

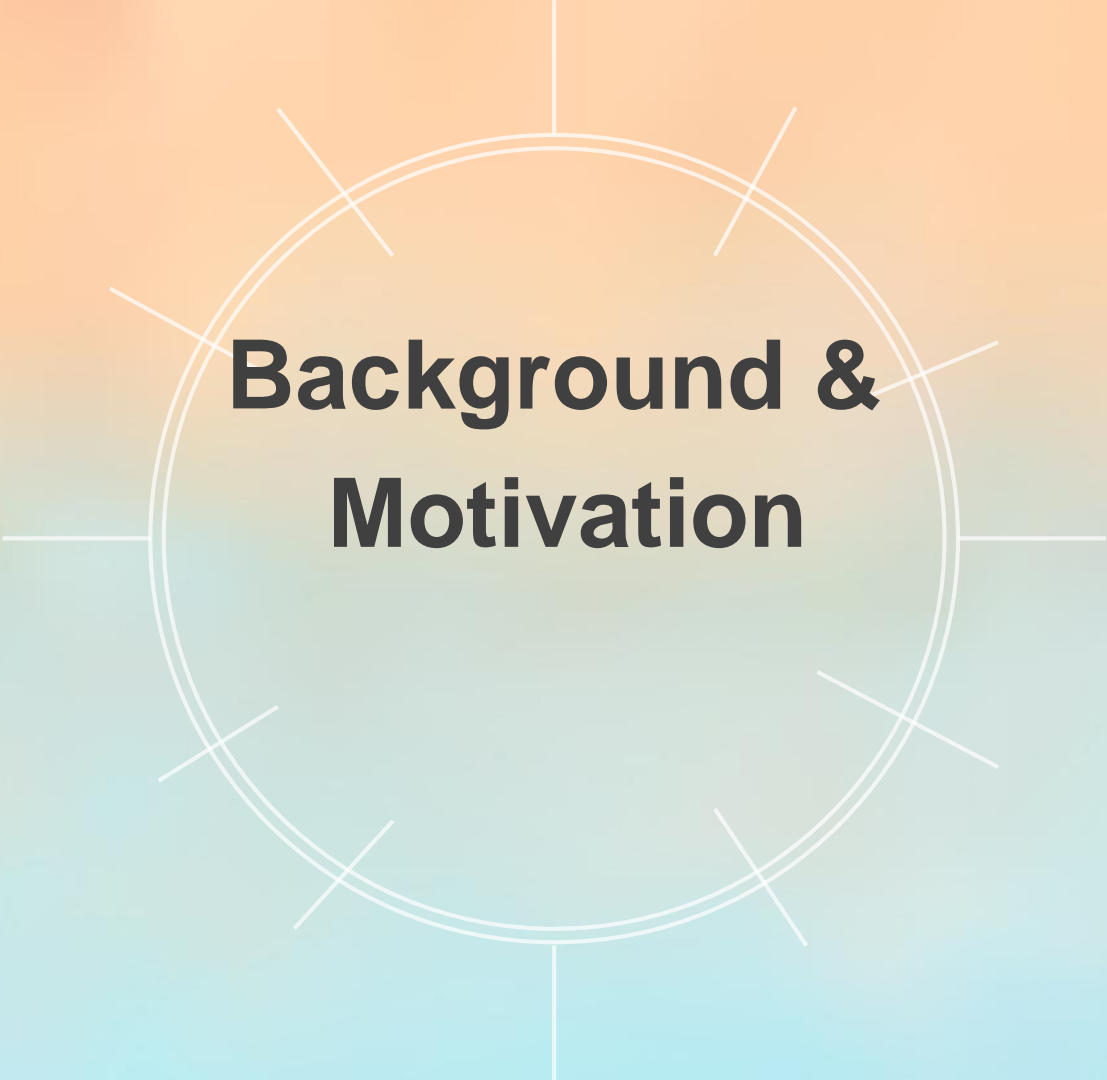
The logo features a large circle with two concentric white lines. Ten white lines radiate from the circle's edge, resembling a compass rose. The background is a gradient from light orange at the top to light blue at the bottom.

ARC DESIGN CONTEST

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Outline

- Background and Motivation
- Thermal Sensor Overview
- Environment Setting
- Feature Selection
- Data Analysis Method and Result
- Conclusion



Background & Motivation

Background

- **Accuracy**
 - An indicator of thermal sensor
 - How close you are to the actual value
- **Calibration methods**
 - Dual sensing variation cancelling

Background

- **Thermal sensor output**
 - Worse linearity (Overly ideal simulation process)
 - Accuracy Issue (Time consuming simulation)

Motivation

- **Our goal**
 - Propose an accurate calibration method based on thermal sensor
 - Build a machine learning model to achieve the goal on EMSK

The diagram features a central circle with a double-line border. Ten short, thin white lines radiate from the circle's perimeter at various angles. The background is a smooth gradient from light orange at the top to light blue at the bottom.

