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WirelessUP!

UPraising VET skills for innovation in European electrotechnical sector

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WirelessUP! Toolkit

Module 1:
Internet of Things: Sensing and Actuator Devices

Intellectual Output 3

February 2019

Content

1. SENSORS AND ACTUATORS

Measuring is an everyday activity. For example, we weigh goods, count items, and measure body temperature, blood pressure, pulse, speed, height, etc. We do all that in order to compare the values of the measured quantities with the values or numbers of units expressing the values of measured quantities.

The basic measurements express:

length and dimensions in meters (m), mass in kilograms (kg), electric current in amperes (A), time in seconds (s), amount of substance in moles (mol), etc.

Values of derived physical quantities are expressed similarly:

pressure (Pa), temperature (K), mass flow rate (kg/s), volumetric flow rate (m3/s), force (N), speed (m/s), energy (J), power (W), etc.

In engineering, all physical and chemical quantities need to be measured. Measuring is important for directions (signalization), recording (registration), protection and control. Measuring physical or chemical quantities used for regulation, management and control of processes is called process measurement. Process measurements are conducted using simple or complex measuring devices called metering sets.

Non-electrical quantities

Examples of non-electrical quantities which can be measured:

a) **In the area of electric motors** – in addition to all electromagnetic quantities, the following is also measured: angular and linear displacement, angular and linear velocity, angular and linear acceleration or deceleration, torque, power, winding temperature, coolant flow rate, bearing lubrication, oil pressure, etc.
b) **In the area of objects in motion** – in addition to the physical quantities above, the following is also measured: height, depth, distance from other objects, position in space, absolute and relative object velocity, force, mass, etc.
c) **In chemical technology, engineering and nuclear technology** – in addition to the physical quantities above, the following is also measured: volume, level of liquid and bulk materials, humidity, pH value, density, viscosity, chemical composition of substances, vibration, noise level, thermal conductivity, heat capacity, amount of heat, friction coefficient, ionizing radiation, light intensity, etc.

Any non-electrical quantity can be measured and are usually converted into electrical ones due to a number of advantages of working with electrical quantities.

Some advantages of working with electrical quantities are:

a) Information devices are electronic
b) High accuracy of operation
c) High sensitivity
d) Easier remote data transmission
e) Simple data storage
f) Simple data reading (indication)
g) Easy installation and maintenance (exploitation) of data

h) Simple recording (registration) of data
i) Many possibilities for monitoring data accuracy
j) New intelligent integrated measuring devices with microprocessors

The human ear is an example of a metering element and a converter which converts sound, i.e. mechanical air vibrations (non-electrical quantity) into electrical signals.

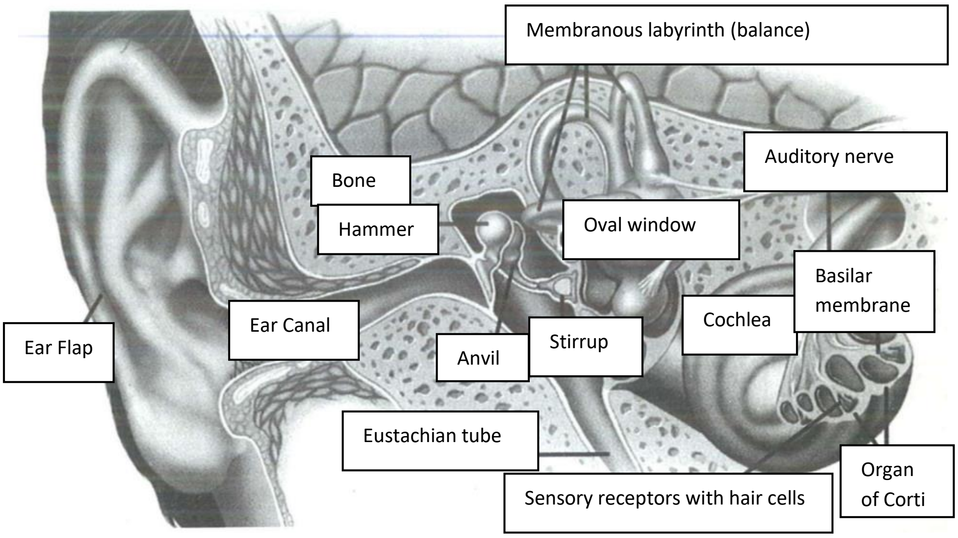


Figure 1. Human ear

Modern information devices are digital. Therefore, analog electrical signals often have to be converted into digital signals using an A/D (analog-to-digital) converter. Some measuring devices immediately output digital signals (for example, optical encoders and magnetic resolvers) so they do not require A/D conversion. The measurement signal is often weak, so it has to be amplified using an amplifier. In addition, it needs to be filtered to remove interference.

