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Sensors for the IoT

Different Types of Sensors

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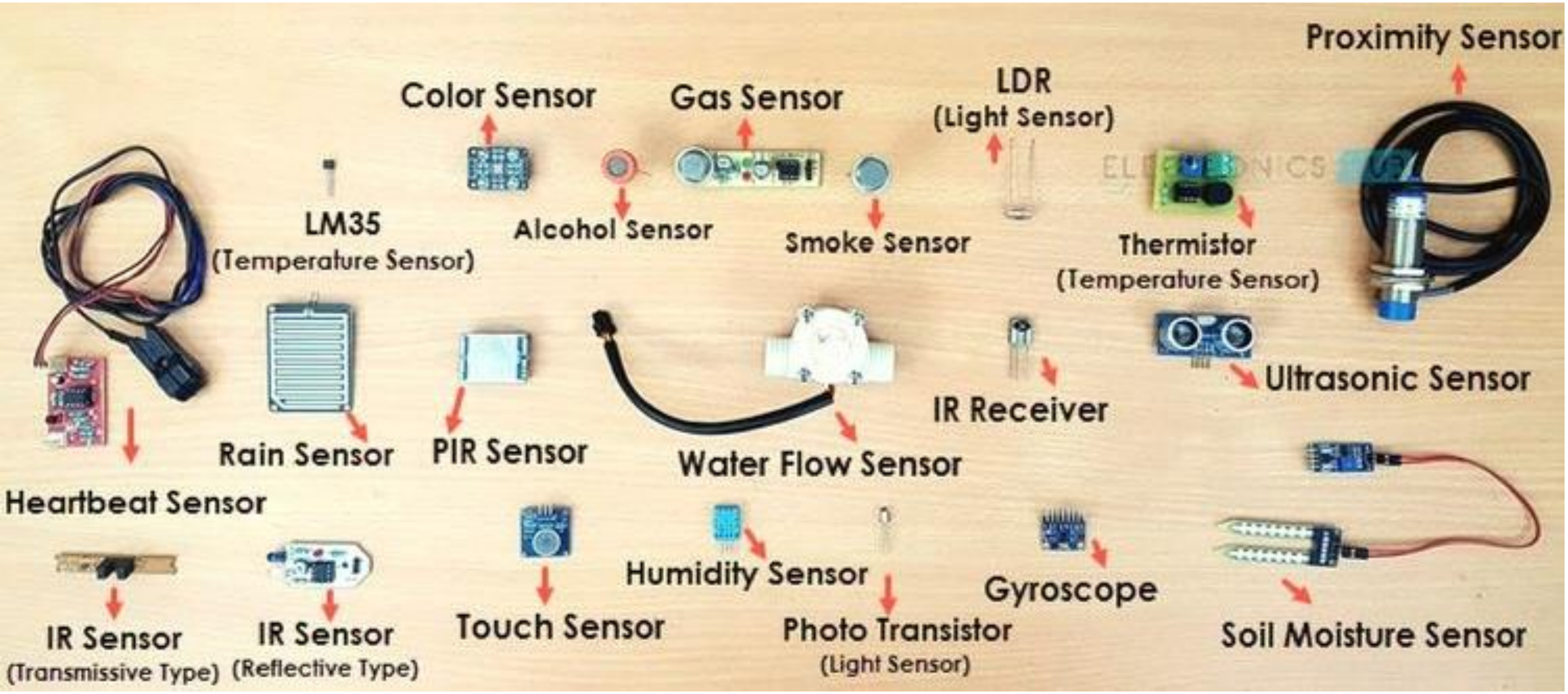

Different Detectable Phenomenon

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Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Starting Point of Sensor Selection

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- Purpose of the system
- Specifications of the systems/ Application→ technical/ observable and non-observable
- Observable specifications include the information regarding

1. **Inputs/ outputs-** their type, range, format, tolerance, accuracy etc.
2. **Interface requirements** esp. of importance in IoT
3. **Environment of deployment**
4. **Form-factor**, weight, etc.