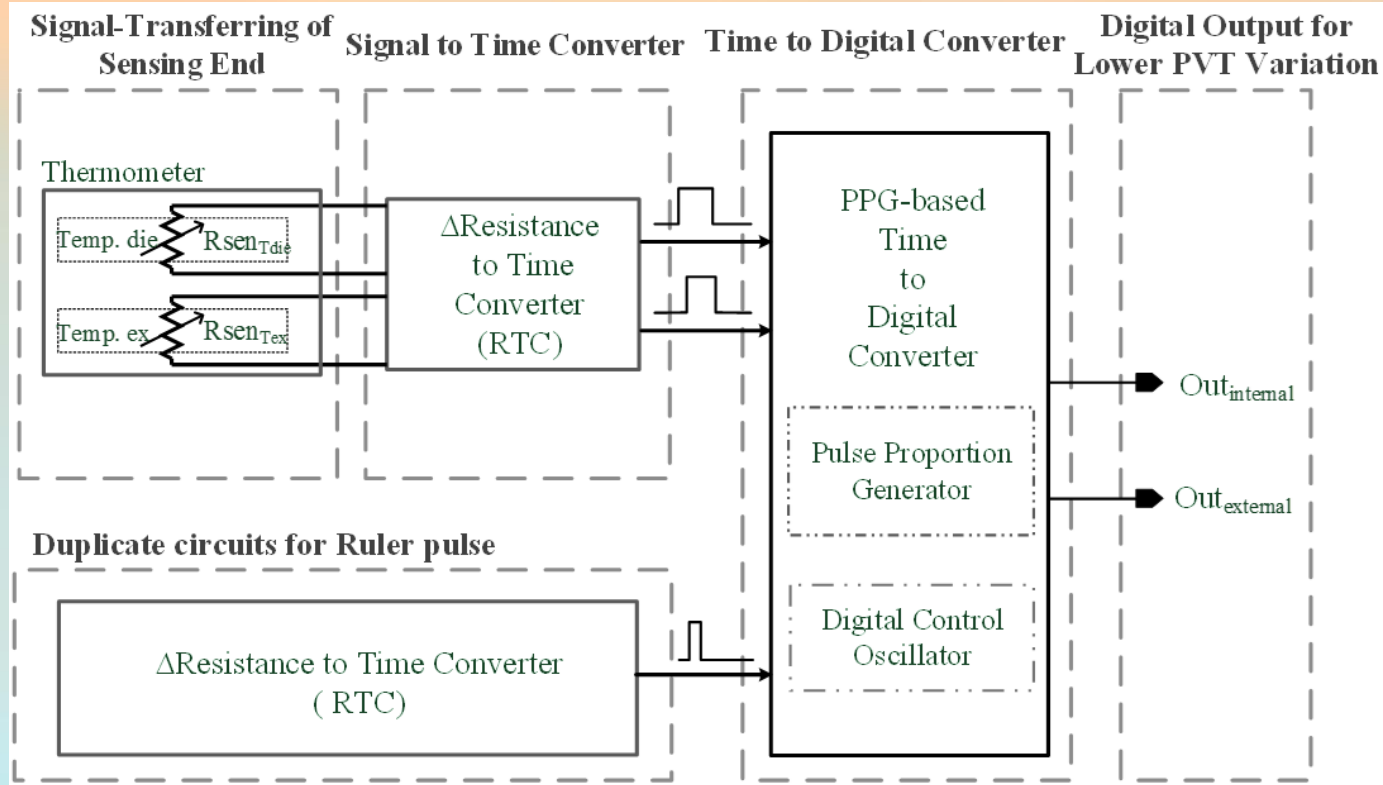
Thermal Sensor Overview

Thermal Sensor Overview

- **DIP 32 Package**
- **Technology Node: 0.18um**
- **IO Pad Voltage: 1.8V**
- **Thermal Sensor**
 - Temperature range: 0~100°C
- **Calibration Features**
 - Dual sensing variation cancelling
 - Pulse Proportion Generator (PPG) for reducing PVT variations

