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Sensing

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Definition

- ✓ A sensor detects (senses) changes in the ambient conditions or in the state of another device or a system, and forwards or processes this information in a certain manner [1].

"A device which detects or measures a physical property and records, indicates, or otherwise responds to it" [2].

- Oxford Dictionary

References:

1. http://www.businessdictionary.com/definition/sensor.html
2. https://en.oxforddictionaries.com/definition/sensor

Sensors

- ✓ They perform some input functions by sensing or feeling the physical changes in characteristics of a system in response to a stimuli.
- ✓ For example heat is converted to electrical signals in a temperature sensor, or atmospheric pressure is converted to electrical signals in a barometer.

Transducers

- Transducers convert or transduce energy of one kind into another.
- For example, in a sound system, a microphone (input device) converts sound waves into electrical signals for an amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves.

Sensor vs. Transducer

✓ The word "Transducer" is the collective term used for both **Sensors** which can be used to sense a wide range of different energy forms such as movement, electrical signals, radiant energy, thermal or magnetic energy etc., and **Actuators** which can be used to switch voltages or currents [1].

References:
1. http://www.electronics-tutorials.ws/io/io_1.html

Sensor Features

- ✓ It is only <u>sensitive to the measured property</u> (e.g., A temperature sensor senses the ambient temperature of a room.)
- ✓ It is insensitive to any other property likely to be encountered in its application (e.g., A temperature sensor does not bother about light or pressure while sensing the temperature.)
- ✓ It does not influence the measured property (e.g., measuring the temperature does not reduce or increase the temperature).

Sensor Resolution

- ✓ The <u>resolution</u> of a sensor is the smallest change it can detect in the quantity that it is measuring.
- ✓ The resolution of a sensor with a digital output is usually the smallest resolution the digital output it is capable of processing.
- ✓ The more is the resolution of a sensor, the more accurate is its precision.
- ✓ A sensor's accuracy does not depend upon its resolution.

Sensor Classes

- **Based on Output**
  - Analog
  - Digital
- **Based on Data type**
  - Scalar
  - Vector/ Multimedia

Analog Sensors

- ✓ **Analog Sensors** produce a continuous output signal or voltage which is generally proportional to the quantity being measured.
- ✓ Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc. are all analog quantities as they tend to be continuous in nature.
- ✓ For example, the temperature of a liquid can be measured using a thermometer or thermocouple (e.g. in geysers) which continuously responds to temperature changes as the liquid is heated up or cooled down.

Digital Sensors

- ✓ **Digital Sensors** produce discrete digital output signals or voltages that are a digital representation of the quantity being measured.
- ✓ Digital sensors produce a binary output signal in the form of a logic "1" or a logic "0", ("ON" or "OFF").
- ✓ Digital signal only produces discrete (non-continuous) values, which may be output as a single "bit" (<u>serial transmission</u>), or by combining the bits to produce a single "byte" output (<u>parallel transmission</u>).

Scalar Sensors

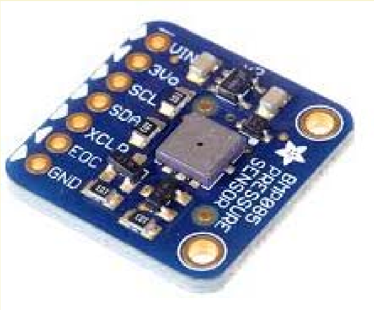
- ✓ **Scalar Sensors** produce output signal or voltage which is generally proportional to the magnitude of the quantity being measured.
- ✓ Physical quantities such as temperature, color, pressure, strain, etc. are all scalar quantities as only their magnitude is sufficient to convey an information.
- ✓ For example, the temperature of a room can be measured using a thermometer or thermocouple, which responds to temperature changes irrespective of the orientation of the sensor or its direction.

Vector Sensors

- ✓ **Vector Sensors** produce output signal or voltage which is generally proportional to the magnitude, direction, as well as the orientation of the quantity being measured.
- ✓ Physical quantities such as sound, image, velocity, acceleration, orientation, etc. are all vector quantities, as only their magnitude is not sufficient to convey the complete information.
- ✓ For example, the acceleration of a body can be measured using an accelerometer, which gives the components of acceleration of the body with respect to the x,y,z coordinate axes.

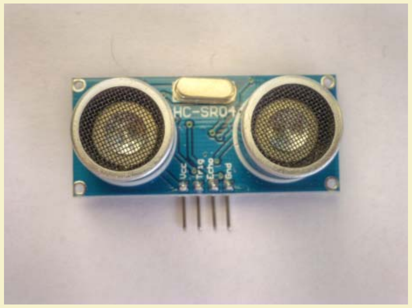
Sensor Types

Light	• Light Dependent resistor • Photo-diode
Temperature	• Thermocouple • Thermistor
Force	• Strain gauge • Pressure switch
Position	• Potentiometer, Encoders • Opto-coupler
Speed	• Reflective/ Opto-coupler • Doppler effect sensor
Sound	• Carbon Microphone • Piezoelectric Crystal
Chemical	• Liquid Chemical sensor • Gaseous chemical sensor



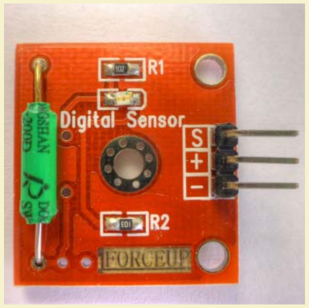
Pressure Sensor

Source: Wikimedia Commons



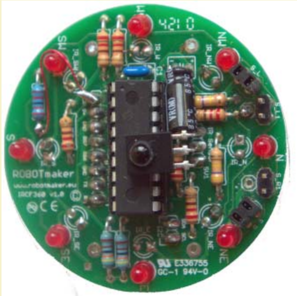
Ultrasonic Distance Sensor

Source: Wikimedia Commons



Tilt Sensor

Source: Wikimedia Commons

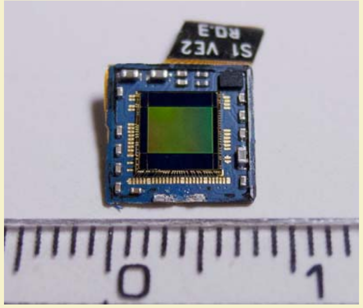


Infrared Motion Sensor

Source: Wikimedia Commons

Analog Temperature Sensor

Source: Wikimedia Commons



Camera Sensor

Source: Wikimedia Commons

Sensorial Deviations

- ✓ Since the range of the output signal is always limited, the output signal will eventually reach a minimum or maximum, when the measured property exceeds the limits. The full scale range of a sensor defines the maximum and minimum values of the measured property.
- ✓ The sensitivity of a sensor under real conditions may differ from the value specified. This is called a **sensitivity error**.
- ✓ If the output signal differs from the correct value by a constant, the sensor has an **offset error** or **bias**.

