2 : ELEMEN DAN KARAKTERISTIK SENSOR

SISTEM PENGUKURAN

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ISI KULIAH

- Elemen Sensor
- Karakteristik Dasar
- Identifikasi Karakteristik Sensor

ELEMEN SENSOR



Elemen Sensor

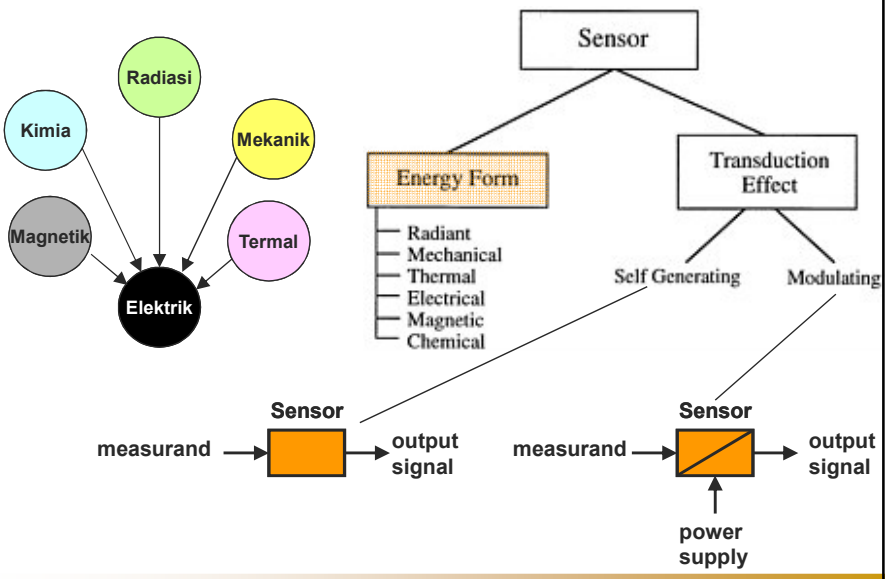
- **Domain elemen sensor**
  - material
  - energi

- **Material**
  - Silicon
  - Plastik
  - Metal
  - Keramik
  - Glass
  - Biological substance

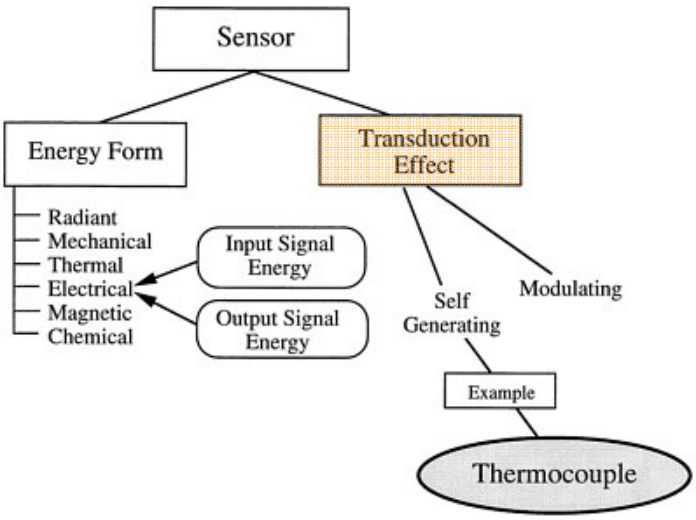
- **Energi**
  - Elektrik
  - Magnetik
  - Termal
  - Akustik
  - Optik

(lihat pembahasan prinsip transduksi)