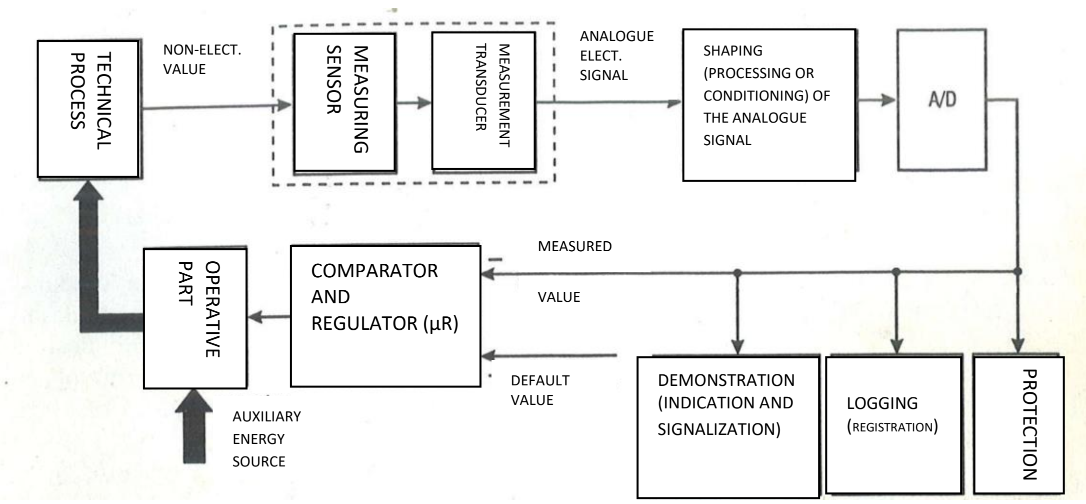


Figure 2. Block diagram of the process measurements and regulations

All blocks do not have to be included every time. The measuring sensor and the converter cannot always be separated. Some modern measuring devices are integrated and may provide processed data. In practice, different terms are used. A sensor may also be referred to as a detector or a metering element, while a converter may also be called a transducer.

A sensor (German: *Sensor*, derived from the Latin *sensus*: sensitivity, feeling, sense), converter or a measurement sensor is a part of a measurement system which is directly in contact with the measured quantity and sends output signals depending on its amount.

An actuator (from the medieval Latin *actuare*: accomplish), in control and regulation technology, mechatronics, robotics etc. is a device which, based on a control signal, places movable parts of a system into desired positions, makes them move or develops a force or momentum whereby those parts affect the environment. Basically, it is a converter which amplifies an input quantity and converts it into mechanical motion.

Robotics are increasingly important in modern control engineering. Its field of process measuring is called sensorics. A metering set is a collective name for a sensor, converter, transmission device, indicating instrument and recorder.

Sometimes, in practice, multiple conversion is used. For example, liquid level is converted into displacement, displacement into an analog electrical signal, and then the analog electrical signal is converted into a digital signal. The best option is when a measurement converter outputs a digital electrical signal. Each conversion implies a loss of signal accuracy.

In conclusion, there is a large number of physical and chemical quantities, and each of them has a large number of measurement methods. There are different instruments on the market for every method. These are commercial devices. There are thousands of different measuring devices in control engineering today. In practice, design engineers choose the device which best suits a certain automated system. The simplest temperature control loop only has a metering element for temperature. Complex automated systems (power stations, refineries, ships, airplanes, etc.) can have thousands of measuring devices for dozens or even hundreds of different quantities.

In process measurement, knowledge on different areas (analog and digital electronics, electrical engineering, engineering, optics, computer science, etc.) has been integrated, so it is clear that it is a (complex) technical field.

Due to its scope, complexity and fast changes, technical experts choose specializations.

Technical devices are becoming standardized. Due to a large number of devices from different manufacturers from around the world, measurement signals, circuitry, lines and connectors are being standardized. Devices should be compliant and compatible. International and national standards exist, and large manufacturers' standards are imposed on the market. Standardization significantly facilitates operations and decreases costs.

