ITP272 SENSOR TECHNOLOGIES AND PROJECT
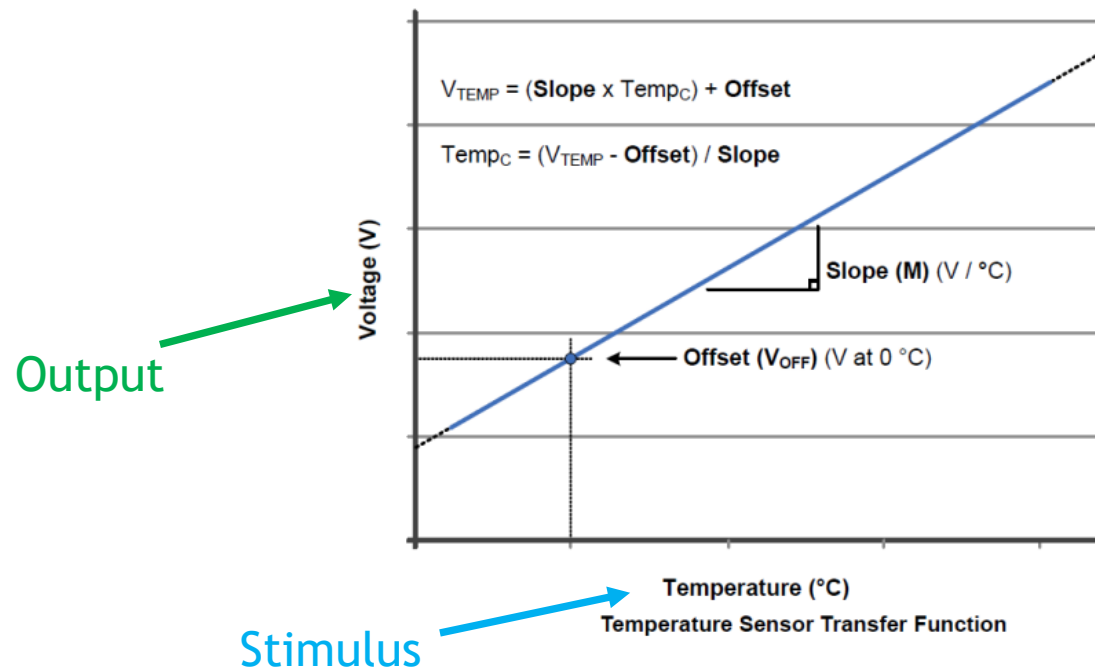
L02: Sensor Fundamentals

SENSOR CHARACTERISTICS

- How do we know whether one sensor performs better than the other?

- When we receive an electrical signal from a sensor, how do we know what it meant?

- How do we know the operating range of a sensor?

- How do we know which sensor is more accurate?

- Designers analyse <u>sensor characteristics</u> listed on datasheet to select sensors
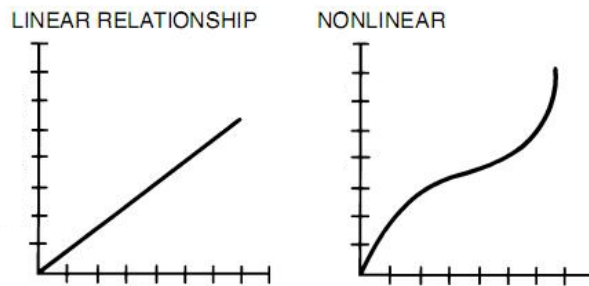
TRANSFER FUNCTION

Transfer Function

- An ideal (theoretical) output–stimulus relationship is characterized by the so-called transfer function

V_{TEMP} = (**Slope** x $Temp_C$) + **Offset**

$Temp_C$ = (V_{TEMP} - **Offset**) / **Slope**

Slope (M) (V / °C)

Offset (V_{OFF}) (V at 0 °C)

Voltage (V)

Output

Temperature (°C)
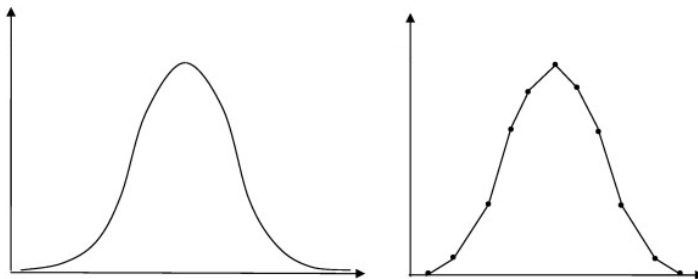**Temperature Sensor Transfer Function**