Non-observable requirements include

1. Maintainability
2. Reliability
3. Portability

Factors/Parameters to be considered while choosing the right sensor

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1. **Measurand of the sensor**
   - what is the sensor expected to measure?
   - The primary or starting factor

2. **Range**- expected parameter ranges

3. **Resolution**- Granularity needed E.g. DS1620 → 0.5^{0}C resolution

4. **Accuracy**- different from resolution. Related to tolerance value

5. **Environmental conditions**- requires the grade of the sensor needed

Factors/Parameters to be considered while choosing the right sensor…

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6. **Repeatability**- How precise it is

7. **Form factor-size of the sensor**

E.g.: joint displacement sensors in robots

8. **Cost-**one of the most important consideration.

E.g.: GPS sensor on all WSN motes???

9. **Weight**

E.g. heavy sensor on robot's arms

10. **Control interface needed-** I2C, SPI, Serial

Factors/Parameters to be considered while choosing the right sensor…

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11. **Output type-** Analog/ Digital
Analog Sensors would require ADCs, additional h/w

11. **Composition of the target-** whether it is a metal or plastic or liquid

12. **Sensitivity-** how the o/p changes with i/p
Highly sensitive sensor- large fluctuations with small inputs →sensitive to noise also!

13. **Response time-** time required to observe a change corresponding to a given input

14. **Reliability-** Measured in terms of probability of a failure

Full scale and span of the sensor

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Full Scale Input or Range of a sensor indicate the limits between which the input can vary.

Eg: TI-LMT84-Q1 Temperature Sensor –40°C to+150°C

Span

Difference between the maximum and minimum values of the input.

Accuracy Evaluation for sensor

Maximum difference between the actual (true) value and the measured value by the sensor.

$$Absolute\ Error = |Measured\ value - True\ value|$$
$$\Rightarrow E_a = |X_m - X_t|$$

Agreement between measured signal & true value

$$Relative\ error = \frac{Absolute\ error}{True\ value}$$
$$\Rightarrow E_r = \frac{|X_m - X_t|}{X_t}$$

Accuracy can be expressed either as a percentage of full scale or as absolute value.

Accuracy example

Example 1: ADT75 :Temperature Sensor

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
TEMPERATURE SENSOR AND ADC					
Accuracy at V_{DD} = 2.7 V to 5.5 V			±1	°C	T_A = 0°C to +70°C
			±2	°C	T_A = −25°C to +100°C
			±3	°C	T_A = −55°C to +100°C
Accuracy at V_{DD} = 2.7 V to 3.6 V			±3	°C	T_A = 100°C to 125°C
Accuracy at V_{DD} = 4.5 V to 5.5 V		±2		°C	T_A = 100°C to 125°C

Example 2: Pressure Sensor

Range of Pressure sensor is 1 KPa -100 MPa.

If accuracy is ±1% full scale,
then the reading given can be expected to be within ± 1 MPa.

Precision

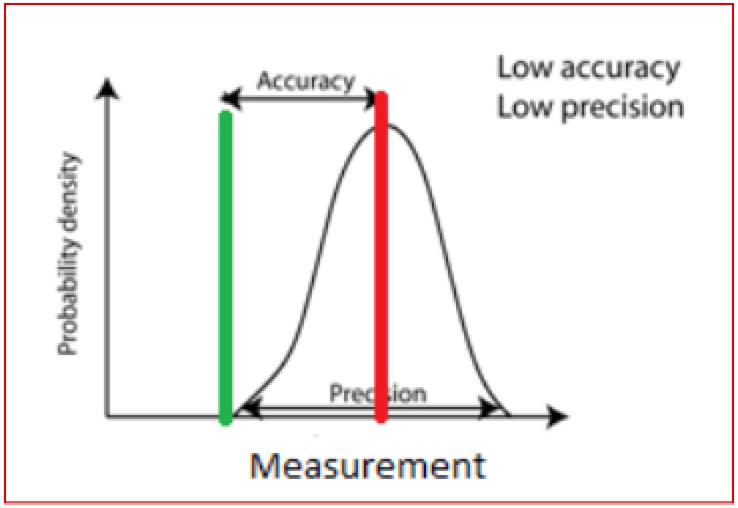
- Precision, refers to the degree of *reproducibility* of a measurement.