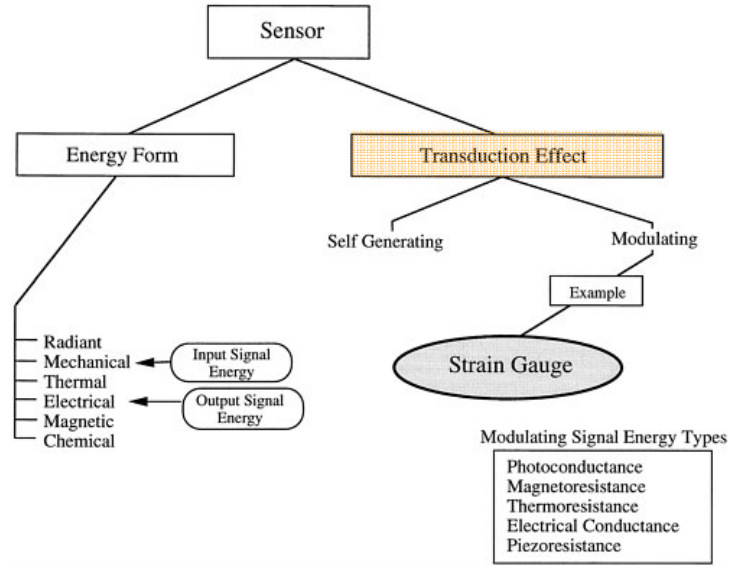
Stimulus



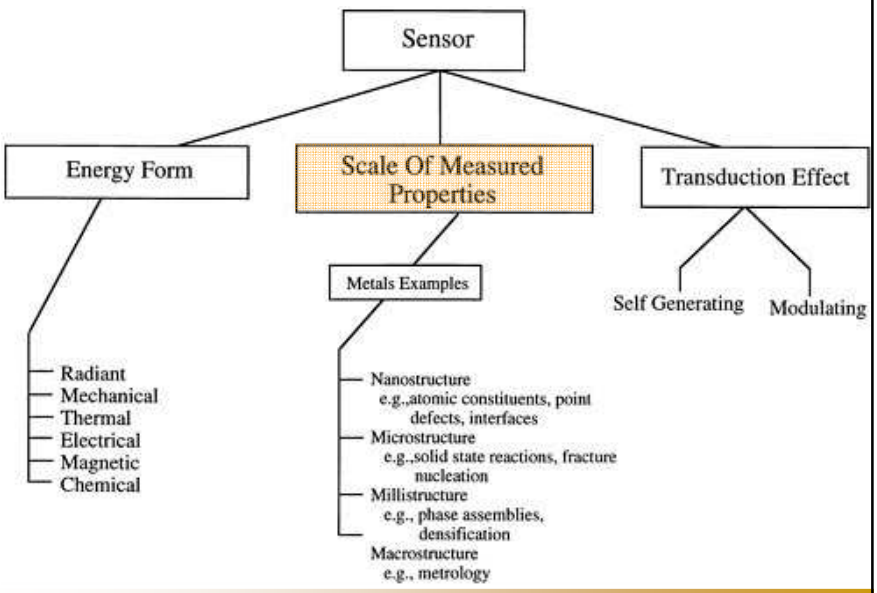
Transduction effect



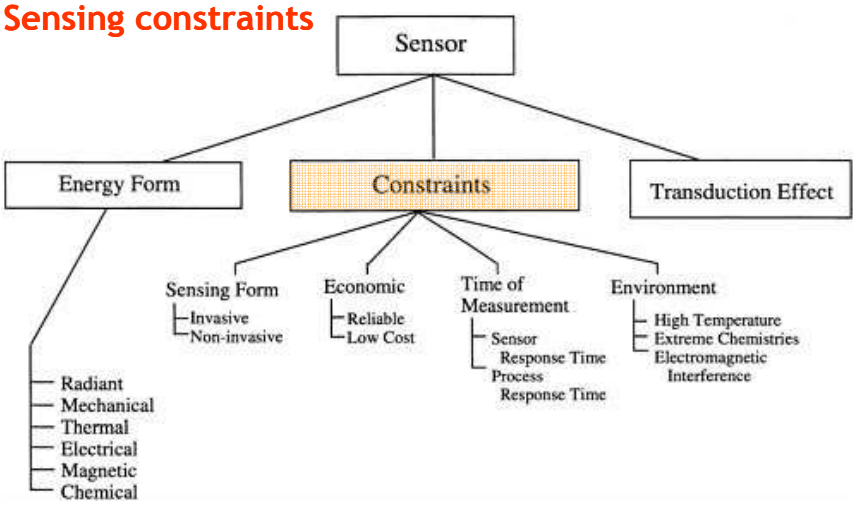
Transduction effect



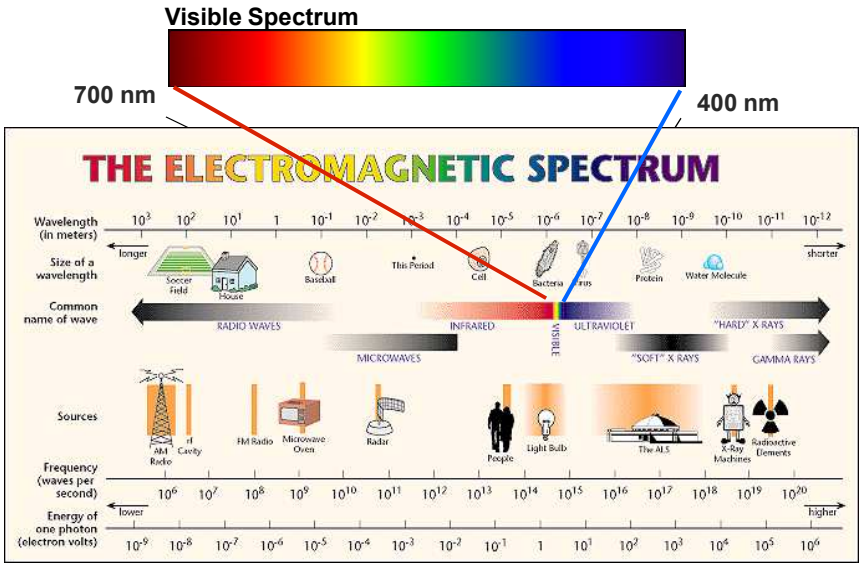
Scale of measurands



Sensing constraints



Radiant Sensors → Electromagnetic Spectrum

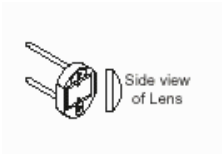


Radiant Sensors ➔ Electromagnetic Spectrum

Light Sensors
- Photodiodes
- Phototransistor
- Photoresistors
- Cooled Detectors
- Thermal Detectors
  - Golay Cells
  - Thermopile Sensors
  - Pyroelectric Sensors
  - Bolometers
  - Active Far-Infrared Sensors
  - Gas Flame Detectors



Radiation Sensors
- Scintillating Detectors
- Ionization Detectors
  - Ionization Chambers
  - Proportional Chambers
  - Geiger–Müller Counters
  - Semiconductor Detectors



Mechanical Sensors

Occupancy and Motion Detectors
- Ultrasonic Sensors
- Microwave Motion Detectors
- Capacitive Occupancy Detectors
- Triboelectric Detectors
- Optoelectronic Motion Detectors
  - Visible and Near-Infrared Light Motion Detectors & Far-IR Motion Detectors

Position, Displacement, and Level
- Potentiometric Sensors
- Gravitational Sensors
- Capacitive Sensors
- Inductive and Magnetic Sensors
  - LVDT and RVDT
  - Eddy Current Sensors & Transverse Inductive Sensor
  - Hall Effect Sensors & Magnetoresistive Sensors
- Optical Sensors
  - Optical Bridge & Proximity Detector with Polarized Light
  - Fiber-Optic Sensors & Fabry–Perot Sensors
  - Grating Sensors & Linear Optical Sensors (PSD)
- Ultrasonic Sensors
- Radar Sensors : Micropower Impulse Radar & Ground-Penetrating Radar
- Thickness and Level Sensors : Ablation & Thin-Film & Liquid-Level Sensors

Mechanical Sensors

Velocity and Acceleration
- Capacitive Accelerometers
- Piezoresistive Accelerometers
- Piezoelectric Accelerometers
- Thermal Accelerometers
  - Heated-Plate Accelerometer
  - Heated-Gas Accelerometer
- Gyroscopes
  - Rotor Gyroscope
  - Monolithic Silicon Gyroscopes
  - Optical Gyroscopes