Stimulus

TRANSFER FUNCTION

Transfer Function

- Maybe linear or non-linear

- Nonlinear transfer function may be modelled by several straight lines. This is called a piecewise approximation

FULL-SCALE INPUT AND OUTPUT

Span (Full-Scale Input)

- It represents the highest possible input value that can be applied to the sensor <u>without</u> causing an unacceptably <u>large inaccuracy</u>

Example

- A sensor that detect distance (within acceptable accuracy) of range 25 m

- The FSI of this sensor is said to be 0 – 25 m

- Distance always starts from 0 but it may not be the case for temperature which may start from –ve value eg. -10°C

FULL-SCALE INPUT AND OUTPUT

% FSI

- Some of the characteristic is often given in terms of FSI % instead of the absolute terms. You need to be able to compute the actual values from the % given

Example

- For a temperature sensor with FSI -50°C to 100°C
  - Resolution or Accuracy of 2% is calculated as follows
  - FSI = -50°C to 100°C => 100% : 150°C
  - Thus 2% = 2/100 * 150 = 3°C

- For a distance sensor with FSI 50m (if not mentioned, distance always starts from 0 m)
  - Resolution or Accuracy of 2% is calculated as follows
  - FSI = 0 – 50 m => 100% : 50m
  - Thus 2% = 2/100 * 50 = 1m
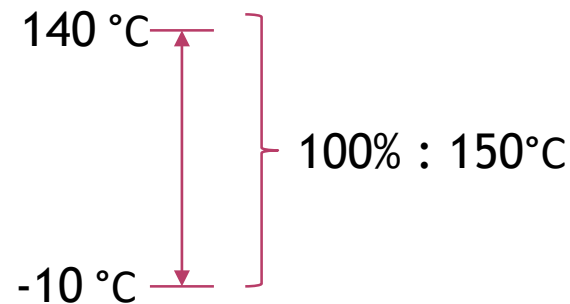
ACCURACY

Accuracy

- Accuracy is measured as a <u>highest deviation</u> of a value represented by the sensor <u>from the ideal</u> or true value at its input

- Can also be seen as <u>largest possible error</u> between actual and ideal output signals

- It may be expressed in terms of input stimulus in absolute figures or as a percentage of FSI

- Error may result reporting in excess or inadequacy

- The lower the %, the more accurate the sensor is

ACCURACY

Given a temperature sensor capable of measuring from -10°C to 140°C. If it reports a temperature of 37°C having accuracy of 1%, what might be the actual temperature?

- FSI = -10°C to 140°C => 100% : 150°C
- 1% of 150°C = 1.5°C
- Thus error is ±1.5°C
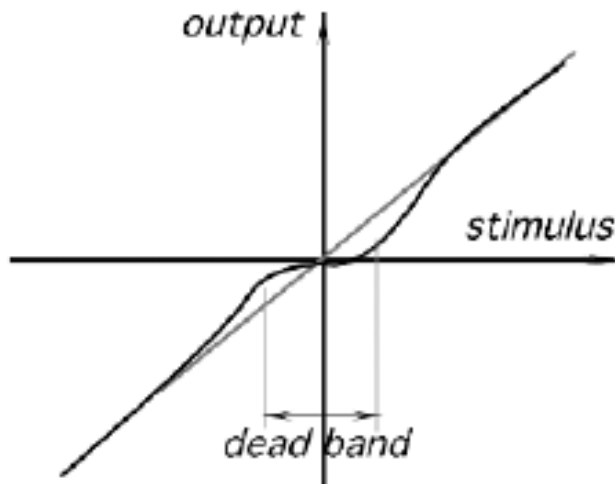- 37-1.5 = 35.5 °C
- 37+1.5 = 38.5 °C

140 °C ⌐
⎫
⎬ 100% : 150°C
⎭
-10 °C ⌐

- The actual temperature maybe in the range 35.5 – 38.5 °C

DEAD BAND

Dead Band

- It is the specific range of input where sensor is insensitive

- The output may remain near a certain value (often zero) over an entire dead-band zone

DEAD BAND

Example

- An RFID reader may be detected card properly from range
  - 2 cm – 5 cm
  - 6 cm – 8 cm