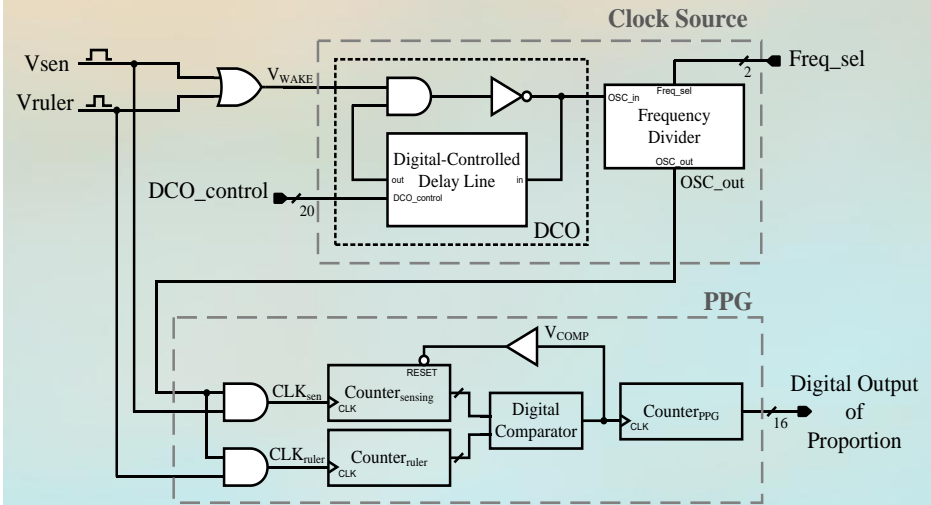
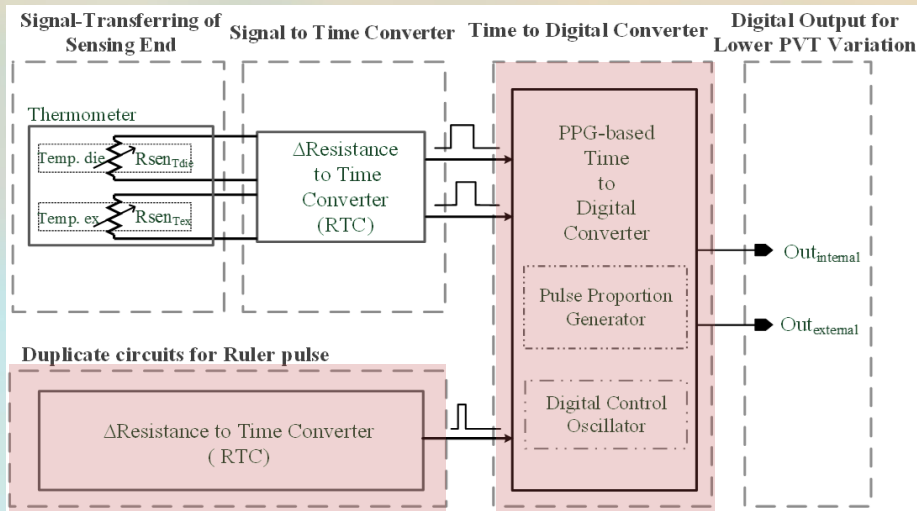
Thermal Sensor Overview

Dual Sensing Variation cancelling



Thermal Sensor Overview

- Pulse Proportion Generator
 - Generate a ruler time-pulse as reference
 - Taking proportion between V_{ruler} and V_{sen}
 - To compensate the P-V-T variations

