number of filters and FC layer size**

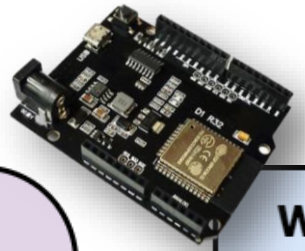
[4] “Mobilenetv2: Inverted residuals and linear bottlenecks,”. in *CVPR*, 2018.
[5] "Real-time object detection method based on improved YOLOv4-tiny," in *arXiv*, 2020.
[6] “YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors,” in *CVPR*, 2023.

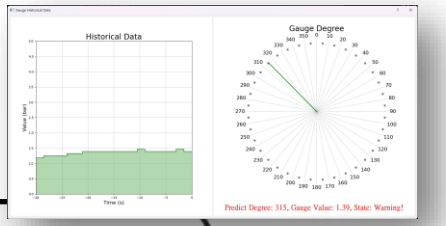
YOLOv7 ➡ **Detector** + **Reader**
6.20 M **0.05 M** **0.11 M**

Reduce 97% Parameters

System Architecture







Analog Gauge

ARC EM9D AIoT DK

- Camera
- EmbARC MLI Lib.
- Controller
- Model 1 — Gauge Detector
- Model 2 — Gauge Reader

UART

Wemos D1 R32

- WiFi module
- Converter

WiFi

PC

- Display
- Data Analyzer

GPIO

LED R/G/B

I2C