- The dead band is then
  - 0 cm – 2cm
  - 5 cm – 6 cm

- So for this RFID reader, card place at a distance in the dead band will not be detected at all

SENSOR RESOLUTION

Resolution

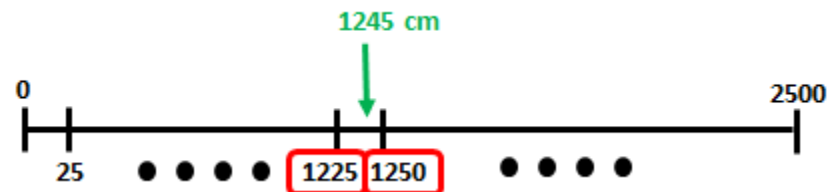- It is the <u>smallest increments</u> of stimulus which can be sensed by the sensor
- It may be expressed in terms of input stimulus in absolute figures or as a percentage of FSI.
- The lower the FSI % resolution, the more sensitive the sensor

Example

- A sensor may sense a distance of up to 5m => FSI = 500 cm
- It may report distance in increments of 20 cm.
- Absolute resolution = 20 cm
- FSI % resolution = 20 / 500 = 4% of FSI

SENSOR RESOLUTION

Given a distance sensor which detects a range up to 25m and has a resolution of 1% FSI. An object is 1245 cm away. What are the <u>possible distances</u> reported by the sensor? You can assume there is no error.

- FSI = 25 m or 2500 cm

- Resolution : 1% of FSI = 1 / 100 * 2500 = 25 cm

- So sensor will report a distance of <u>1225</u> cm or <u>1250</u> cm!

  - Actual distance divide by resolution : 1245 / 25 = 49.8

  - Get nearest <u>2</u> integers to 49.8 => 49 and 50

  - Multiply back resolution

    - 49 * 25 = <u>1225</u> cm,   50 * 25 = <u>1250</u> cm

REVIEW QUESTIONS

REVIEW QUESTION
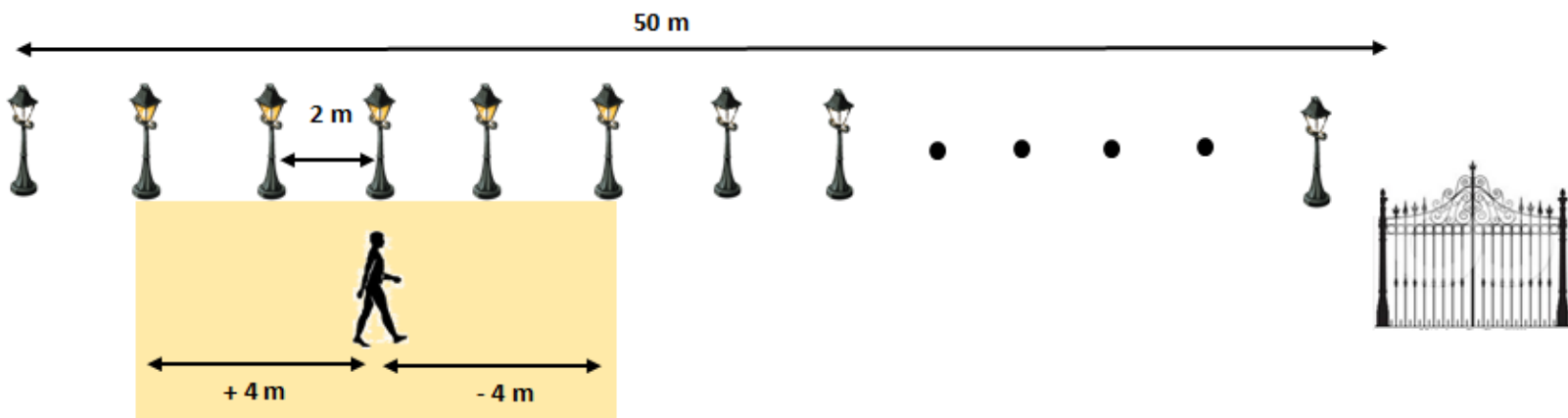
You are required to select a <u>sensor</u> for a system. It detects person approaching from a distance and turn on the nearby lamp posts. The <u>furthest lamp post is 50 m</u> away and <u>every lamp post is 2m</u> apart. In order not to turn on too many lamp posts, the sensor should report <u>distance within a 4 m tolerance</u> .