Pressure Sensors
- Mercury Pressure Sensor
- Piezoresistive Sensors
- Capacitive Sensors .
- VRP Sensors
- Optoelectronic Sensors
- Vacuum Sensors
  - Pirani Gauge
  - Ionization Gauges
  - Gas Drag Gauge

Force, Strain, and Tactile Sensors
- Strain Gauges
- Tactile Sensors .
- Piezoelectric Force Sensors

Mechanical Sensors

Flow Sensors
- Thermal Transport Sensors
- Ultrasonic Sensors
- Electromagnetic Sensors
- Microflow Sensors
- Breeze Sensor
- Coriolis Mass Flow Sensors
- Drag Force Flow Sensors

Acoustic Sensors
- Resistive Microphones
- Condenser Microphones
- Fiber-Optic Microphone
- Piezoelectric Microphones
- Electret Microphones
- Solid-State Acoustic Detectors

Temperature Sensors

- Thermoresistive Sensors
  - Resistance Temperature
  - Silicon Resistive Sensors
  - Thermistors
    - NTC Thermistors
    - Self-Heating Effect in NTC Thermistors
    - PTC Thermistors
- Thermoelectric Contact Sensors
- Semiconductor P-N Junction Sensors
- Optical Temperature Sensors
  - Fluoroptic Sensors
  - Interferometric Sensors
  - Thermochromic Solution Sensor
- Acoustic Temperature Sensor
- Piezoelectric Temperature Sensors

Magnetic Sensors

Direct Sensors
- Metal-Oxide Chemical Sensors
- ChemFET
- Electrochemical Sensors
- Potentiometric Sensors
- Conductometric Sensors
- Amperometric Sensors
- Enhanced Catalytic Gas Sensors
- Elastomer Chemiresistors

Complex Sensors
- Thermal Sensors
- Pellister Catalytic Sensors
- Optical Chemical Sensors
- Mass Detector
- Biochemical Sensors
- Enzyme Sensors

Humidity and Moisture Sensors
- Capacitive Sensors
- Electrical Conductivity Sensors
- Thermal Conductivity Sensor
- Optical Hygrometer
- Oscillating Hygrometer

Chemical Sensors

Direct Sensors
- Metal-Oxide Chemical Sensors
- ChemFET
- Electrochemical Sensors
- Potentiometric Sensors
- Conductometric Sensors
- Amperometric Sensors
- Enhanced Catalytic Gas Sensors
- Elastomer Chemiresistors

Complex Sensors
- Thermal Sensors
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Humidity and Moisture Sensors
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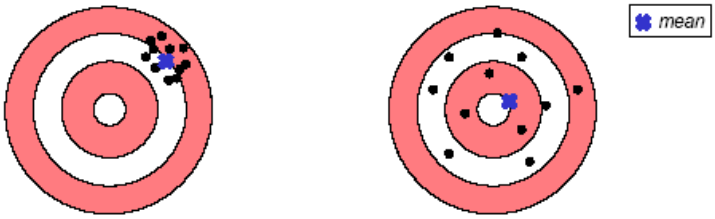
KARAKTERISTIK SENSOR



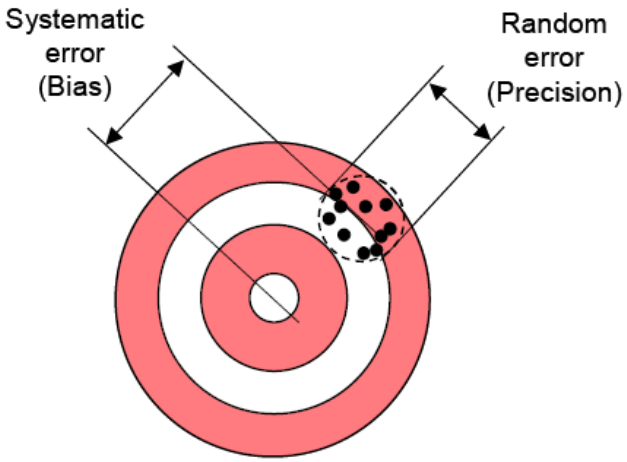
- Karakteristik **STATIK**
- Karakteristik **DINAMIK**

Karakteristik : Pendahuluan

- **Shooting darts**
  - Discrimination
    - The size of the hole produced by a dart
  - Which shooter is more accurate?
  - Which shooter is more precise?