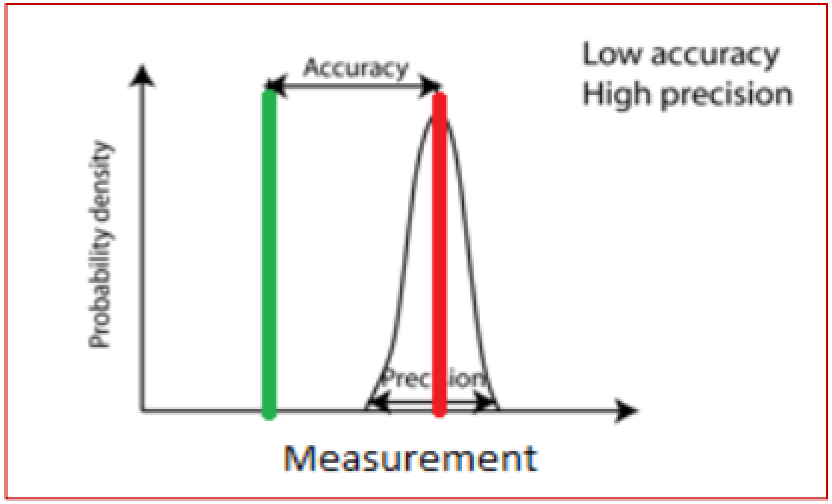
- If measurement is repeated number of times, an ideal sensor would output exactly the same value every time under the same measurement conditions.

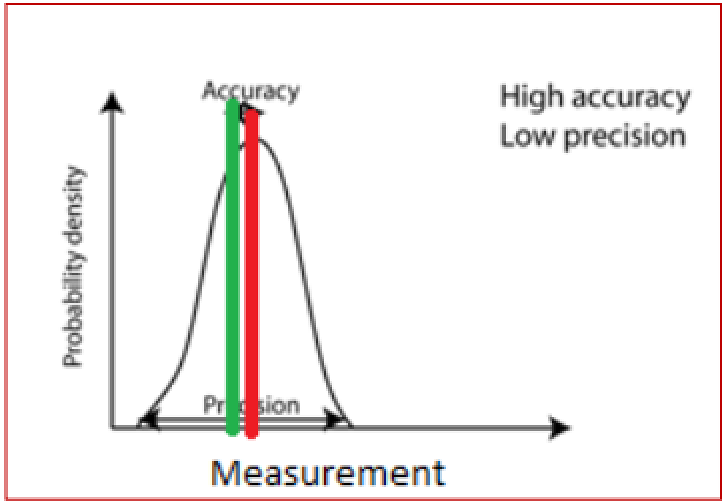
- Precision implies agreement between successive readings, NOT closeness to the true value