(a) List down the sensor characteristic specifications

REVIEW QUESTION

(b) You are given sensors with the below characteristics.

Select a suitable sensor for this.

- ⦿ Compute all absolute values for the sensor characteristics
- ⦿ Justify how the selected sensor meets all requirements
- ⦿ List down why other sensors are not suitable

	Sensor A	Sensor B	Sensor C	Sensor D
FSI	50 m	60 m	70 m	80 m
Accuracy	10 %	5 %	5%	5%
Dead Band	None	0 – 1 m	52 – 55m	60 -75 m
Resolution	4 % FSI	2 % FSI	2.5 % FSI	6.25% FSI

ANSWER

(a) List down the sensor characteristic specifications

- Furthest lamp post is 50 m
  - FSI : 0 – 50 m minimum

- No mention of area within FSI that can be ignored
  - Dead Band allowed is > 50 m (beyond FSI)

- Every lamp post is 2m
  - Resolution must be ≤ 2m

- Report distance within a 4 m tolerance
  - Accuracy must be ≤ ±4 m

ANSWER

	Sensor A
FSI	50 m
Accuracy	10 %
Dead Band	None
Resolution	4 % FSI

Sensor A

- ◉ Accuracy
  - ▪ 10% : 10/100 * 50 m = **5 m**
- ◉ Resolution
  - ▪ 4% FSI : 4 / 100 * 50 m = **2 m**

	Specs	Sensor A	
FSI	Min 50 m	50 m	✔
Accuracy	≤ 4 m	5 m	✘
Dead Band	Allowed > 50 m	None	✔
Resolution	≤ 2 m	2 m	✔

Sensor A is not suitable as it **cannot report distance within 4 m tolerance**

ANSWER

	Sensor B
FSI	60 m
Accuracy	5 %
Dead Band	0 - 1 m
Resolution	2 % FSI

Sensor B

- Accuracy
  - 5% : 5/100 * 60 m = **3 m**
- Resolution
  - 2% FSI : 2 / 100 * 60 m = **1.2 m**

	Specs	Sensor B	
FSI	Min 50 m	60 m	✔
Accuracy	≤ 4 m	3 m	✔
Dead Band	Allowed > 50 m	0 – 1 m	✘
Resolution	≤ 2 m	1.2 m	✔

Sensor B is not suitable as **lamp post will be off when person within 0 – 1 m**

ANSWER

	Sensor C
FSI	70 m
Accuracy	5%
Dead Band	52 - 55m
Resolution	2.5 % FSI

Sensor C

- Accuracy
  - 5% : 5/100 * 70 m = **3.5 m**

- Resolution
  - 2.5% FSI : 2.5 / 100 * 70 m = **1.75 m**

	Specs	Sensor C	
FSI	Min 50 m	70 m	✔
Accuracy	≤ 4 m	3.5 m	✔
Dead Band	Allowed > 50 m	52 – 55m	✔
Resolution	≤ 2 m	1.75 m	✔

Sensor C is selected because **all characteristics met** the requirement !

ANSWER

	Sensor D
FSI	80 m
Accuracy	5%
Dead Band	60 -75 m
Resolution	6.25% FSI

Sensor D

◉ Accuracy

- 5% : 5/100 * 80 m = **4 m**

◉ Resolution

- 6.25% FSI : 6.25 / 100 * 80 m = **5 m**

	Specs	Sensor D	
FSI	Min 50 m	80 m	✔
Accuracy	≤ 4 m	4 m	✔
Dead Band	Allowed > 50 m	60 -75 m	✔
Resolution	≤ 2 m	5 m	✘

Sensor D is not suitable as **its 5 m resolution exceed 1 lamp post distance**

REVIEW QUESTION

GeeGee Pte Ltd is developing a device that measures environment temperature with the following requirements.

- Allows maximum error of ±4 °C
- Able to report every 1°C of temperature changes
- Surrounding temperature ranges from -20°C to 120°C
- It is not critical to measure temperature between 40°Cto 70 °C

(a) List down the sensor characteristic specifications

REVIEW QUESTION

(b) You are given sensors with the below characteristics. Select a suitable sensor for this.