Contoh : Kesalahan sistematik dan random



Karakteristik Sensor

- **Static characteristics**
  - The properties of the system after all transient effects have settled to their final or steady state
    - **Accuracy**
    - **Discrimination**
    - **Precision**
    - Errors
    - Drift
    - Sensitivity
    - Linearity
    - Hystheresis (backslash)
- **Dynamic characteristics**
  - The properties of the system transient response to an input
    - Zero order systems
    - First order systems
    - Second order systems

Akurasi, Diskriminasi dan Presisi

- **Accuracy is the capacity of a measuring instrument to give RESULTS close to the TRUE VALUE of the measured quantity**
  - Accuracy is related to the bias of a set of measurements
  - (IN)Accuracy is measured by the absolute and relative errors

$$\text{ABSOLUTE ERROR} = \text{RESULT} - \text{TRUE VALUE}$$

$$\text{RELATIVE ERROR} = \frac{\text{ABSOLUTE ERROR}}{\text{TRUE VALUE}}$$

    - More on errors in a later slide
- **Discrimination is the minimal change of the input necessary to produce a detectable change at the output**
  - Discrimination is also known as RESOLUTION
  - When the increment is from zero, it is called THRESHOLD

Presisi

- **The capacity of a measuring instrument to give the same reading when repetitively measuring the same quantity under the same prescribed conditions**
  - Precision implies agreement between successive readings, NOT closeness to the true value
    - Precision is related to the variance of a set of measurements
  - Precision is a necessary but not sufficient condition for accuracy
- **Two terms closely related to precision**
  - Repeatability
    - The precision of a set of measurements taken over a short time interval
  - Reproducibility
    - The precision of a set of measurements BUT
      - taken over a long time interval or
      - Performed by different operators or
      - with different instruments or
      - in different laboratories

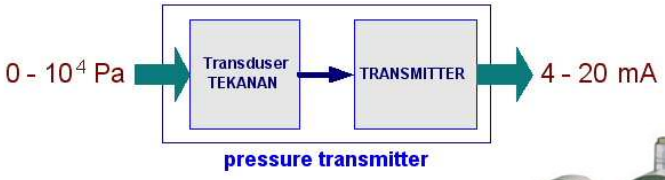
Akurasi dan Errror

- **Systematic errors**
  - Result from a variety of factors
    - Interfering or modifying variables (i.e., temperature)
    - Drift (i.e., changes in chemical structure or mechanical stresses)
    - The measurement process changes the measurand (i.e., loading errors)
    - The transmission process changes the signal (i.e., attenuation)
    - Human observers (i.e., parallax errors)
  - Systematic errors can be corrected with COMPENSATION methods (i.e., feedback, filtering)
- **Random errors**
  - Also called NOISE: a signal that carries no information
  - True random errors (white noise) follow a Gaussian distribution
  - Sources of randomness:
    - Repeatability of the measurand itself (i.e., height of a rough surface)
    - Environmental noise (i.e., background noise picked by a microphone)
    - Transmission noise (i.e., 60Hz hum)
  - Signal to noise ratio (SNR) should be >>1
    - With knowledge of the signal characteristics it may be possible to interpret a signal with a low SNR (i.e., understanding speech in a loud environment)

Rentang Input & Output

RANGE

- **Input Range**
  - Rentang nilai antara input minimum dan input maksimum
  - Misal : Input range suatu transduser tekanan **0 s/d 10^4 Pa**
- **Output Range**
  - Rentang nilai antara output minimum dan output maksimum
  - Misal : Output range suatu transmitter **4 s/d 20 mA**