Reference: https://en.wikipedia.org/wiki/Sensor

Non-linearity

- ✓ Nonlinearity is deviation of a sensor's transfer function (TF) from a straight line transfer function.
- ✓ This is defined by the amount the output differs from ideal TF behavior over the full range of the sensor, which is denoted as the percentage of the full range.
- ✓ Most sensors have linear behavior.

Reference: https://en.wikipedia.org/wiki/Sensor

- ✓ If the output signal slowly changes independent of the measured property, this is defined as **drift**. Long term drift over months or years is caused by physical changes in the sensor.
- ✓ **Noise** is a random deviation of the signal that varies in time.

Reference: https://en.wikipedia.org/wiki/Sensor

Hysteresis Error

- ✓ A hysteresis error causes the sensor output value to vary depending on the sensor’s previous input values.
- ✓ If a sensor's output is different depending on whether a specific input value was reached by increasing or decreasing the input, then the sensor has a hysteresis error.
- ✓ The <u>present reading depends on the past input values</u>.
- ✓ Typically in analog sensors, magnetic sensors, heating of metal strips.

Reference: https://en.wikipedia.org/wiki/Sensor

Other Errors

- ✓ If the sensor has a digital output, the output is essentially an approximation of the measured property. This error is also called **quantization error**.
- ✓ If the signal is monitored digitally, the sampling frequency can cause a dynamic error, or if the input variable or added noise changes periodically at a frequency proportional to the multiple of the sampling rate, **aliasing errors** may occur.
- ✓ The sensor may to some extent be sensitive to properties other than the property being measured. For example, most sensors are influenced by the temperature of their environment.

Reference: https://en.wikipedia.org/wiki/Sensor

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Actuation

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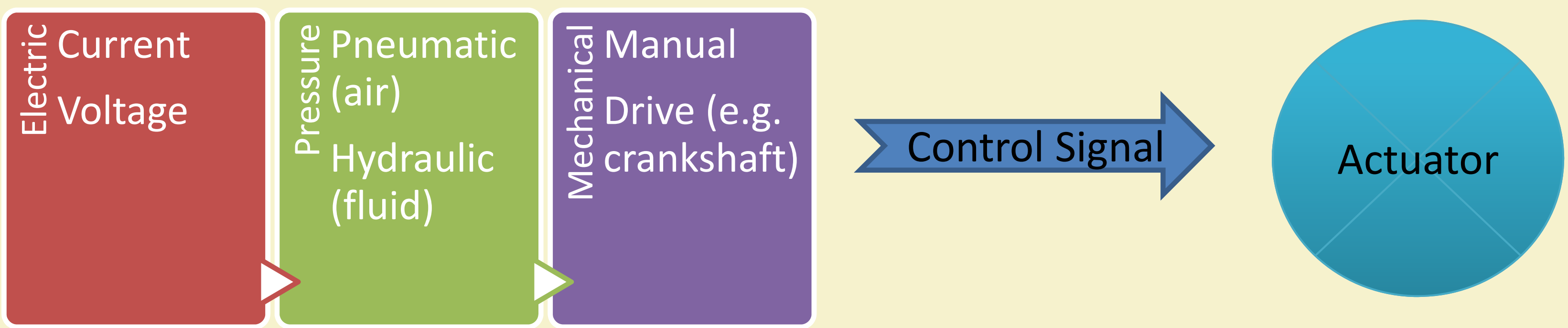
Actuator

- ✓ An actuator is a component of a machine or system that moves or controls the mechanism or the system.
- ✓ An actuator is the mechanism by which a control system acts upon an environment
- ✓ An actuator requires a control signal and a source of energy.

- ✓ Upon receiving a control signal is received, the actuator responds by converting the energy into mechanical motion.
- ✓ The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.



Actuator Types

- Hydraulic
- Pneumatic
- Electrical
- Thermal/ Magnetic
- Mechanical

Hydraulic Actuators

- ✓ A hydraulic actuator consists of a cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation.
- ✓ The mechanical motion is converted to linear, rotary or oscillatory motion.
- ✓ Since liquids are nearly impossible to compress, a hydraulic actuator exerts considerable force.
- ✓ The actuator's limited acceleration restricts its usage.