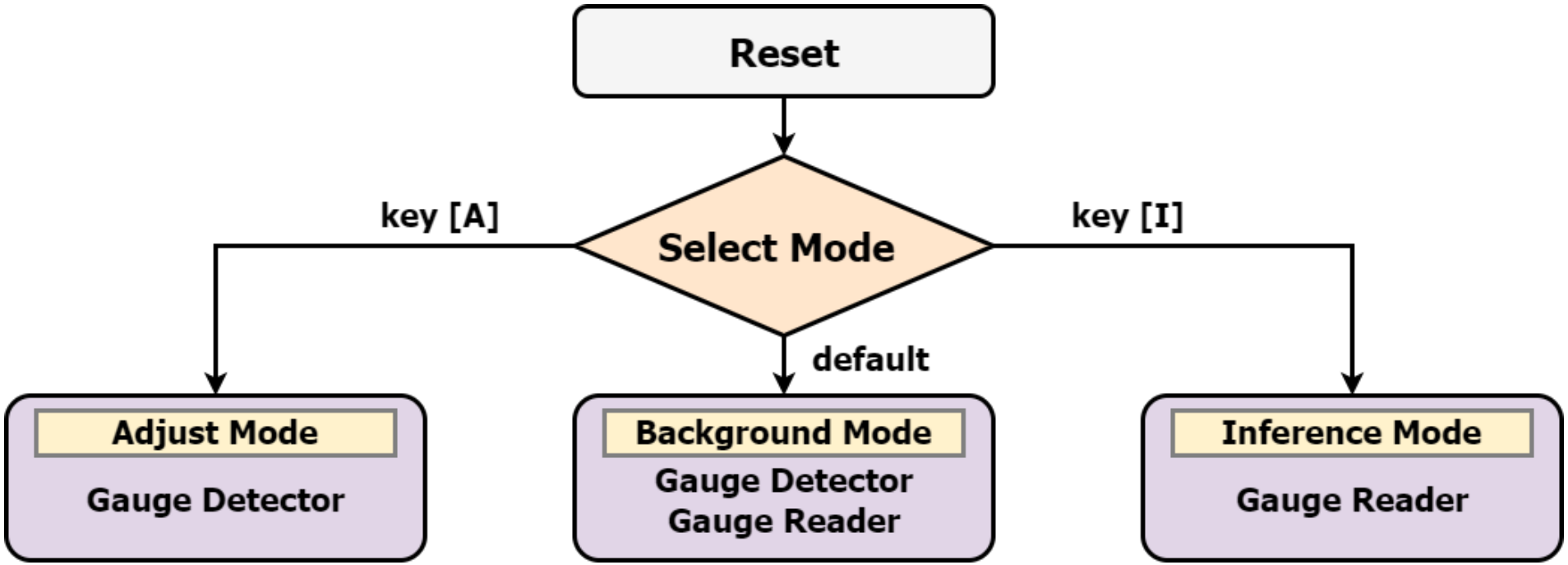
OLED Display

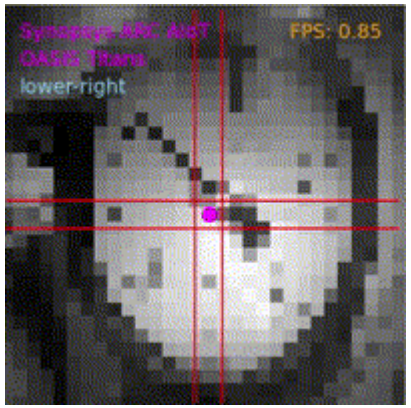
Converter

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

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

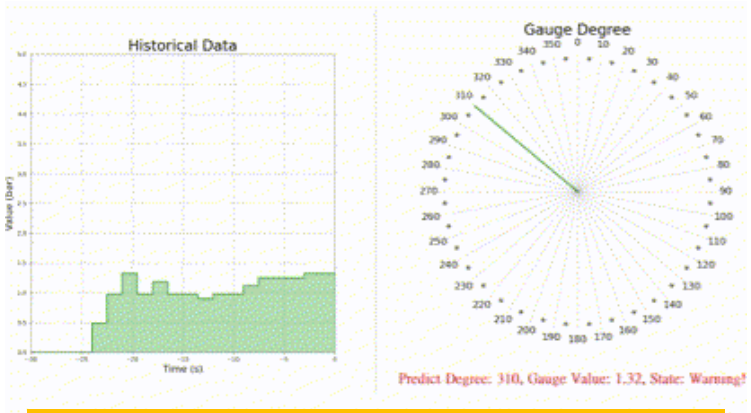
Application-driven Operation Flow





Compress the image size by 96%
(150x150x1 → 30x30x1)

Show detection & reading result on OLED display



Transmit gauge reading result on PC via Wi-Fi

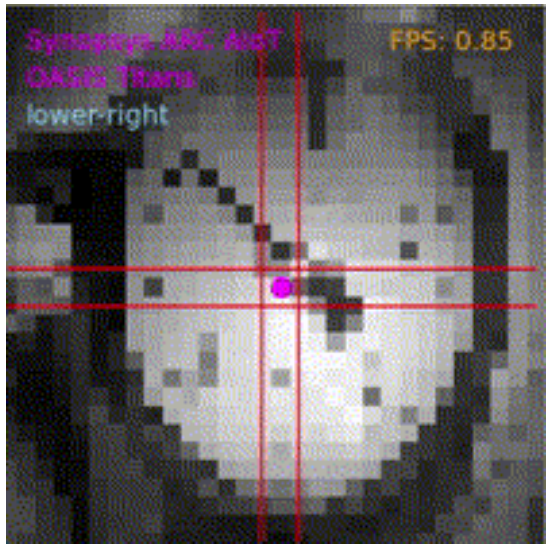
Experimental Results

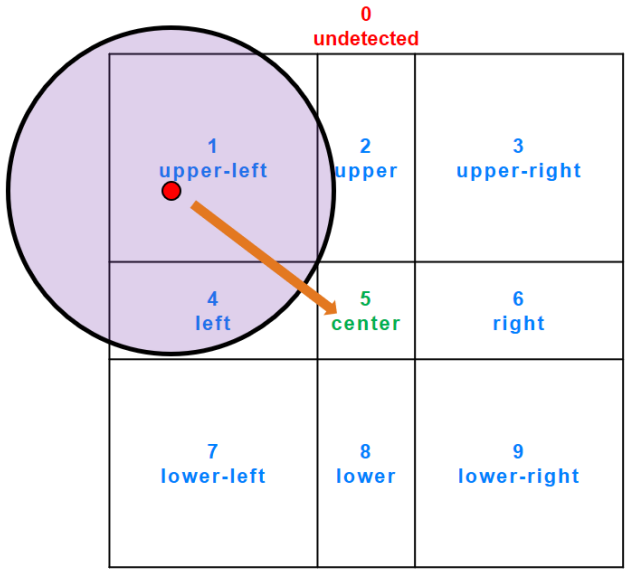
Gauge Detector

- Locate the gauge reader accurately
- MobileNetV2-pico (#Param: 0.05 M)

Model (MobileNetV2)	#Param (M)	Top-1 Acc.
Tiny	0.26	98.89%
Micro	0.11	97.10%
Nano	0.08	96.48%
Pico	0.05	96.15%