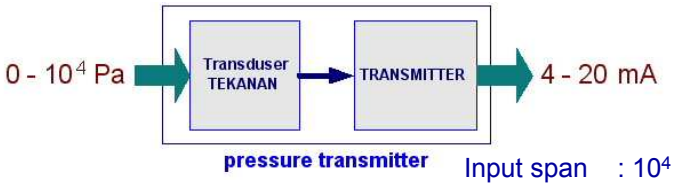


Input range : 0 s/d 10^4 Pa
Output range : 4 s/d 20 mA

Span

SPAN

- **Variasi maksimum input atau output suatu sistem pengukuran**
  - Input Span = $Input_{max} - Input_{min}$
  - Output Span = $Output_{max} - Output_{min}$
- **Contoh**
  - Suatu *Pressure Transmitter* memiliki span sebagai berikut
    - Input Span = 10^4 Pa
    - Output Span = 16 mA



Input span : 10^4 Pa
Output span : 16 mA

Linieritas

LINIERITAS

- **Suatu sistem dikatakan linier jika hubungan input dan output merupakan suatu garis lurus**
- Nilai output suatu sistem linier dinyatakan sbb

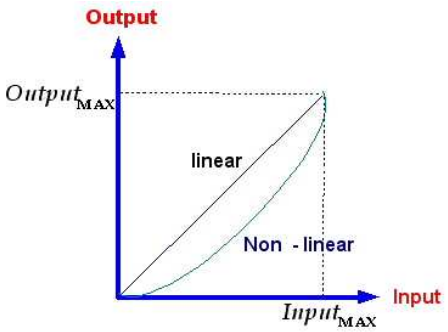
$$Output_{\text{ideal}} = K \times Input + a$$

$$K = \text{Kemiringan Garis Lurus} = \frac{Output_{\text{MAX}} - Output_{\text{MIN}}}{Input_{\text{MAX}} - Input_{\text{MIN}}}$$

Non-linieritas

NON-LINIERITAS

- **Suatu sistem dikatakan non-linier jika hubungan input dan output bukan merupakan suatu garis lurus**
- Contoh kurva **linier** dan **non-linier :**



Persamaan Output

- **Secara umum, *Output* suatu sistem merupakan fungsi *Input* dengan bentuk persamaan polinomial berikut**

$$Out(In) = a_0 + a_1 In + a_2 In^2 + \ldots + a_m In^m = \sum_{k=0}^{k=m} a_i In^k$$

Contoh

Tegangan keluaran suatu termokopel **copper-constantan** (type T), diekspresikan dengan persamaan polinom berikut,

$$E(T) = 38.74T + 3.319 \cdot 10^{-2} T^2 + 2.071 \cdot 10^{-4} T^3 + \ldots + f(T^4)$$

Untuk rentang 0 s/d 400 °C, tegangan keluaran $E(T{=}0) = 0$ µV & $E(T{=}400^{o}C) = 20869$ µV . Persamaan linier untuk rentang tsb,

$$E_{linear} = 52.17\,T$$

Kesalahan linierisasi adalah,

$$error(T) = -13.43T + 3.319 \cdot 10^{-2} T^2 + 2.071 \cdot 10^{-4} T^3 + \ldots + f(T^4)$$

Sensitivitas

SENSITIVITAS

- **Perbandingan perubahan keluaran sistem terhadap perubahan masukan sistem**

$$\text{Sensitivity} = \frac{d(Out)}{d(In)}$$

Contoh : Sensitivitas Termokopel Cooper - Constantant

$$\text{Sensitivity} = \frac{dE}{dT} = 38.74 + 6.638 \cdot 10^{-2} T + 6.213 \cdot 10^{-4} T^2 + \ldots..$$

Input Gangguan

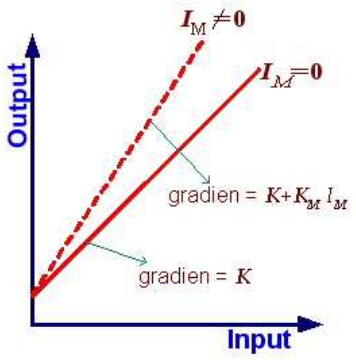
EFEK LINGKUNGAN (*environmental effect*)