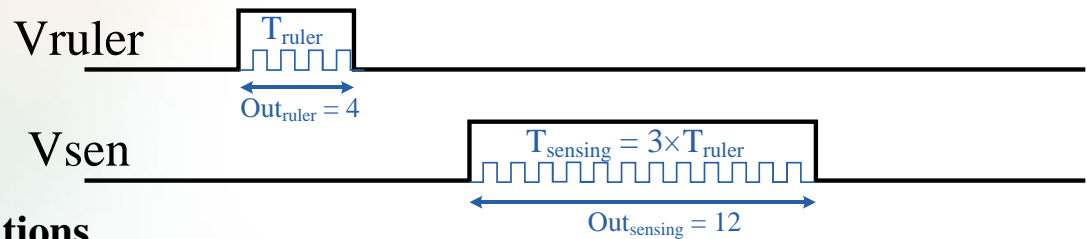


Thermal Sensor Overview

- PVT variations will be eliminated

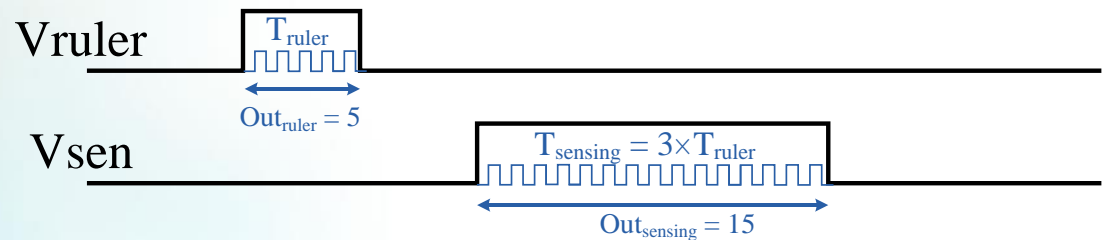
Without variations

$$P_{ideal} = \frac{k \times Sense}{k \times Ruler}$$



With variations

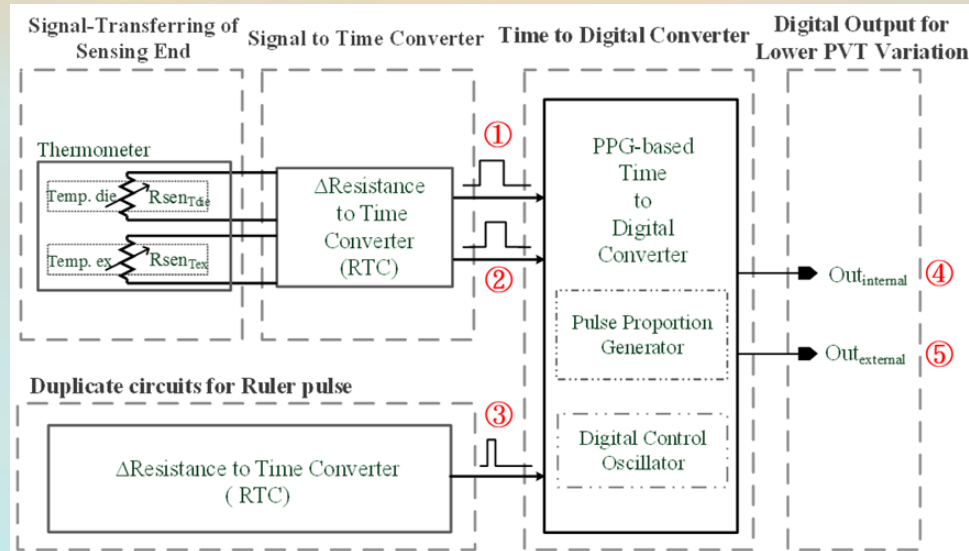
- Supply voltage
- Temperature



Thermal Sensor Overview

- **Thermal Sensor Output**

- ①Sense_in ②Sense_ex ③Ruler
- ④PPG_in=Sense_in/Ruler ⑤PPG_ex=Sense_ex/Ruler

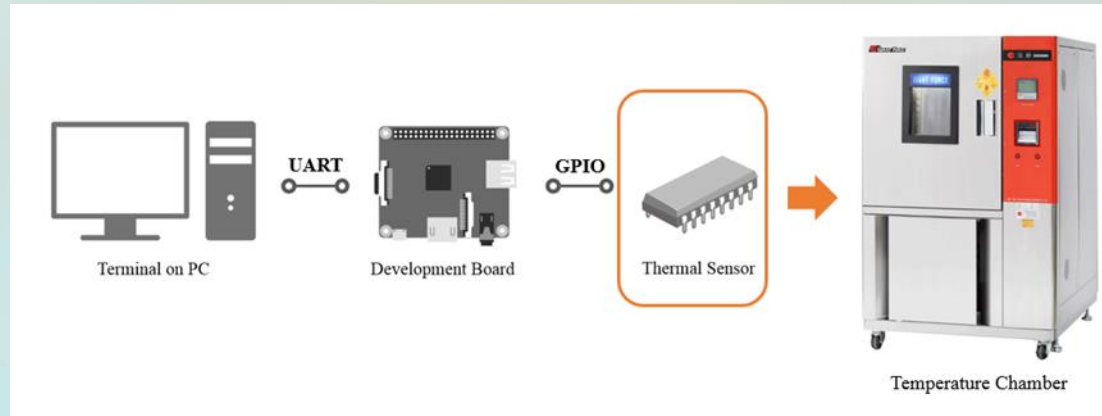




Environment Setting

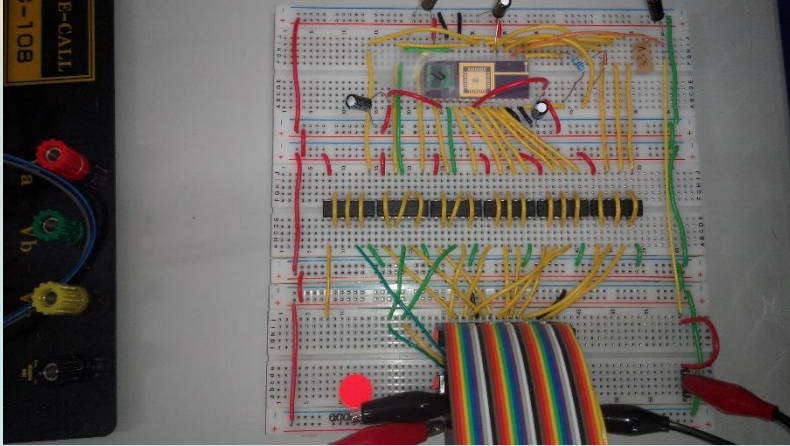
Environment Setting

- **System Architecture**
 - Embedded ARC Starter Kit
 - Thermal Sensor Circuit
 - UART/GPIO
 - Temperature chamber

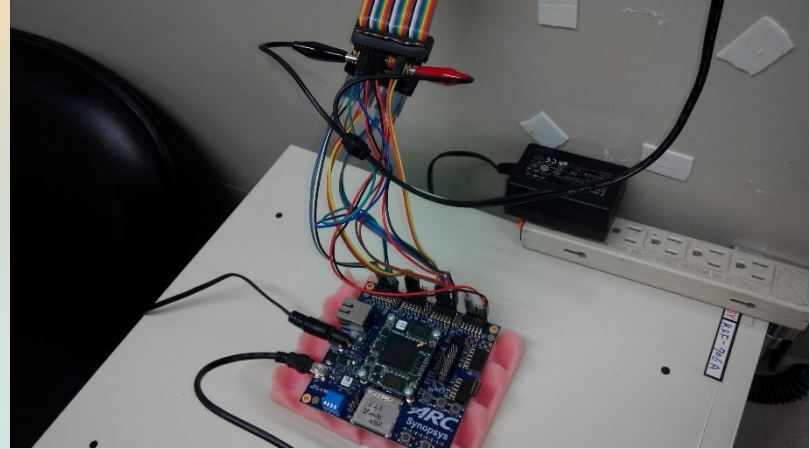


Environment Setting

Thermal Sensor Circuit



ARC EMSK Platform



Environment Setting

- **PMOD**

- Set PMOD as GPIO to control our signal

```
port_output = gpio_get_dev(DW_GPIO_PORT_C);  
port_output -> gpio_open(0x00ffff00);  
port_output -> gpio_control(GPIO_CMD_SET_BIT_DIR_OUTPUT, (void *)0x00ffff00);  
port_output -> gpio_control(GPIO_CMD_DIS_BIT_INT, (void *)0x00ffff00);
```

```
port_output-> gpio_write(PATTERN_EXCEL[count]<<PMOD_OFFSET0, MASK_GPIO0);
```