Reference: https://en.wikipedia.org/wiki/Actuator

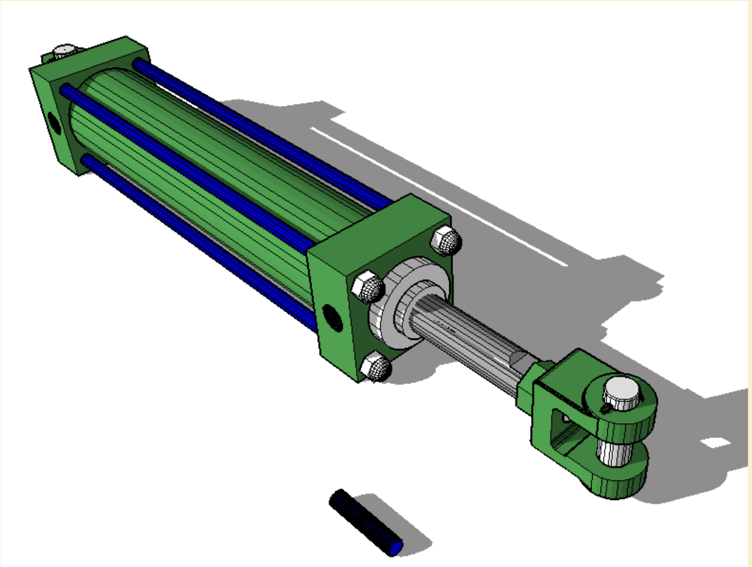


Fig: An oil based hydraulic actuator

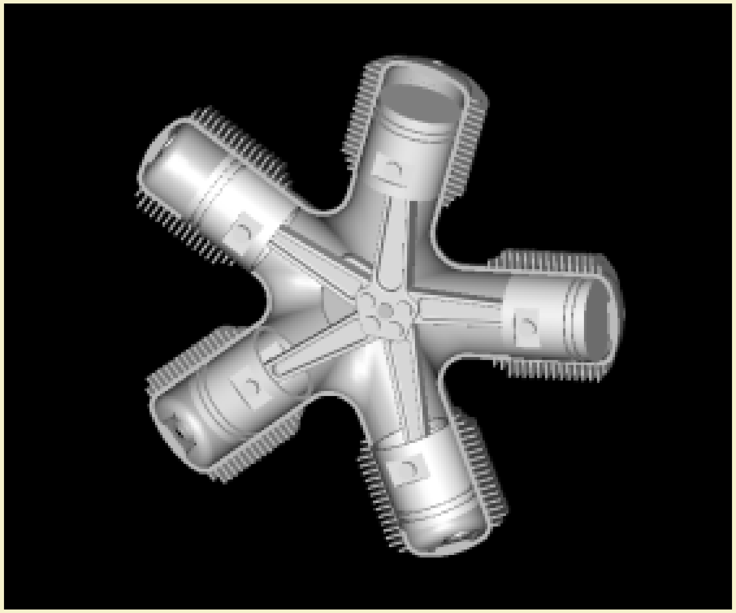


Fig: A radial engine acts as a hydraulic actuator

Source: Wikimedia Commons

File: Radial_engine.gif

Pneumatic Actuators

- ✓ A pneumatic actuator converts energy formed by vacuum or compressed air at high pressure into either linear or rotary motion.
- ✓ Pneumatic rack and pinion actuators are used for valve controls of water pipes.
- ✓ Pneumatic energy quickly responds to starting and stopping signals.
- ✓ The power source does not need to be stored in reserve for operation.

Reference: https://en.wikipedia.org/wiki/Actuator

- ✓ Pneumatic actuators enable large forces to be produced from relatively small pressure changes (e.g., Pneumatic brakes can are very responsive to small changes in pressure applied by the driver).
- ✓ It is responsible for converting pressure into force.

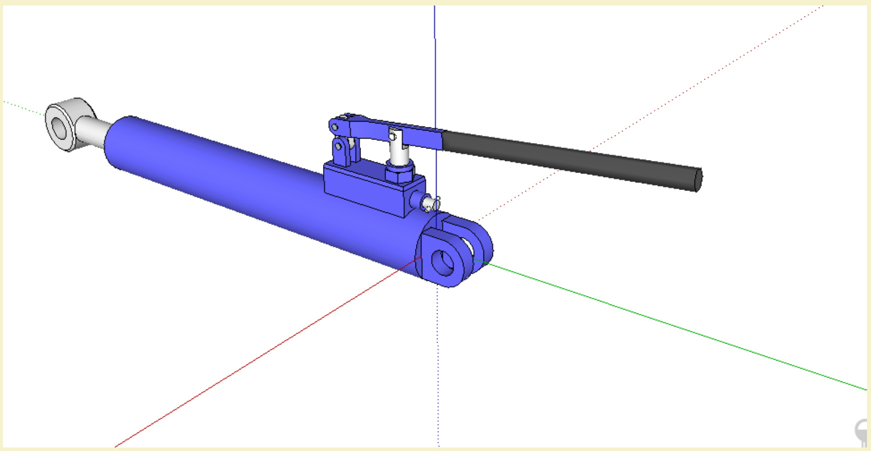


Fig: A manual linear pneumatic actuator

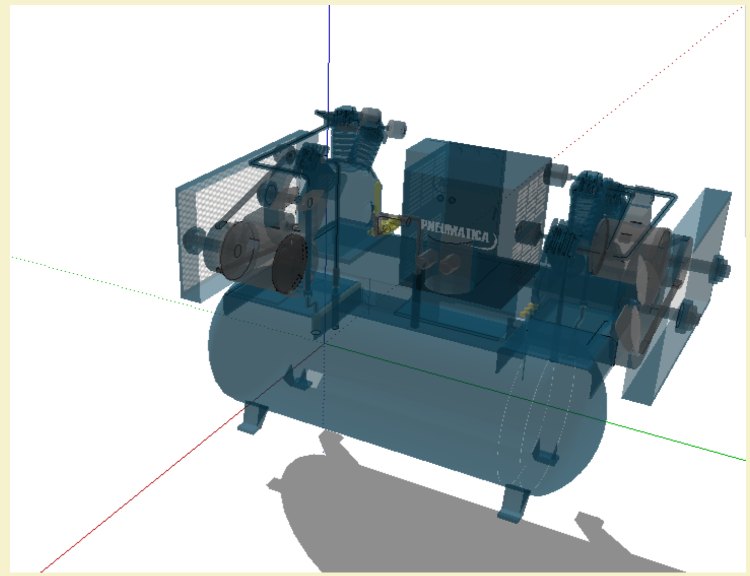


Fig: An air pump acts as a pneumatic actuator

Electric Actuators

- ✓ An electric actuator is generally powered by a motor that converts electrical energy into mechanical torque.
- ✓ The electrical energy is used to actuate equipment such as solenoid valves which control the flow of water in pipes in response to electrical signals.
- ✓ Considered as one of the cheapest, cleanest and speedy actuator types available.