- **Secara umum, output pengukuran tidak hanya fungsi input pengukuran, tetapi juga fungsi input lingkungan seperti temperatur lingkungan, tekanan atmosfir, kelembaban relatif, suplai tegangan dsb.**

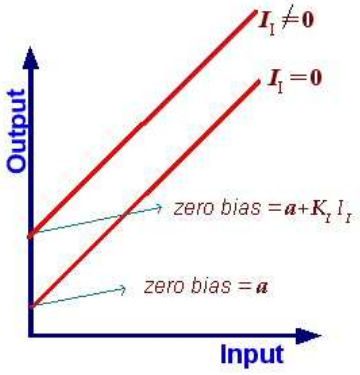
- **Terdapat 2 jenis input lingkungan**
  - **Modifying Input**
    - **Menyebabkan sensitivitas linier sistem pengukuran berubah**
  - **Interfering Input**
    - **Menyebabkan intersepsi atau *zero bias* sistem pengukuran berubah**

Input Gangguan

Efek lingkungan



Efek Modifying Input



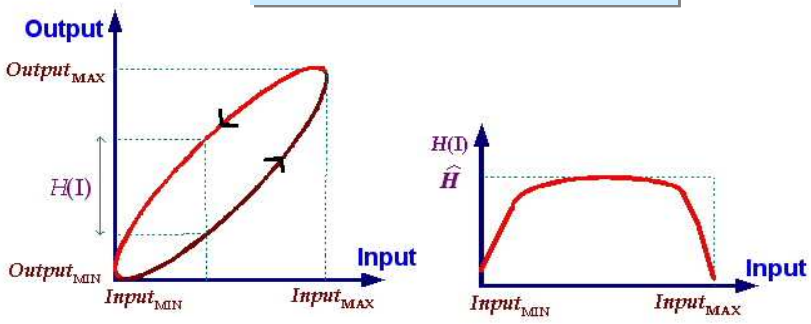
Efek Interfering Input

Histeresis

HYSTERESIS

- Histeresis adalah perbedaan nilai *Output* pengukuran pada saat nilai *Input* pengukuran membesar (naik) dan mengecil (turun).

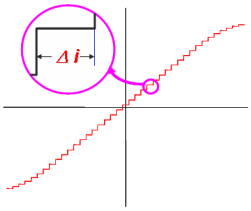
$$Hysteresis(I) = Out(In)_{\uparrow} - Out(In)_{\downarrow}$$

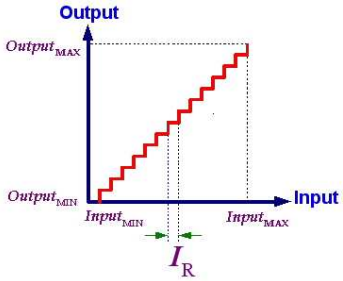


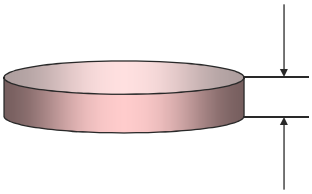
Resolusi

RESOLUSI

- Perubahan nilai terkecil *Input* pengukuran yang memberikan respon pada *Output* pengukuran







Hasil pengukuran:
- 4,235 mm
- 4,240 mm
- 4,236 mm
- 4,235 mm
- 4,237 mm

Resolusi ?