Analog electrical signals have the following standard values:

a) Electrical (DC): 0-1 mA, 0-5 mA, 0-20 mA, 4-20 mA, 0-50 mA,
b) Voltage (DC and AC): 0-1 mV, 0-15 mV, 0-100 mV, 0-3 V.
c) Pneumatic analog measuring signals have been standardized: 20-100 kPa

1.1. Basic characteristics of metering sets

Basic characteristics (features) of devices for measuring non-electrical quantities and their conversion to corresponding electrical quantities have been divided into groups.

1.1.1. Input characteristics

a) Physical quantity
b) Measuring area
c) Measuring range

1.1.2. Output characteristics

A measuring signal is the output of a measurement converter. It may be analog or digital. Output impedance describes the behavior of a measurement converter when it is connected to circuitry in a measurement chain, i.e. when it is loaded. If $R_i = R_T$, the power transfer from the converter to the next stage is at a maximum.

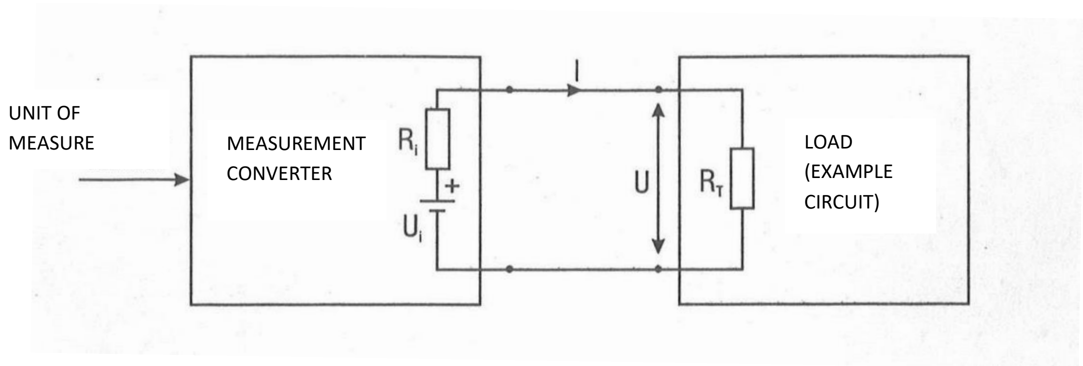


Figure 3. Simplified graph of output impedance

1.1.3. Operating conditions

The operating conditions of calculation and calibration (adjustment) of a measurement converter have been standardized:

temperature: 20 ± 5°C

relative air humidity: 60 ± 20%

atmospheric pressure: 101.325 ± 2.66 kPa

These are room conditions.

1.1.4. Static characteristics

Metering sets have static characteristics referring to the ratio between input and output. Usually they are represented by graphs.

The ideal static characteristic is linear. In practice, various deviations occur, and static characteristics are non-linear.

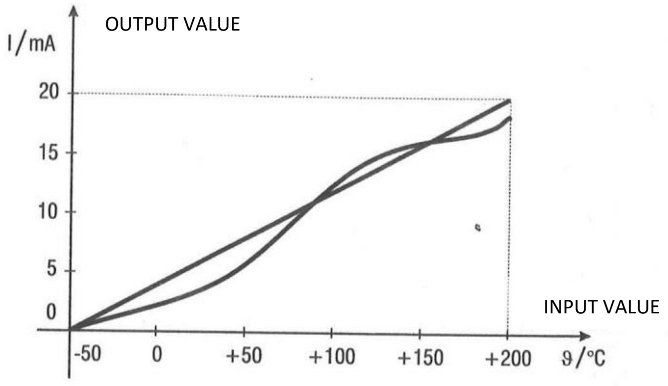


Figure 4. Example of the linear and continuous non-linear static characteristic

1.1.5. Dynamic characteristics

The dynamic characteristics of metering sets are as important as the static ones. They are defined experimentally, by conducting experiments. They are described using:

a) transitional characteristics,
b) frequency characteristics.

Transitional characteristics are time responses to step excitation. Frequency characteristics are responses to sinusoidal excitation in the stationary state.

1.2. Overview of measurement converters

With measurement converters, some non-electrical quantities are converted into electrical ones.