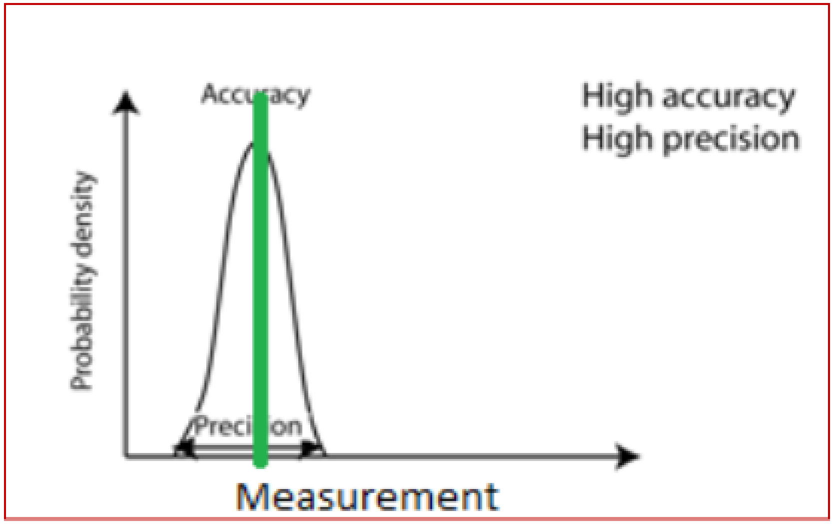
Accurate= Correct
Precise= Consistent

Accuracy vs Precision









Transfer function

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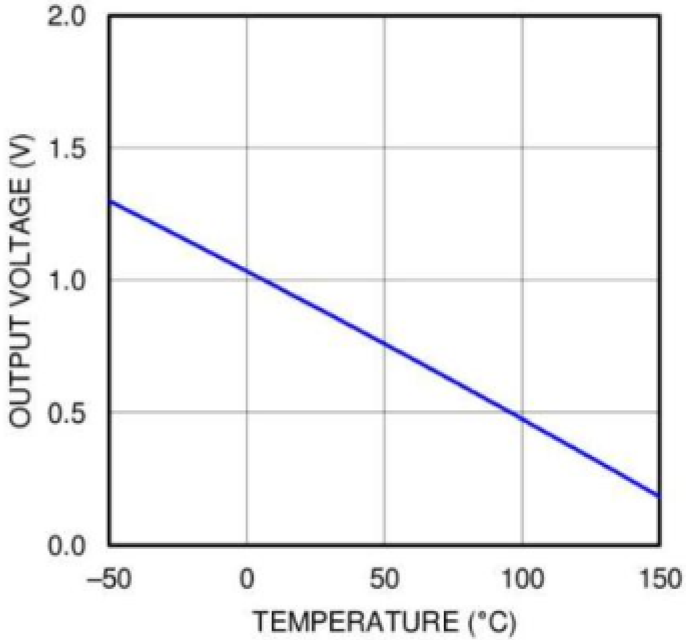
The transfer function is the functional relationship between physical input signal and electrical output signal.



Output characteristics of TI-LMT84-Q1
Temperature Sensor
Automotive Grade –40°C to+150°C

$$V = (-5.50\ \mathrm{mV} / {}^{o}\mathrm{C}) \times T + 1035\ \mathrm{mV}$$

Logarithmic function:

$$S = a + b \ln s.$$

Exponential function:

$$S = ae^{ks}.$$

Power function:

$$S = a_0 + a_1 s^k,$$

where k is a constant number.

Output electrical signal (S)
Input Signal or Stimulus (s)

Transfer function

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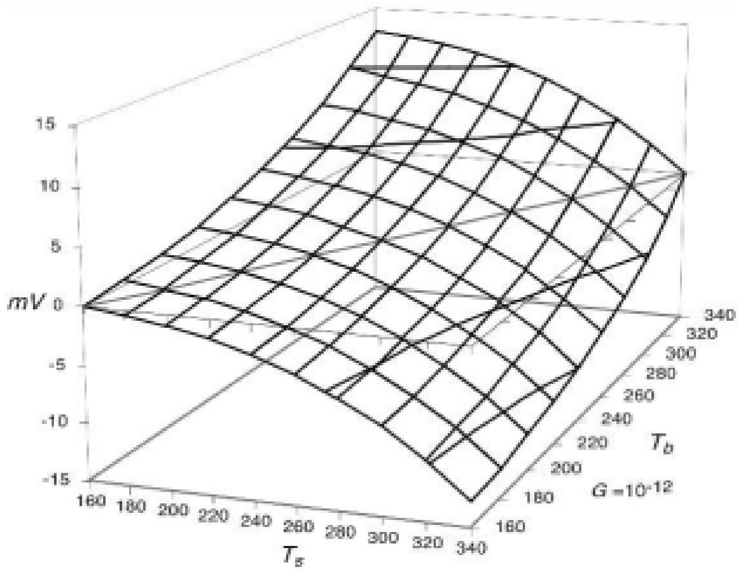
- A transfer function may have more than one dimension, when the sensor's output is influenced by more than one input stimuli.

- Example - Transfer function of a thermal radiation (infrared) sensor.

$$V = G(T_b^4 - T_s^4)$$

- *Tb*- the absolute temperature of the object of measurement, *Ts*-the absolute temperature of the sensor's surface, *V* is the output voltage.



Plot of two-dimensional transfer function of a thermal radiation sensor.

Sensitivity

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- The ratio between a small change in electrical signal to a small change in physical signal.

$$S = a + bs \quad \Longrightarrow \quad V = (-5.50 \text{ mV} / {}^{o}\text{C}) \times T + 1035 \text{ mV}$$

“High sensitivity” if a small input change results in a large output change.