- **Timer interrupt**

- At specific frequency range, we output signal to IC from our specific pattern

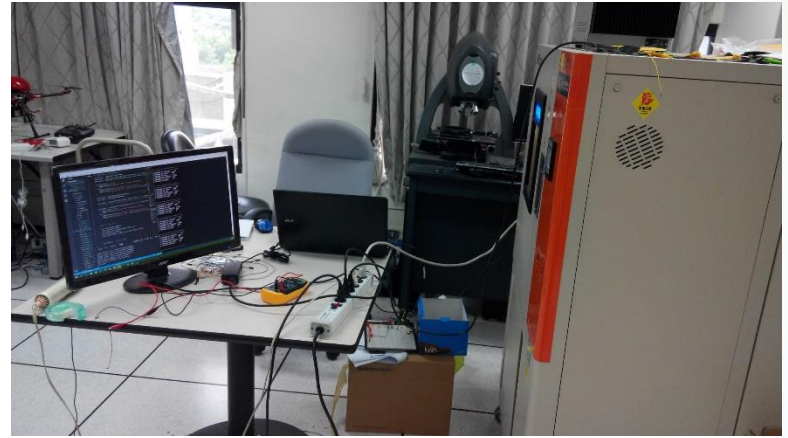
```
int_disable(INTNO_TIMER0);  
timer_stop(INTNO_TIMER0); // stop timer for setting handler  
int_handler_install(INTNO_TIMER0, timer0_isr);  
int_enable(INTNO_TIMER0);  
timer_start(TIMER_0, TIMER_CTRL_IE, BOARD_CPU_CLOCK/1000);
```


Environment Setting

Put the Circuit In Chamber



Start Data Collection



A diagram featuring a central circle with the text "Feature Selection" inside. The circle is composed of two concentric white lines. Ten short white line segments radiate from the outer edge of the circle, pointing outwards in various directions. The background is a smooth gradient from light orange at the top to light blue at the bottom.