- Compute all absolute values for the sensor characteristics
- Justify how the selected sensor meets all requirements
- List down why other sensors are not suitable

	Sensor X	Sensor Y
FSI	-200°C to 200°C	-50°C to 150°C
Accuracy	0.5 %	1 %
Dead Band	None	50°C to 60°C
Resolution	1 %	0.5 %

ANSWER

(a) List down the sensor characteristic specifications

- ◉ Surrounding temperature ranges from -20°C to 120°C
  - ▪ FSI : -20°C to 120°C minimum

- ◉ Allows maximum error of ±4 °C
  - ▪ Accuracy must be ≤ ±4 °C

- ◉ Not critical to measure temperature between 40°C to 70 °C
  - ▪ Dead Band allowed is
    - ○ < -20°C   (Beyond FSI)
    - ○ 40°C to 70 °C
    - ○ > 120°C   (Beyond FSI)

- ◉ Report every 1°C of temperature changes
  - ▪ Resolution must be ≤ 1°C

ANSWER

	Sensor X
FSI	-200°C to 200°C
Accuracy	0.5 %
Dead Band	None
Resolution	1 %

100% FSI => 400 °C

0.5% FSI = ?

1% FSI = ?

Sensor X

- ⊙ Accuracy
  - ■ 0.5% FSI : 0.5/100 * 400 °C = 2 °C
- ⊙ Resolution
  - ■ 1% FSI   : 1 / 100 * 400 °C = 4 °C

	Specs	Sensor X	
FSI	-20°C to 120°C min	-200°C to 200°C	✔
Accuracy	≤ ±4 °C	± 2°C	✔
Dead Band	Allowed < 20°C, 40°C to 70°C, > 120°C	None	✔
Resolution	≤ 1 °C	4°C	✘

Sensor X is not suitable as it **cannot report every 1°C of temperature changes**

ANSWER

	Sensor Y
FSI	-50°C to 150°C
Accuracy	1 %
Dead Band	50°C to 60°C
Resolution	0.5 %

100% FSI => 200 °C

1 % FSI = ?

0.5 % FSI = ?

Sensor Y

- ◉ Accuracy
  - ▪ 1% FSI : 1/100 * 200 °C = 2 °C
- ◉ Resolution
  - ▪ 0.5% FSI : 0.5 / 100 * 200 °C = 1 °C

	Specs	Sensor Y	
FSI	-20°C to 120°C min	-50°C to 150°C	✔
Accuracy	≤ ±4 °C	± 2°C	✔
Dead Band	Allowed < 20°C, 40°C to 70°C, > 120°C	50°C to 60°C	✔
Resolution	≤ 1 °C	1°C	✔

Sensor Y is selected because **all characteristics met** the requirement !

REVIEW QUESTIONS

Given a distance sensor which detects a range up to 20m and has a resolution of 1% FSI. An object is 90 cm away. What are the <u>possible distances</u> reported by the sensor? You can assume there is no error.

- FSI = 0-20 m or 2000 cm
- Resolution : 1% of FSI = 1 / 100 * 2000 = 20 cm
  - Actual distance divide by resolution : 90 / 20 = 4.5
  - Get nearest <u>2</u> integer : 4.5 => 4 and 5
  - Multiply back resolution
    - 4 * 20 = <u>80</u> cm,   5 * 20 = <u>100</u>cm
- So sensor will report a distance of <u>80</u> cm or <u>100</u> cm!

STRUCTURED QUESTIONS

Wonder Sensor PTE LTD tasked you to select a ultrasonic <u>sensor</u> for their new smart monitoring system with the following requirements.

- Detects any person as far as 100 m away
- Updates real time display every 4 m changes in distance
- Turns on all spot light when the person is 20 m away. It does not need to monitor if person < 20 m away
- Allows a maximum error of ±1 m

(a) List down the sensor characteristic specifications.

STRUCTURED QUESTIONS

(b) You are given sensors with the below characteristics. Select a suitable sensor for this.

◉ Compute all absolute values for the sensor characteristics

◉ Justify how the selected sensor meets all requirements

◉ List down why other sensors are not suitable

	Sensor A	Sensor B	Sensor C	Sensor D
FSI	150 m	200 m	200 m	250 m
Accuracy	0.5 %	0.4 %	0.25%	0.5%
Dead Band	None	0 – 15 m	120 – 130 m	None
Resolution	5 % FSI	2 % FSI	2.5 % FSI	1% FSI