Reference: https://en.wikipedia.org/wiki/Actuator

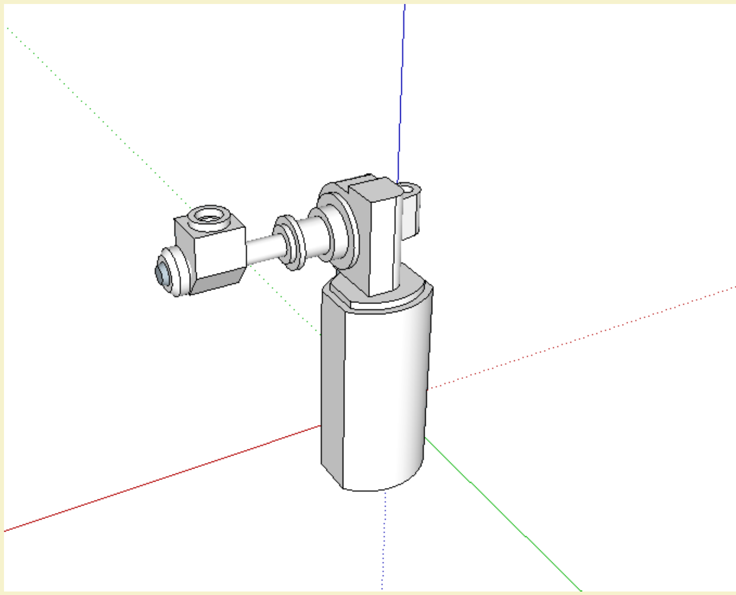


Fig: A motor drive-based rotary actuator

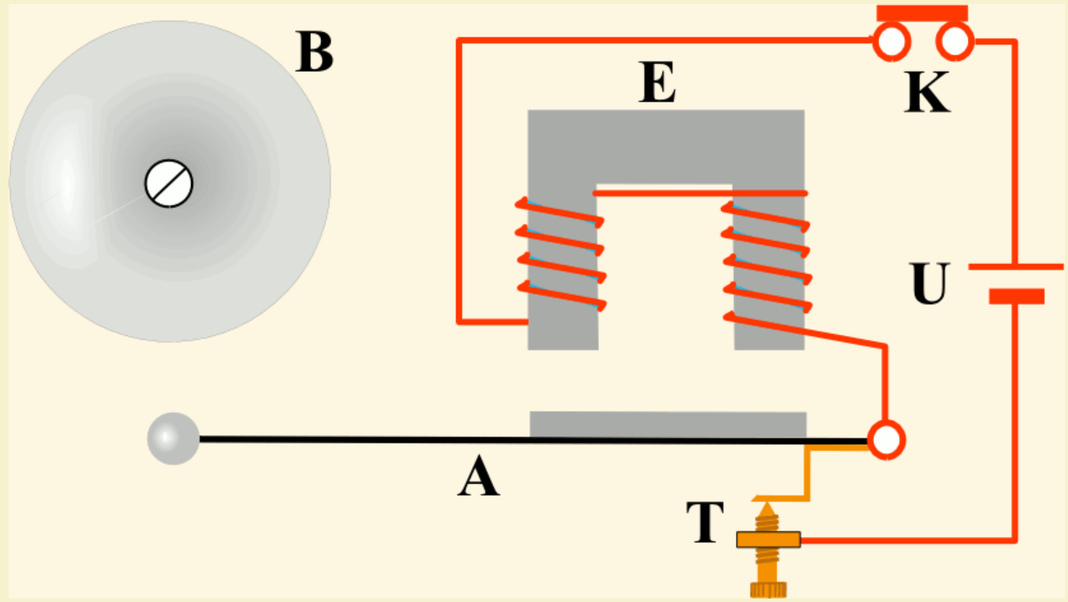


Fig: A solenoid based electric bell ringing mechanism

Source: Wikimedia Commons

File: Electric_Bell_animation.gif

Thermal or Magnetic Actuators

- ✓ These can be actuated by applying thermal or magnetic energy.
- ✓ They tend to be compact, lightweight, economical and with high power density.
- ✓ These actuators use shape memory materials (SMMs), such as shape memory alloys (SMAs) or magnetic shape-memory alloys (MSMAs).
- ✓ Some popular manufacturers of these devices are *Finnish Modti Inc.* and *American Dynalloy*.