Feature Selection

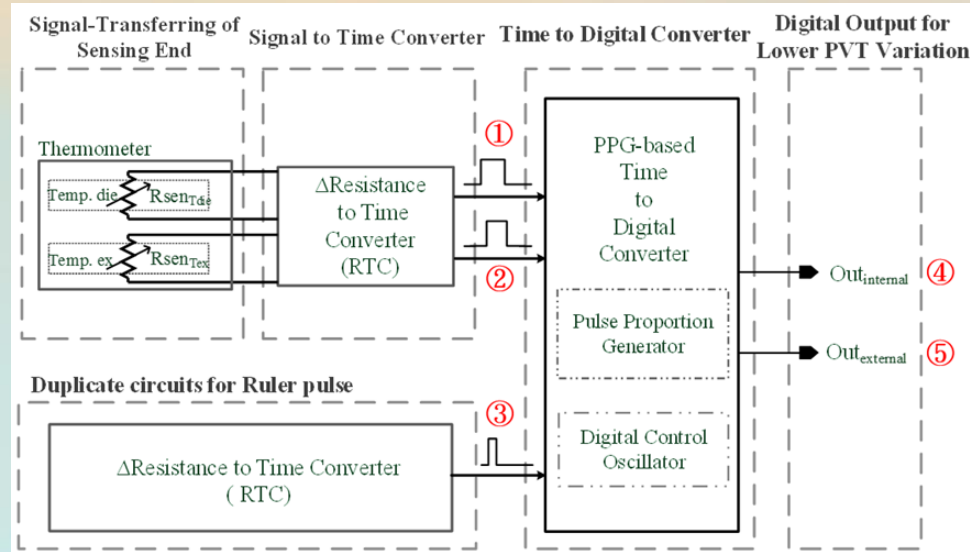
Feature Selection

- **Five Output**

- ①Sense_in ②Sense_ex ③Ruler
- ④PPG_in=Sense_in/Ruler ⑤PPG_ex=Sense_ex/Ruler

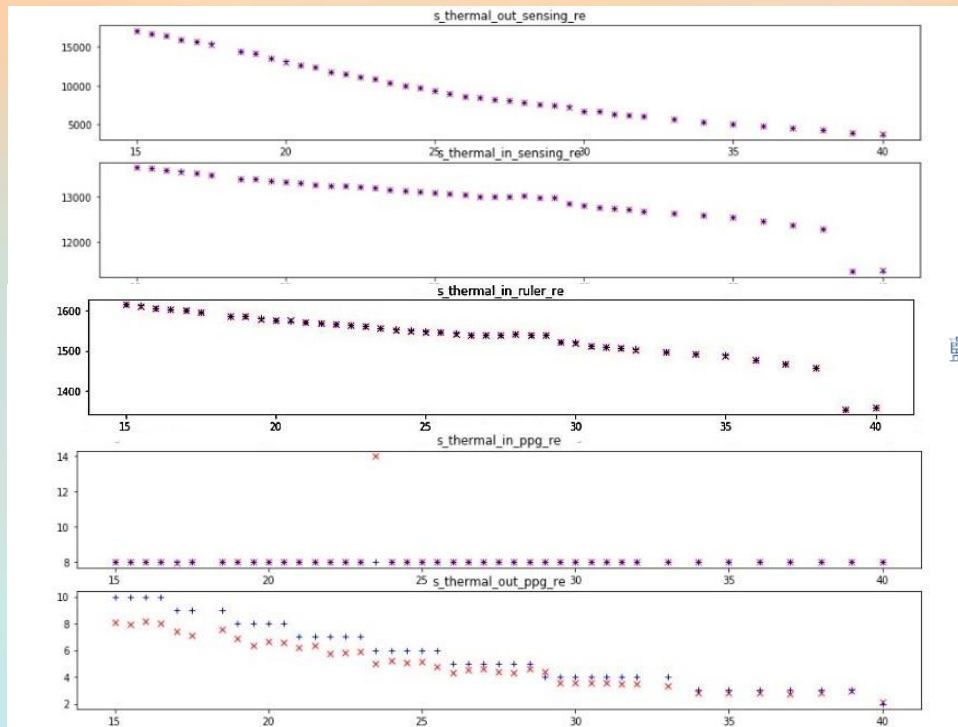
- **Feature Selection**

- Linearity
- Function



Feature Selection - Linearity

- **Ruler breaks the linearity of sensing output**



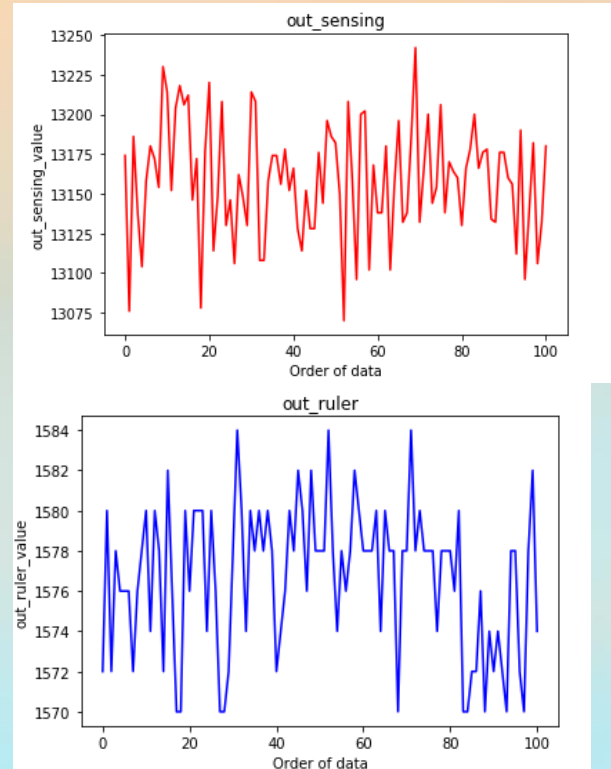
藍色:median 紅色:mean

Feature Selection – PPG Function

- The difference between SENSE_in and Ruler is not proportional, same as SENSE_ex and Ruler

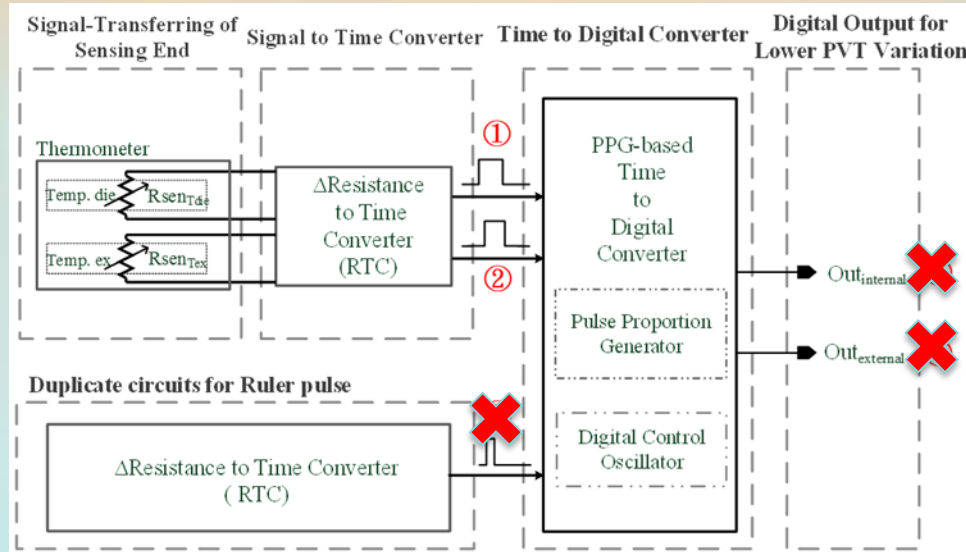
$$P_{ideal} = \frac{k \times Sense}{k \times Ruler}$$

$$P_{measurement} = \frac{k \times Sense + n}{k \times Ruler + n'}$$



Feature Selection

- We only chose **Sense_in** and **Sense_ex** as training input
 - Ruler does not have great linearity in small range
 - The variation between ruler and sensing is not constant in 15°C to 40°C