$$V = G(T_b^4 - T_s^4)$$

Sensititivity = $\dfrac{\partial V}{\partial T_b}$

Saturation

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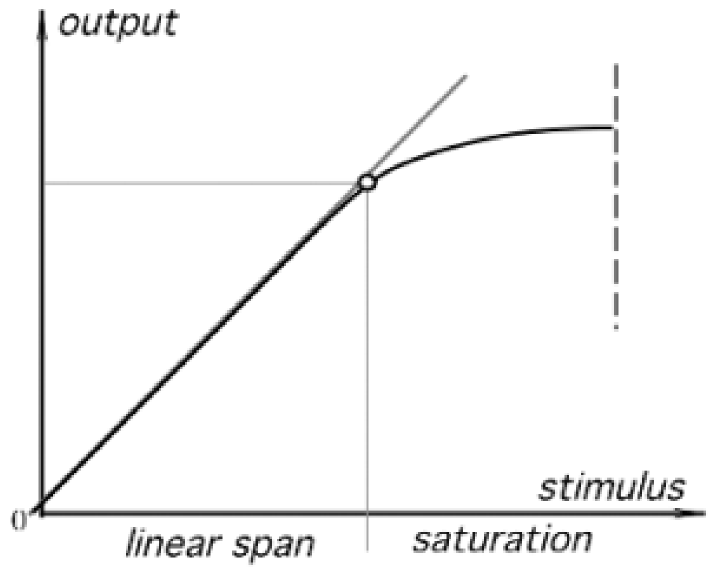
- Every sensor has its operating limits.
- Even if it is considered linear, at some levels of the input stimuli, its output signal no longer will be responsive.
- When a further increase in stimulus may not produce a desirable output, the sensor is said to have reached a span-end nonlinearity or saturation.



Deadband and Selectivity

Deadband : Range of input signal over which the sensor may be insensitive.

Selectivity: is the sensors ability to measure a targeted measurand in the presence of other interferences.

Eg: an oxygen gas sensor that does not show any response to other gases, such as carbon dioxide or nitrogen oxide, can be considered a selective sensor.

Case study: Weather Monitoring System (WMS)

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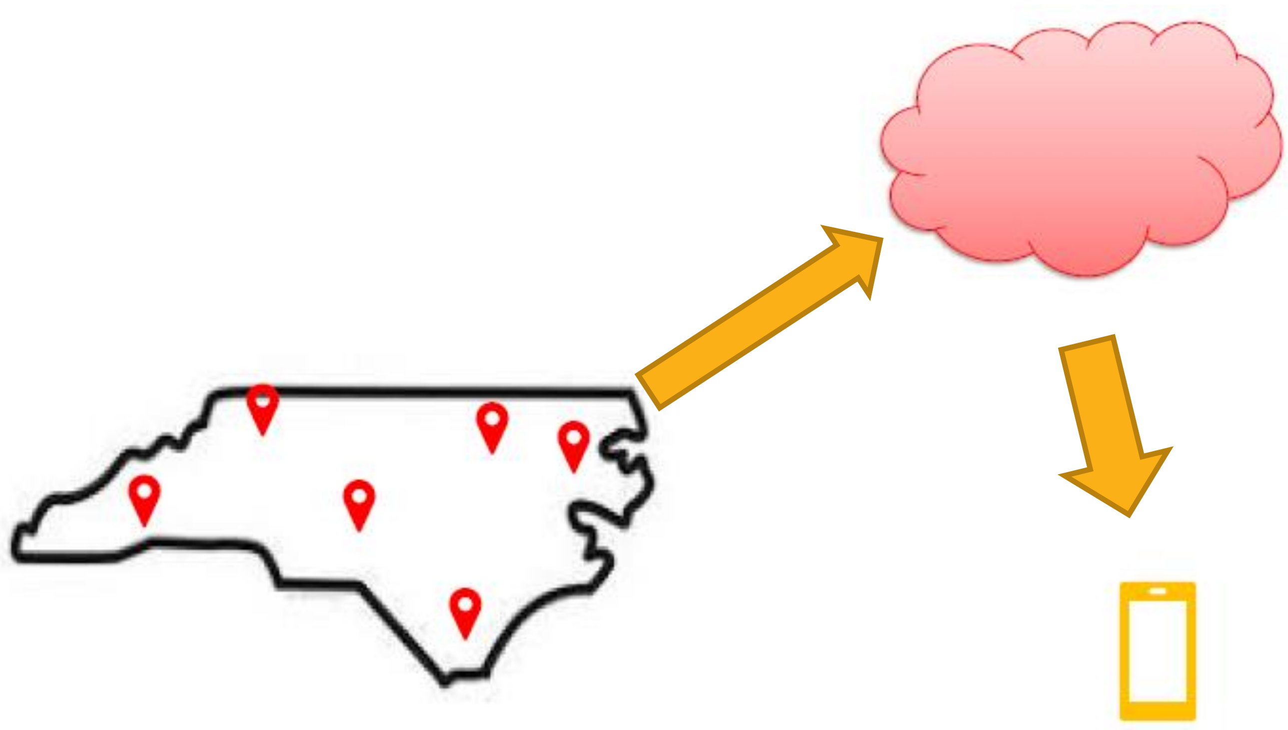