Reference: https://en.wikipedia.org/wiki/Actuator

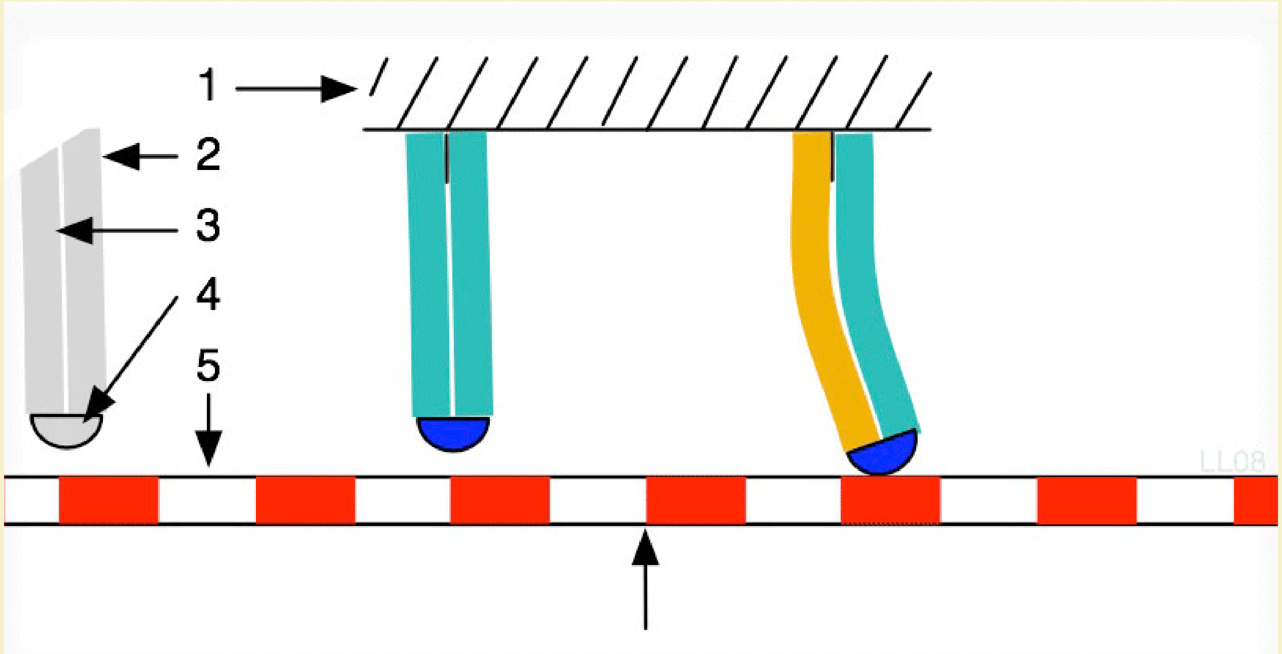


Fig: A piezo motor using SMA

Source: Wikimedia Commons
File: Piezomotor type bimorph.gif

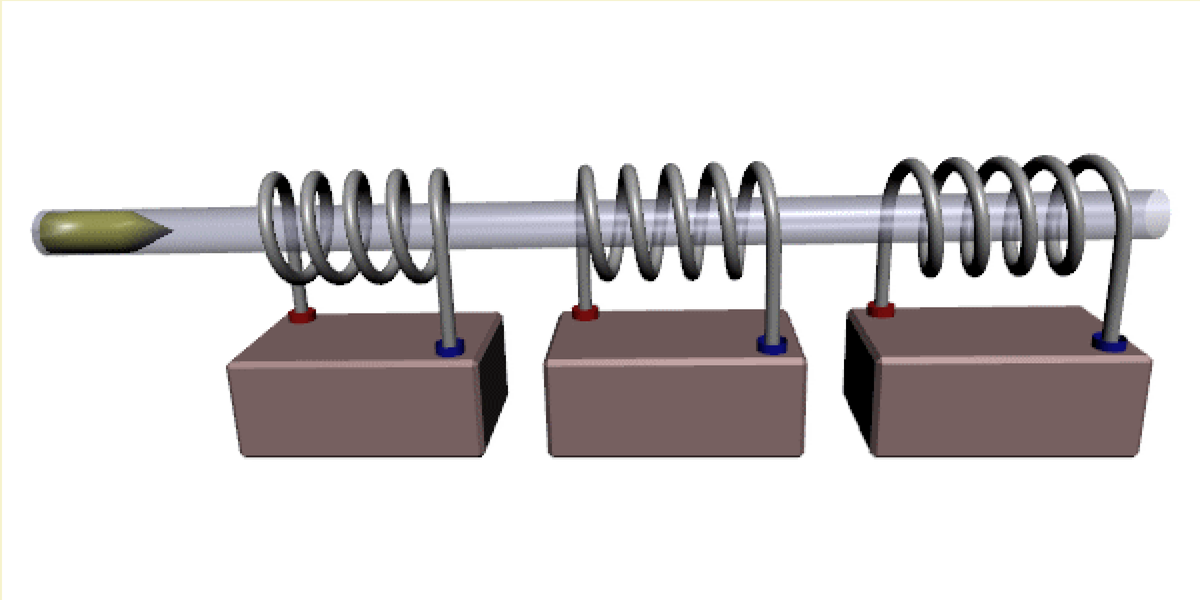


Fig: A coil gun works on the principle of magnetic actuation

Source: Wikimedia Commons
File: Coilgun animation.gif

Mechanical Actuators

- ✓ A mechanical actuator converts rotary motion into linear motion to execute some movement.
- ✓ It involves gears, rails, pulleys, chains and other devices to operate.
- ✓ Example: rack and pinion.

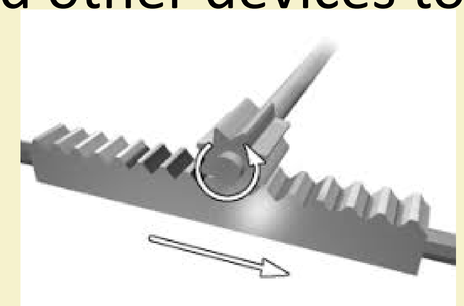


Fig: A rack and pinion mechanism
Source: Wikimedia Commons
File: Rack and pinion.png

Reference: https://en.wikipedia.org/wiki/Actuator

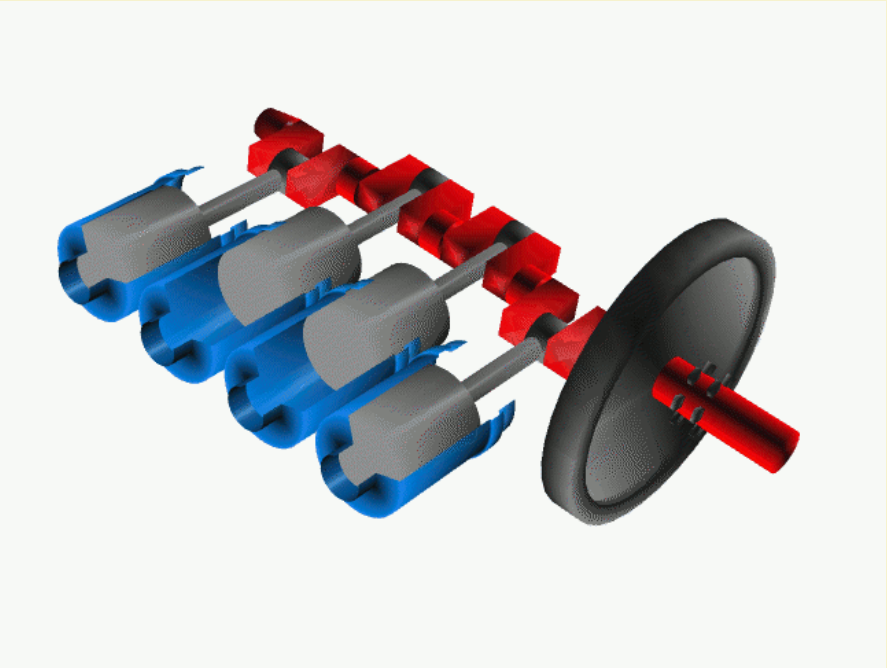


Fig: A crank shaft acting as a mechanical actuator

Source: Wikimedia Commons
File: Cshaft.gif

Soft Actuators

- ✓ Soft actuators (e.g. polymer based) are designed to handle fragile objects like fruit harvesting in agriculture or manipulating the internal organs in biomedicine.
- ✓ They typically address challenging tasks in robotics.
- ✓ Soft actuators produce flexible motion due to the integration of microscopic changes at the molecular level into a macroscopic deformation of the actuator materials.

Reference: https://en.wikipedia.org/wiki/Actuator

Shape Memory Polymers

- ✓ Shape memory polymer (SMP) actuators function similar to our muscles, even providing a response to a range of stimuli such as light, electrical, magnetic, heat, pH, and moisture changes.
- ✓ SMP exhibits surprising features such a low density, high strain recovery, biocompatibility, and biodegradability.

Reference: https://en.wikipedia.org/wiki/Actuator

Light Activated Polymers

- ✓ Photopolymer/light activated polymers (LAP) are a special type of SMP that are activated by light stimuli.
- ✓ The LAP actuators have instant response.
- ✓ They can be controlled remotely without any physical contact, only using the variation of light frequency or intensity.