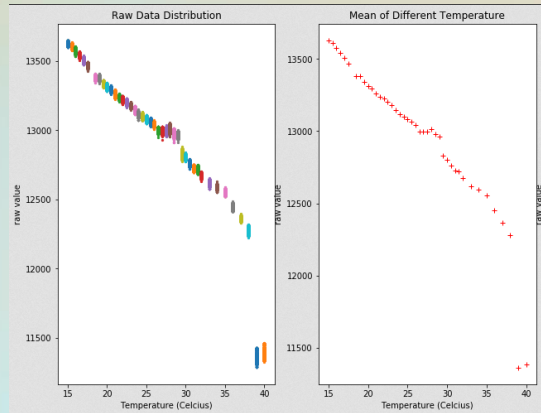


A decorative graphic consisting of two concentric white circles. Between the circles, there are eight short white line segments, each perpendicular to the radius at its outer endpoint, resembling tick marks on a clock face.

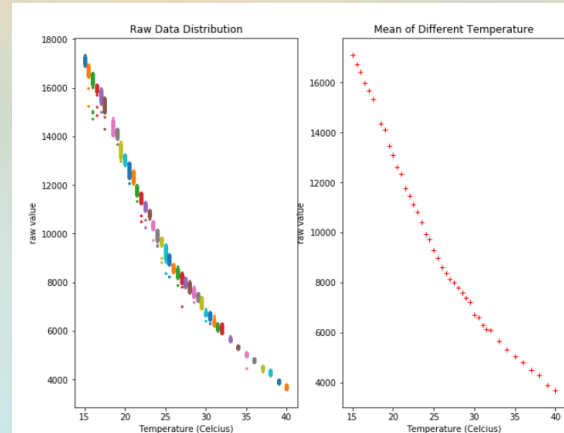
Data Analysis & Machine Learning Based Method

Data Analysis

- **Sense_out** is the linear data
- **Sense_in** can be the auxiliary data



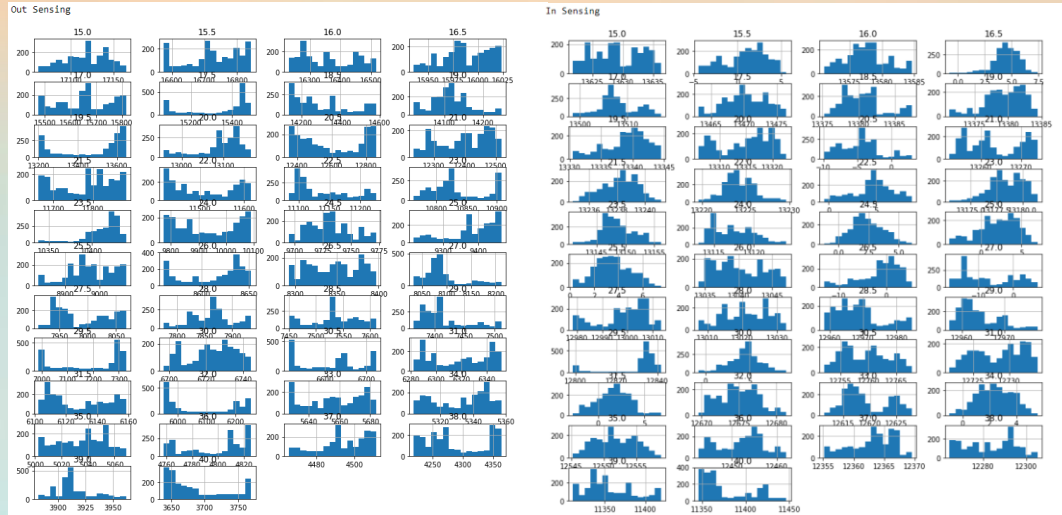
(s_thermal_in_sensing)



(s_thermal_out_sensing)