The general classification of measurement converters are:

a) **passive** (must have an auxiliary power source)
b) **active** (convert a non-electrical quantity into electric quantity and do not require an auxiliary power source)

The General classification of passive measurement converters are:

a) **Resistance:**
- solid
- liquid
- gas

b) **Inductance:**
- dependent on the location of the core
- dependent on the changes in permeability

c) **Capacitance:**
- dependent on the surface of plates
- dependent on the distance between plates
- dependent on the change in dielectrics
- cylindrical capacitor converters

The General classification of passive measurement converters are:

a) Converters of mechanical energy into electrical energy (usually the generator principle is applied – tachogenerator, the principle of piezoelectricity).
b) Converters of heat into electrical energy (the thermoelectric phenomenon is applied – thermocouples).
c) Converters of luminous energy into electrical energy (the photoelectric phenomenon is applied – photovoltaics).
d) Converters of chemical energy into electrical energy (electrolyte with electrodes of different materials serves as a power source – battery).

1.2.3. Displacement measurement

Angular and linear displacement may be measured in many ways using resistance, inductance or capacitance measurement converters in an analog way. Digital displacement measurement converters have also been developed: optical and inductance. They can be used for measuring the speed of rotation, not just angular rotation.

The resistance method with a variable resistor is the best example. It is a wire coiled resistor with a slider in a rheostat (Figure 5) and potentiometric circuit.

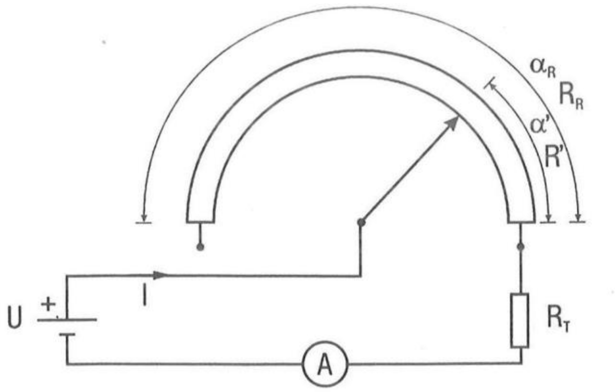


Figure 5. Rheostat circuit of the measurement converter for the angular rotation

The rheostat circuit of the resistance method is an example of a passive measurement converter since it must have an auxiliary power source.

For $R_T = 0$: $I = k \frac{1}{\alpha'}$

Current is inversely proportional to angular rotation α'. The slider is attached to the shaft rotated by a moving object. In this case the largest angle αR = 180°, but it may be any other angle. An ammeter shows the amount of electricity, but we would like to know the angular displacement so the instrument is calibrated in degrees. If we include a low voltage resistor in the circuit, we can measure the voltage dip proportional to the electricity. This voltage measurement signal may be processed or transferred using a remote converter.

1.2.4. Rotation speed measurement

This is a very important field of measurement, especially in regulated electric motors. Angular velocity is important for electrical rotating machines. Several measurement methods have been developed. The older approach includes tachogenerators, while the newer approach includes pulse measurement converters.

1.3. Tachogenerators

Tachogenerators are analog metering elements and converters which convert rotation speed into a corresponding electrical signal. These are electromechanical devices since they convert mechanical energy into electrical energy. There are several types of tachogenerators:

AC: a) synchronous
b) asynchronous

DC: a) brush
b) brushless

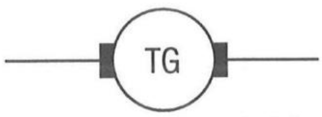


Figure 6. Symbol of the brush tachogenerator

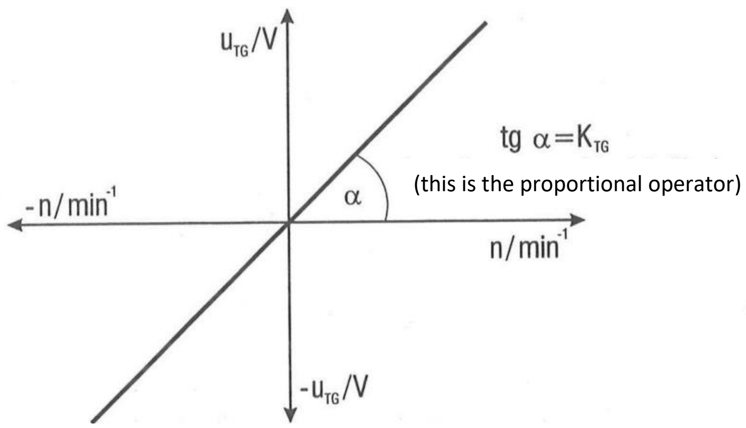


Figure 7. Static characteristic of DC tachogenerator

Typical features of DC tachogenerators are: sensitivity (V/o/min), voltage ripple (%) and maximum rotation speed (o/min).