Reference: https://en.wikipedia.org/wiki/Actuator

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Basics of IoT Networking – Part I

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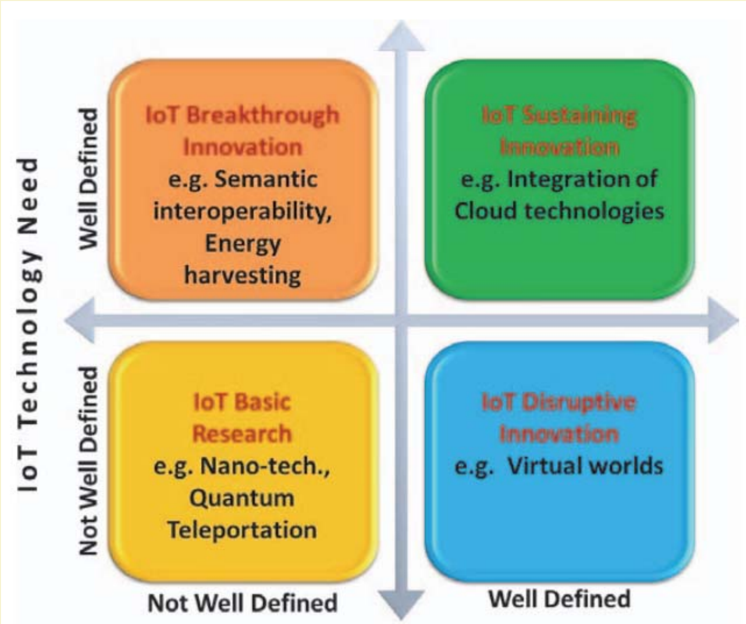
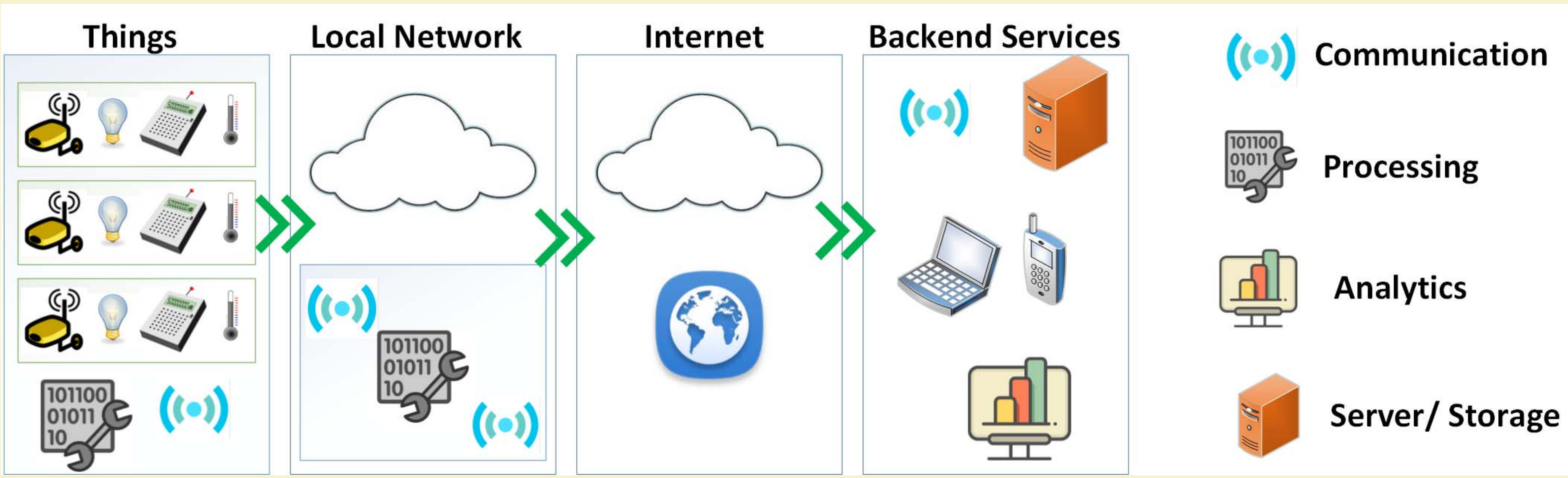
Convergence of Domains



Source: O. Vermesan, P. Friess, "Internet of Things – Converging Technologies for Smart Environments and Integrated Ecosystems", River Publishers, Series in Communications, 2013

IoT Components

- Device (The Thing)
- Local Network
- Internet
- Backend Services
- Applications