Data Analysis

- **Data is not Gaussian distribution**
 - Use moving average to smooth raw data

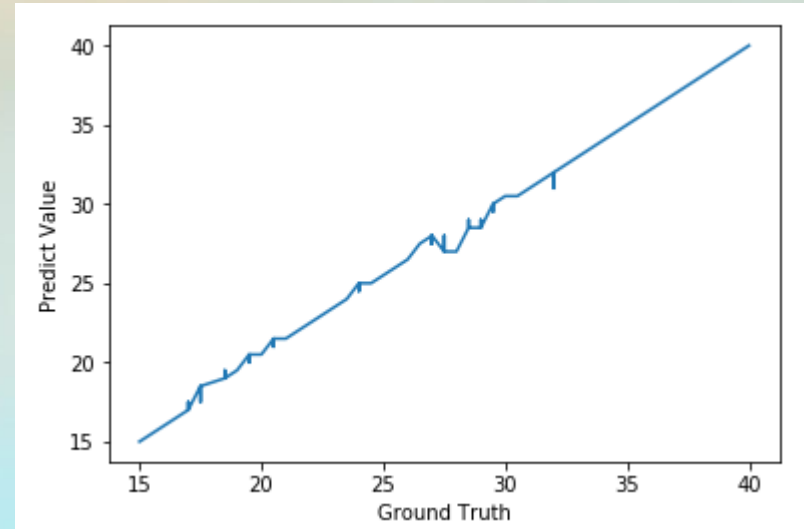
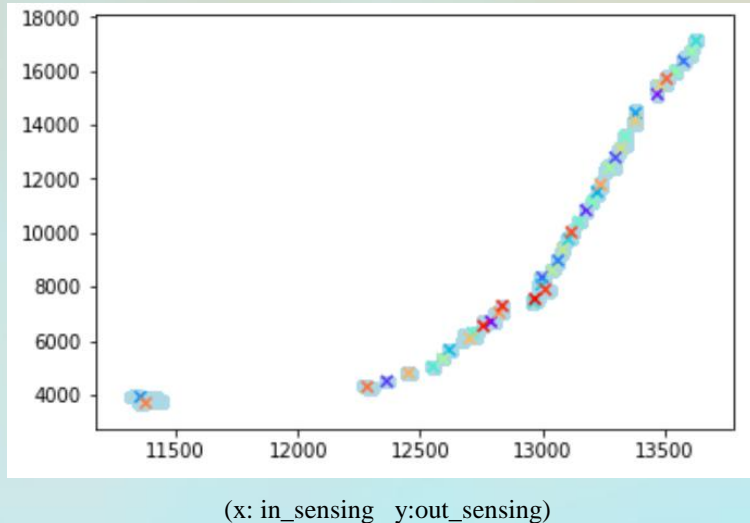


(thermal_out_sensing)

(thermal_in_sensing)

K-mean Clustering

- **X means clustering center**
 - Centers are very close to each other
- **Result**
 - Only 87% accuracy falls on $\pm 0.5^{\circ}\text{C}$



Multiple Linear Regression

- **Equation:**

$$\beta_0 out^3 + \beta_1 out^2 + \beta_2 out^1 + \beta_3 in^2 + \beta_4 in^1 + \beta_5 = \text{Estimated Temperature}$$

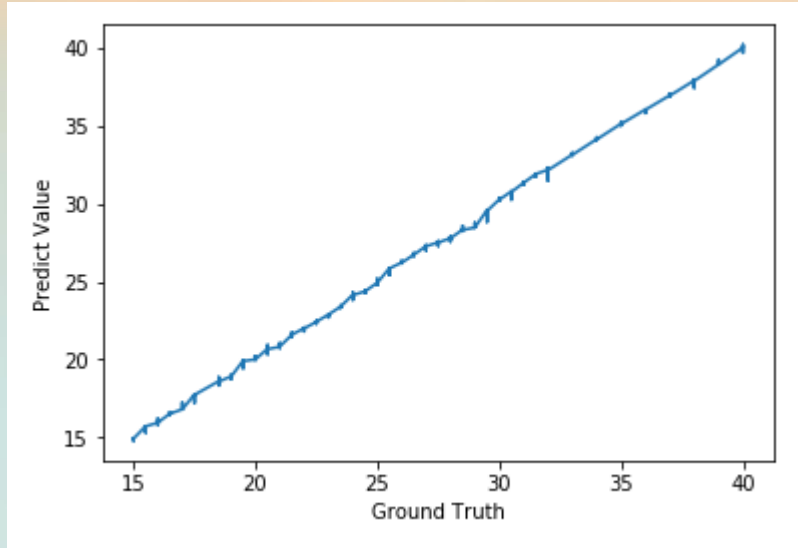
- **Using minimum mean square error to train weights**

$$L = \sum_{i=1}^n \varepsilon_i^2 = \varepsilon' \varepsilon = (y - X\beta)'(y - X\beta)$$
$$\frac{\partial L}{\partial \beta} = 0 \Rightarrow X'X \hat{\beta} = X'y$$

L: square error
y: true temperature
 β : weight
X: input data matrix

Multiple Linear Regression

- **Result**
 - 97.48% accuracy falls on $\pm 0.5^{\circ}\text{C}$





Demo Video

Demo Video(open the link at picture)

The logo for the Synopsis ARC Design Contest is centered on a black rectangular background. The word "SYNOPSIS" is written in a large, bold, purple sans-serif font. A vertical orange bar separates "SYNOPSIS" from "ARC". The word "ARC" is in a smaller, blue sans-serif font. Below "ARC", the words "DESIGN CONTEST" are written in an orange sans-serif font.

SYNOPSIS | **ARC**
DESIGN CONTEST



Conclusion

Conclusion

- **An accurate calibration method is proposed**
 - multiple linear regression
- **Improve the accuracy from 1°C to 0.5°C**



Thank you