Sensors on the Sensor Node of WMS

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- Temperature
- Barometric Pressure
- Rainfall
- Relative Humidity
- Solar Radiation
- Wind Speed & Direction

Sensor requirements for WMS

1. Depends on the geographic location
2. Rugged
3. Must keep in mind the power source available
4. Budget and pricing
5. Interfacing microcontroller’s capabilities and limitations

Temperature Sensor

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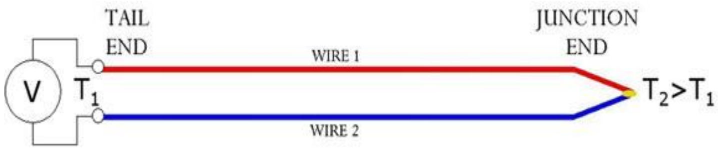
Wide variety of sensors and different characteristics

1. **Thermocouples:** Based on Seebeck effect.

Has a Junction end of dissimilar metals

Voltage diff measured at Tail end related to Temp

- Large Temp range
- Inexpensive
- Requires amplification, filtering, cold-jn compen.



2. **RTD (resistance temperature detectors)**

Uses metals like Pt. Resistance changes with temp

- Highly accurate. Highly linear
- Requires current excitation, amplification

3. **Thermistor**

Similar to RTD. But are non linear.

- Highly sensitive to slight change in temp.
- Often used where high resolution is required over a narrow temp range

Eg: Medical devices

Temperature Sensor

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4. Semiconductor:

E.g.: LM35- Analog Sensor

Wide range- -55^{0}C to 125 ^{0}C

Linear + 10-mV/°C Scale Factor

0.5°C Ensured Accuracy

DS1620-Digital Temp Sensor

Wide Range-55°C to +125°C

User-defined Nonvolatile Thermostatic Settings

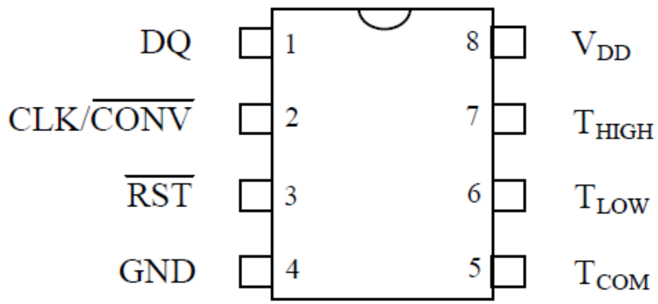
Data is Read From/Written Via a 3-Wire Serial Interface (CLK, DQ, RST)

Supply Voltage Range Covers From 2.7V to 5.5V

In steps of 0.5°C resolution

No ADC required

Fast conv time750ms



DS1620 8-Pin DIP (300-mil)

1. Temperature

- **Requirements for WMS:**
- -40^0C to 55^0C
- Rugged
- Accuracy of 0.1^0C would suffice
- High precision

Temperature sensors of some commercial WMS

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Model	Global Water WE700	Omega WMS25	Vaisala HMP155
Type	Precision RTD		Precision RTD
Output	4-20 mA		0 to 1 V, 0 to 5 V, 0 to 10 V
Range	-50 to +50°C (-58 to +122°F)	-26 to 70°C (-15 to 158°F)	-80 to +60 °C (-112 to+140 °F)
Accuracy	±0.2°F or ±0.1°C	±0.5°C (±1°F) typical	±0.25°C
Operating Voltage	10-36 VDC	10-30 VDC	7 ... 28 VDC Min i/p 12V for 5V o/p and 16V for 10V o/p
Warm up time	3 seconds (min)	50 seconds (response time)	60 seconds
Current Draw	Same as sensor output		

2. Humidity Sensor

- **Requirements for WMS:**
- 0 to 100% RH
- Rugged
- Accuracy of ±1%
- High precision