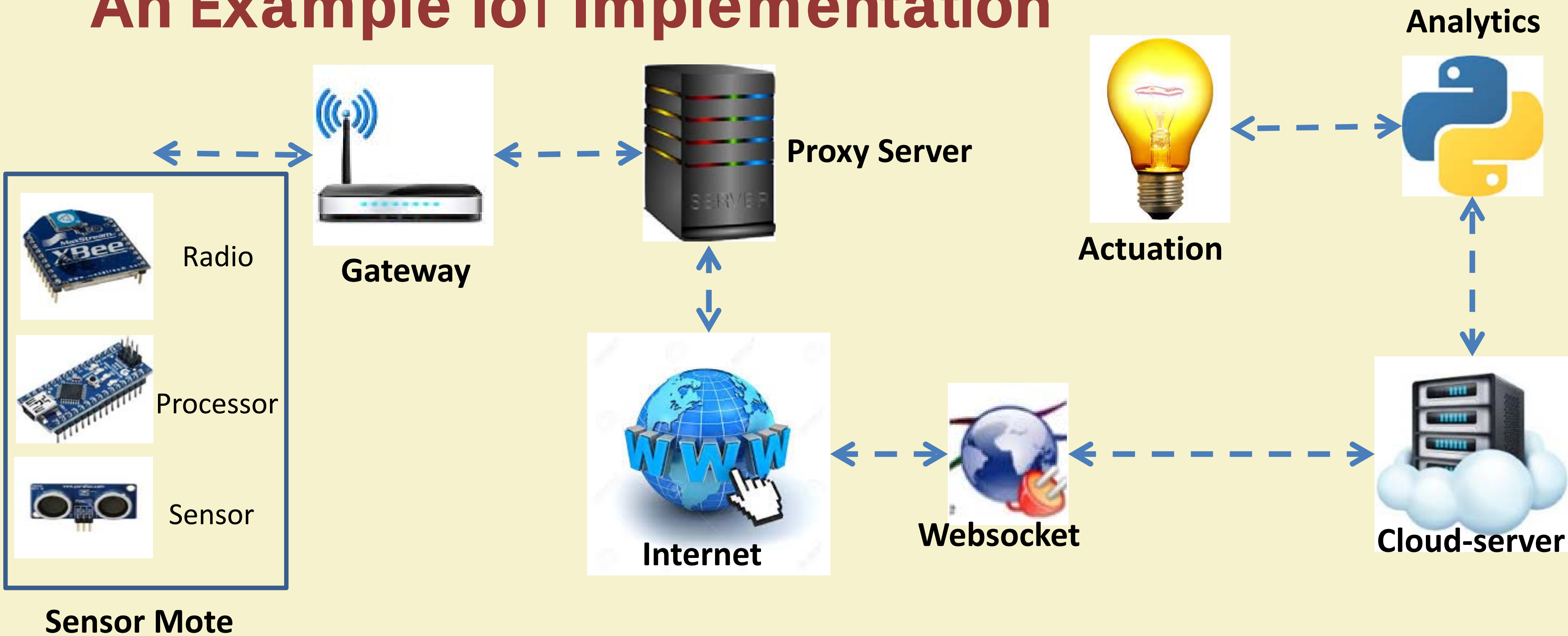

Things
Local Network
Internet
Backend Services
101100
01011
10
101100
01011
10
Communication
Processing
Analytics
Server/ Storage

Functional Components of IoT

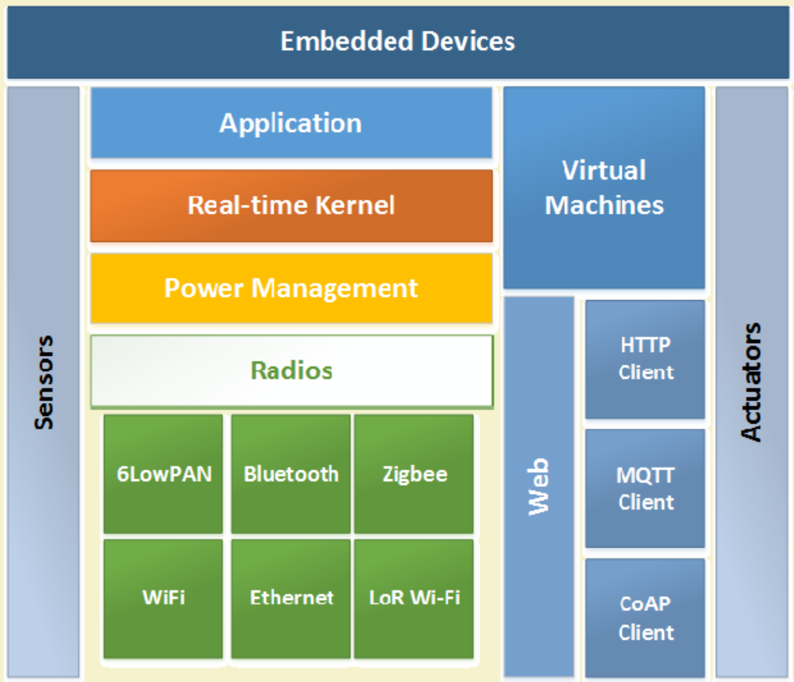
- ✓ Component for interaction and communication with other IoT devices
- ✓ Component for processing and analysis of operations
- ✓ Component for Internet interaction
- ✓ Components for handling Web services of applications
- ✓ Component to integrate application services
- ✓ User interface to access IoT

Source: O Vermesan, P. Friess, "Internet of Things – Converging Technologies for Smart Environments and Integrated Ecosystems", River Publishers, Series in Communications, 2013

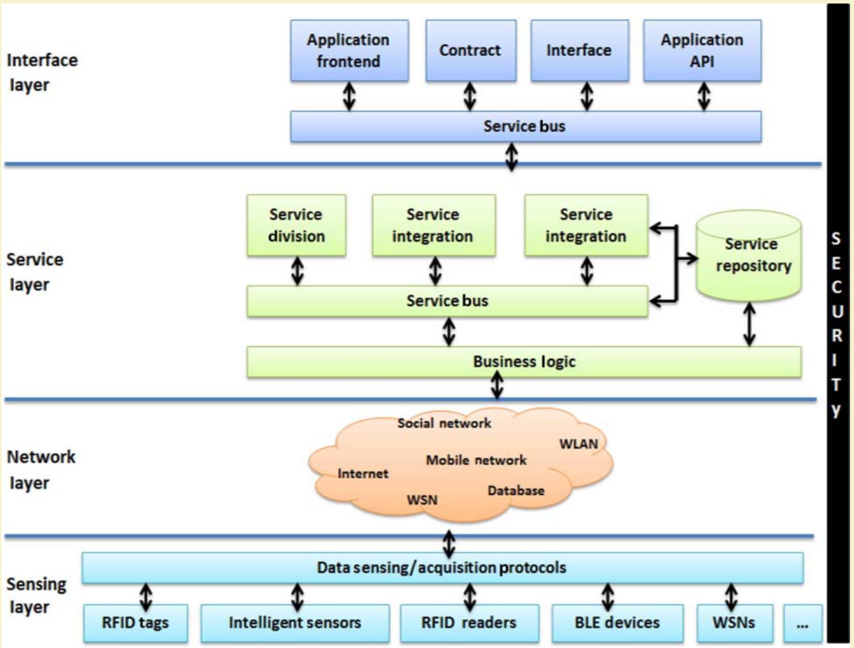
An Example IoT Implementation



IoT Interdependencies



IoT Service Oriented Architecture



Source: Li Da Xu, Wu He, and Shancang Li, "Internet of Things in Industries: A Survey ", IEEE Transactions on Industrial Informatics, Vol. 10, No. 4, Nov. 2014.