The best tachogenerators are electrical commuted tachogenerators, also known as brushless tacho. These are contactless electromechanical converters.

1.3.3. Pulse converters

Tachogenerators have a number of deficiencies. They output analog voltage signals, but modern IT electronics are digital. This means that A/D converters are required. The goal is to have digital measurement sets. There are different designs of pulse metering elements and converters.

a) **A stroboscope** is a device for measuring rotation speed in an open system. It is an optical measuring device based on the persistence of the human eye. Light pulses of modern stroboscopes are controlled by an electric circuit, so the rotation speed may be read directly.

b) **Mechanical pulse converters** are obsolete solutions. They use fixed and moving electrical contacts. The contacts wear out. They are slow (operating frequency) and have poor accuracy. With every shaft rotation using eccentricity, the moving contact closes the circuit.

c) **Magnetic pulse converters** use electromagnetic inductance, so they are also called inductance magnetic converters. Usually the permanent magnet is attached to the shaft, while the immovable coil is located near the shaft. The coil induces a voltage pulse at each turn of the shaft. The pulse is irregularly shaped and weak, so it is amplified using an amplifier and formed by a Schmitt trigger. A notched disc with magnetic notches is often used and the disc spins through the air gap of the coil. Therefore, more pulses are created per turn. Pulse count defines angular rotation, rotation speed and shaft acceleration. These converters are appropriate for digitally controlled closed automated systems. A microcomputer receives pulses and performs the functions of a measurement converter, comparator and regulator.
Resolvers are modern inductance devices for measuring the rotor position or angular rotation, and rotation speed.

d) **Optical pulse converters** are also called optical encoders. These are contactless devices of high accuracy and reliability. They do not create engine load torque. They are sensitive to dust, so they need to be hermetically sealed. They do not wear out, so they do not require maintenance. The measuring range is wide, up to 100,000 r/min. These are used in digital systems for positioning and adjusting the speed of rotation. Optical encoders are photoelectric rotary converters which work on the principle of interrupting a beam of light. This converts rotation into a series of rectangular voltage pulses suitable for processing in µR. Optical encoders are common feedback elements in servo systems.
Basic components of an optical encoder are: a light source (usually a light-emitting diode), a rotating perforated disc (this means that it has little holes on the rim), a photo sensor or an image decoder (photodiode or phototransistor) which creates electrical signals under the influence of light, grating or mask between the light source and the non-rotating disc (or the disc and light receiver), electronic circuitry for signal processing, enclosure and a coupling for connecting the encoder shaft with the engine shaft.

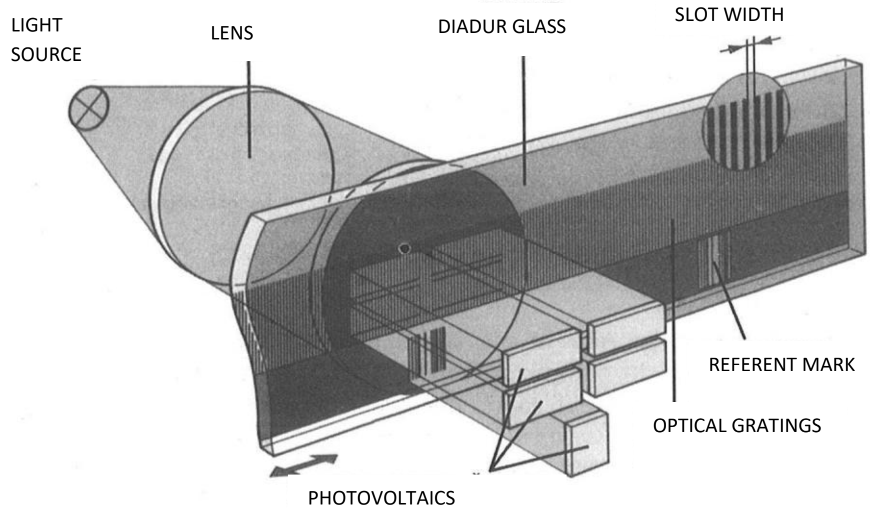


Figure 8. Principal view of the incremental optical encoder operation

1.3.3.1. Force measurement

A force causes objects to move. If forces acting on an object are balanced, no movement will occur and the object will become deformed. The majority of measurement converters are based on the principle of balance of forces, therefore object stress is measured. Different forces are measured: pressure, tension, shear, bending and torsion. Different measurement methods have been developed as well as different measuring device designs. Resistance, inductance, piezoelectric, magnetoelastic, electrolytic and hydraulic methods are used.