Aging

WEAR & AGING

- Efek ini mengakibatkan karakteristik sistem pengukuran seperti konstanta pengukuran ***K*** dan *zero bias* ***a*** berubah secara perlahan-lahan selama masa pakai



Kesalahan

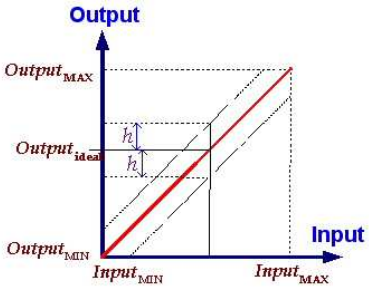
ERROR BANDS (pita *error*)

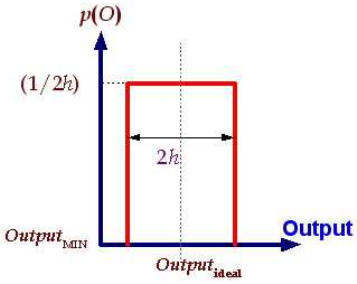
- Efek non-linieritas, histeresis dan resolusi, pada sistem pengukuran relatif sulit untuk dikuantifikasi secara tepat.
- Kinerja suatu sistem pengukuran dinyatakan dalam ***error bands***
- Kinerja sistem pengukuran dinyatakan dalam fungsi ***probability density*** *p*(*O*)

$$p(O)\begin{cases} = \dfrac{1}{2h} & Out_{ideal} - h \le Out \le Out_{ideal} + h \\ = 0 & 0 > Out_{ideal} + h \\ = 0 & Out_{ideal} - h > 0 \end{cases}$$

Kesalahan

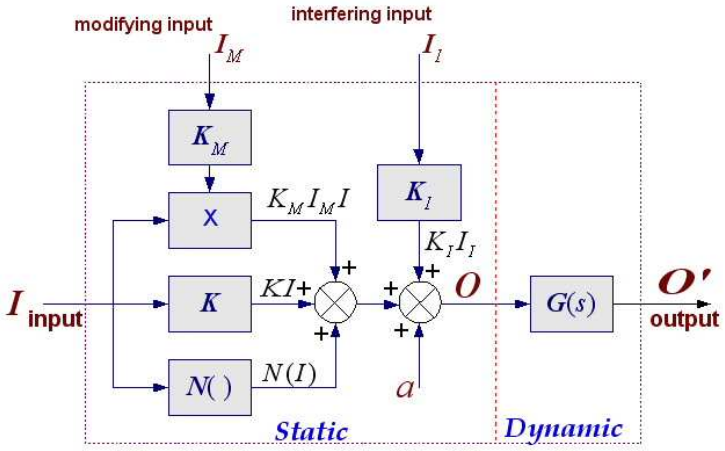
ERROR BANDS (pita *error*)

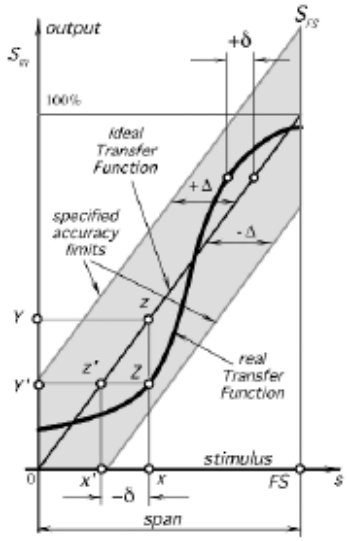


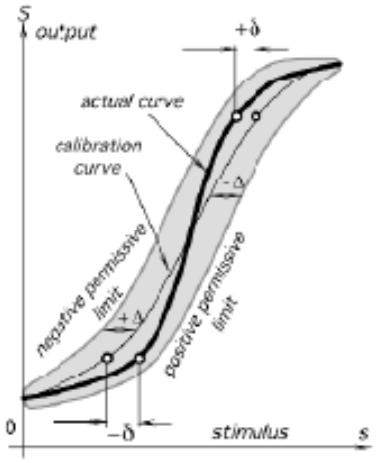


MODEL Umum Sensor

$$Out = K \cdot I + a + N(In) + K_M \cdot I_M \cdot I + K_I I_I$$




output
S_{FS}
S_o
+δ
100%
Ideal
Transfer
Function
+Δ
-Δ
specified
accuracy
limits
Y
Y'
z
z'
Z
real
Transfer
Function
stimulus
0
x'
x
−δ
FS
s
span


S
output
+δ
actual curve
calibration
curve
-Δ
negative permissive
limit
+Δ
positive permissive
limit
0
−δ
stimulus
s