IoT Categories

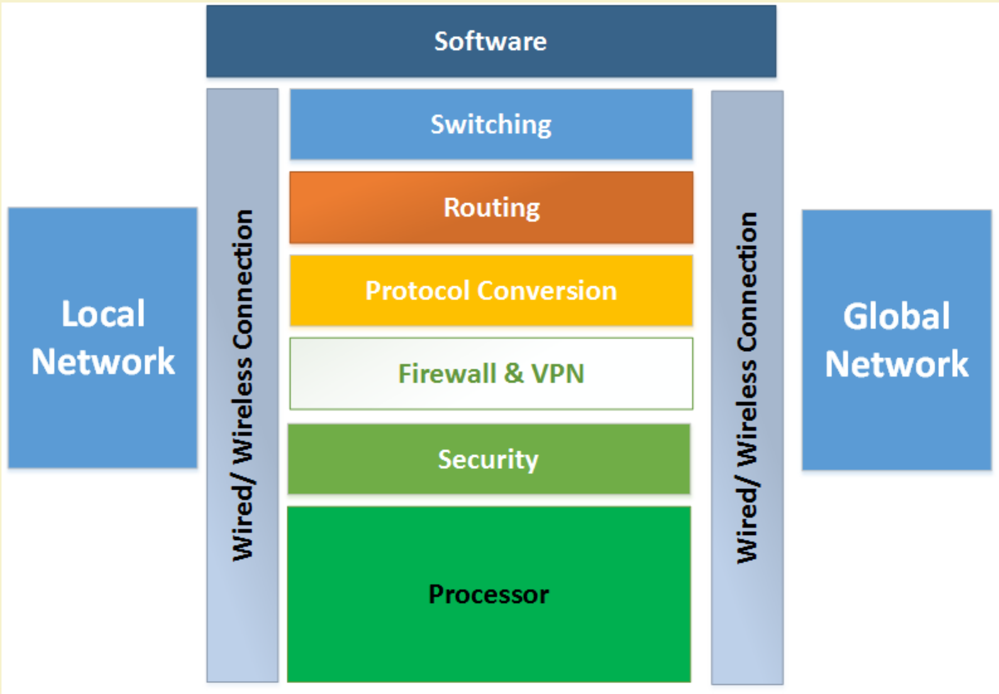
✓ **Industrial IoT**

- IoT device connects to an IP network and the global Internet.
- Communication between the nodes done using regular as well as industry specific technologies.

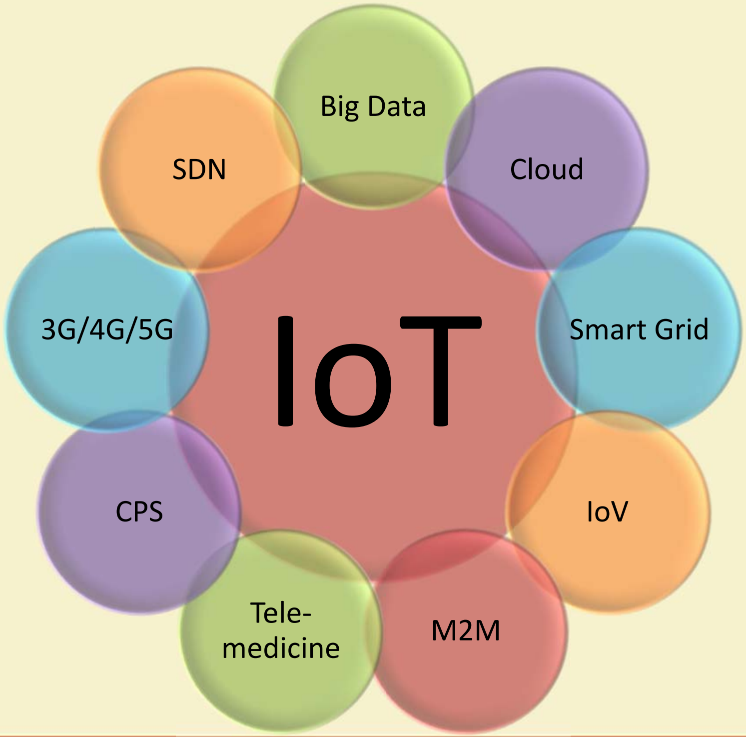
✓ **Consumer IoT**

- IoT device communicates within the locally networked devices.
- Local communication is done mainly via Bluetooth, Zigbee or WiFi.
- Generally limited to local communication by a Gateway

IoT Gateways



IoT and Associated Technologies



Technical Deviations from Regular Web

IoT Stack		Web Stack
Applications	Management	Web Applications
Binary, JSON, CBOR		HTML, XML, JSON
MQTT, CoAP, XMPP, AMQP		HTTP, DHCP,DNS,TLS/SSL
UDP, DTLS		TCP, UDP
IPv6		IPv6, IPv4, IPSec
6LoWPAN		
IEEE802.15.4 MAC		Ethernet, DSL, ISDN, Wireless LAN, Wi-Fi
IEEE802.15.4 PHY/ Radio		

Key Technologies for IoT

Source: O Vermesan, P. Friess**, "**Internet of Things – Converging Technologies for Smart Environments and Integrated Ecosystems", River Publishers, Series in Communications, 2013

IoT Challenges

- ✓ Security
- ✓ Scalability
- ✓ Energy efficiency
- ✓ Bandwidth management
- ✓ Modeling and Analysis
- ✓ Interfacing
- ✓ Interoperability
- ✓ Data storage
- ✓ Data Analytics
- ✓ Complexity management (e.g., SDN)

Considerations

- ✓ Communication between the IoT device(s) and the outside world dictates the network architecture.
- ✓ Choice of communication technology dictates the IoT device hardware requirements and costs.
- ✓ Due to the presence of numerous applications of IoT enabled devices, a single networking paradigm not sufficient to address all the needs of the consumer or the IoT device.

Complexity of Networks

- ✓ Growth of networks
- ✓ Interference among devices
- ✓ Network management
- ✓ Heterogeneity in networks
- ✓ Protocol standardization within networks

Source: O Vermesan, P. Friess**, "**Internet of Things – Converging Technologies for Smart Environments and Integrated Ecosystems", River Publishers, Series in Communications, 2013

Wireless Networks

- Traffic and load management
- Variations in wireless networks – Wireless Body Area Networks and other Personal Area Networks
- Interoperability
- Network management
- Overlay networks

Source: O. Vermesan, P. Friess, **"**Internet of Things – Converging Technologies for Smart Environments and Integrated Ecosystems", River Publishers, Series in Communications, 2013

Scalability

- Flexibility within Internet
- IoT integration
- Large scale deployment
- Real-time connectivity of billions of devices

Thank You!!