MobileNetV2 (fp32) @NVIDIA GeForce GTX 2080 Ti





▲ Position Correction

Gauge Reader

- Classify the angles of the gauge pointer
- MobileNetV2-nano (#Param: 0.11 M)

Model (MobileNetV2)	#Param (M)	Top-1 Acc.	Top-2Acc.	±1 classes Acc.
Tiny	0.34	78.95%	99.60%	100%
Micro	0.19	75.20%	98.35%	100%
Nano	0.11	82.65%	98.90%	100%
Pico	0.05	70.19%	98.27%	99.83%

MobileNetV2 (fp32) @NVIDIA GeForce GTX 2080 Ti

▼ Post-Training Quantization

Model	Acc. (fp32)	Acc. (int8)
Detector	96.15%	96.15%
Reader	82.65%	82.10%

MobileNetV2 (fp32) @NVIDIA GeForce GTX 2080 Ti
MobileNetV2 (int8) @Intel Xeon CPU E5-2660 v4

Demo Video

Overall Summary

Data Synthesis & Annotation

- **Fisheye transforms** for realistic photos
- Calibration for optimal model size, accuracy & precision

▲ w/ Fisheye Transform ▲ w/o Fisheye Transform

2-phase Pipelined Models

- **Detector** detects the relative position of analog gauge
- **Reader** classifies the angle of analog gauge
- Redesign MobileNetV2 for embedded AI
- 97% parameters reduction compared to YOLOv7-tiny

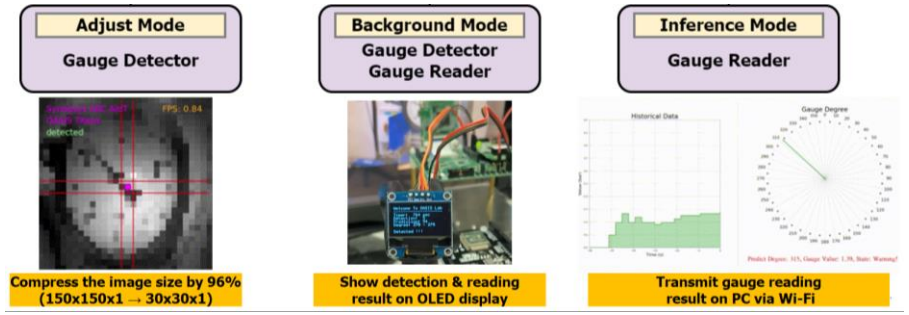
region	Used Size	Region Size	%age Used
ICCM0:	0 GB	64 KB	0.00%
ICCM1:	312492 B	320 KB	95.36%
SYSTEM0:	944812 B	957168 B	98.71%
DCCM:	104 KB	256 KB	40.62%
XCCM:	32 KB	32 KB	100.00%
YCCM:	32 KB	32 KB	100.00%

▲ Memory Usage on ARC EM9D

(1 MB for 2 models)

Application-driven Operation Flow

- **Adjust** and **Inference mode** for different scenarios
- **Background mode** for default settings



Reference

[1] Chavan, Shruti, X. Yu, and S. Jafar, "High Precision Analog Gauge Reader Using Optical Flow and Computer Vision," in *International Conference on Electro Information Technology (eIT).* IEEE, 2022.

[2] Trairattanapa, Visarut, et al., "Real-time Multiple Analog Gauges Reader for an Autonomous Robot Application," in *17th International Joint Symposium on Artificial Intelligence and Natural Language Processing (iSAI-NLP)*. IEEE, 2022.

[3] B. Howells, J. Charles, and R. Cipolla. "Real-time analogue gauge transcription on mobile phone," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. 2021.

[4] M. Sandler, A. Howard, M. Zhu, A. Zhmoginov, and L. C. Chen, "Mobilenetv2: Inverted residuals and linear bottlenecks,". in *Proceedings of the IEEE Conference on computer vision and pattern recognition (CVPR)* (pp. 4510-4520). IEEE, 2018.

[5] Z. Jiang, L. Zhao, S. Li, and Y. Jia, "Real-time object detection method based on improved YOLOv4-tiny," in *arXiv preprint arXiv:2011.04244,* 2020.

[6] C. Y. Wang, A. Bochkovskiy, & H. Y. M. Liao, "YOLOv7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. IEEE, 2023, pp. 7464-7475.

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