Humidity sensors of some commercial WMS

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Model	**Global Water WE600**	**Omega WMS25**	**Vaisala HMP155**
Type	Capacitance		
Output	4-20 mA		0 ... 1 V, 0 ... 5 V, 0 ... 10 V
Range	0 to 100% RH	3% to 100%	0 to 100% RH
Accuracy	±2%RH	±3% typical	±1%RH
Operating Voltage	10-36 VDC (-40to 55^{0}C)	10-30 VDC (-40to 60^{0}C) @ 20mA	7 ... 28 VDC 12V for 5V o/p 16V for 10V o/p
Warm up time	3 seconds	25 seconds (response time)	About 60 sec
Current Draw	Same as sensor output		Less than 4mA

3. Barometer Pressure

- Measured in atmospheres or mbar
- 1 atm=1013.25mbar
- Varies with altitude
- **Requirements for WMS:**
- Rugged
- Variation of the pressure- highest on earth is 1050mbar (Siberian High) and lowest 870mbar (in the middle of tornadoes)
- 800-1100mbar is sufficient range
- Accuracy of ±1%
- High precision

Barometric Pressure sensors of some commercial WMS

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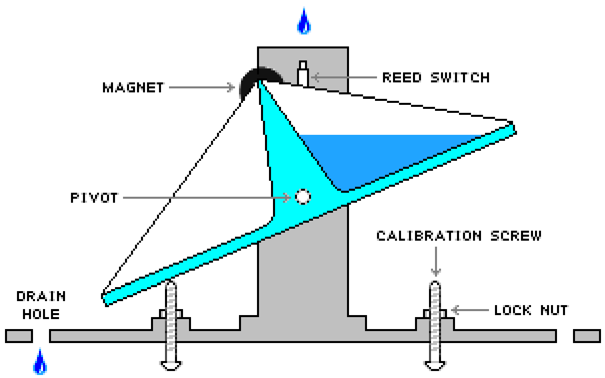
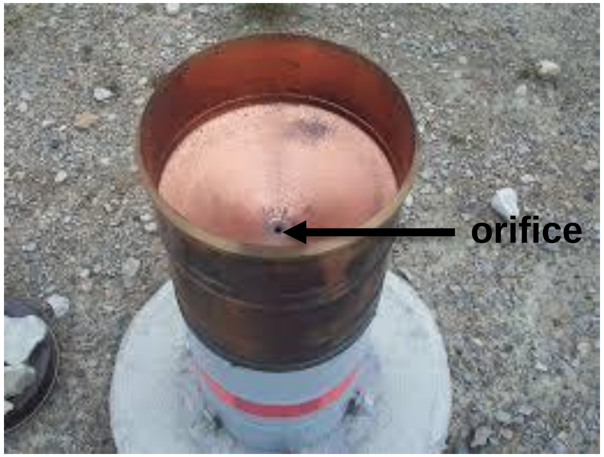
Model	Global Water WE100B	Omega WMS25	Vaisala PTB110
Type	Capacitance		
Output	4-20 mA		0 … 2.5 or 0 … 5 VDC
Range	800 to 1100 mbar	500 to 1100 mbar	500 to 1100 mbar
Accuracy	±1% of full scale ~3mbar	±0.3 mbar ~0.1% of full scale	±0.25 mb~0.1% of full scale (at 20^0C) Repeatability -±0.03 mbar
Operating Voltage	10-36 VDC (-40to 55^0C)	10-30 VDC (-40to 60^0C) @ 20mA	10-30 VDC (-40to 60^0C)
Warm up time	3 seconds (min)	25 seconds (response time)	
Current Draw	Same as sensor output		Less than 4mA

4. Rainfall

1. Rain gauge is used
2. Typically consists of tipping bucket
3. Switch closure for specified amount of rainfall



Tipping bucket



Circuitry

Interior of tipping bucket

fulcrum

Water collected here

Rain Gauge of some commercial WMS

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Model	Global Water RG600	Omega WMS25	Vaisala QMR101
Type	Reed Switch		
Output	4-20 mA		0 … 2.5 or 0 … 5 VDC
Accuracy	±1% at < 2" per hour	±2% at < 2" per hour	<0.94 inch/h < ± 5 % < 4.72inch/h < ± 10%
Resolution	0.01 inches	0.01 inch/tip	2mm~0.78 inch
Operating Voltage	10-36 VDC (-40to 55^{0}C)	10-30 VDC (-40to 60^{0}C) @ 20mA	10-30 VDC (-40to 60^{0}C)
Response time	135ms switch closure time	< 0.1 sec switch closure	
Current Draw	Same as sensor output		Less than 4mA