1.3.3.2. Resistance method

This method is appropriate for smaller pressure and tension forces. Measurement converters are capsules with coal powder which change the amount of electrical resistance under the influence of force. These are two variable resistors located in a DC bridge (Wheatstone bridge). The bridge diagonal voltage is a measure of force acting on the converters. An analog instrument is calibrated in N, and not in V.

The other option is force measurement using strain measuring sensors. It is widely applied. Semiconducting or metal strips connected to measurement bridges are used as variable resistors. Resistance depends on the force. The resulting voltage is proportional to force. Resistors dependent on force are called tensoresistors.

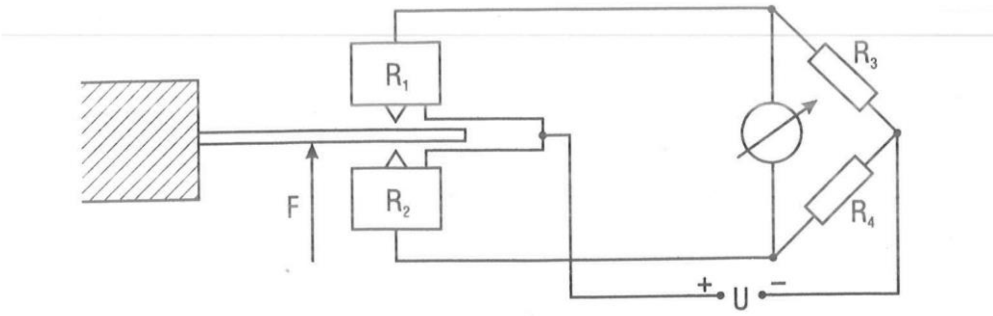


Figure 9. Force measurement converter with coal powder

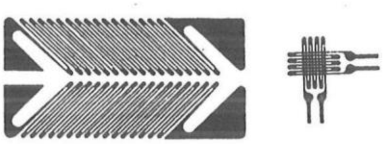


Figure 10. Different versions of the strain measuring sensors

1.3.3.3. Piezoelectric method

A large number of crystals are piezoelectric. The most famous one is quartz. It has broad application in different areas, and it is also used for force measurement. When a force acts on a crystal, voltage occurs on its surfaces, and vice versa – when a force acts on crystal surfaces, electric charge is accumulated. The difference in electric potential is voltage. Thus, by measuring voltage, force is indirectly measured. A device is appropriate for measuring pulse forces (rate of change of force, both in amount and direction) it follows up to 15 kHz. These are dynamic strains. The device is used to measure large forces in heat engines, compressors, cannon barrels, etc.

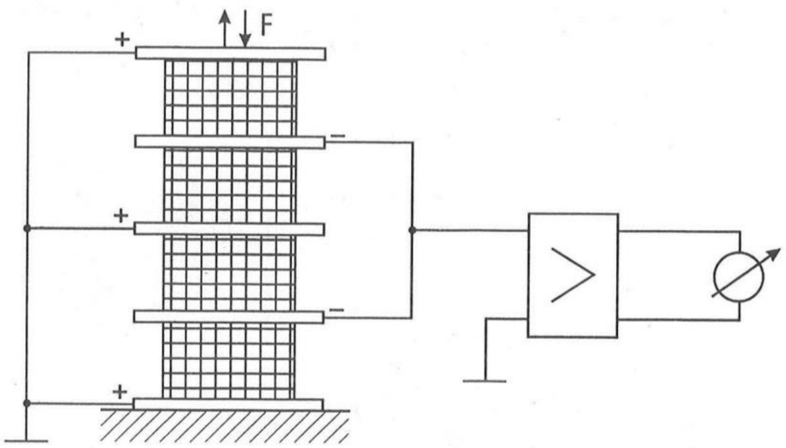


Figure 11. Principal view of the force measurement with the help of piezoelectric

1.3.3.4. Pressure measurement

Pressure is force applied to a surface and vacuum is space devoid of matter. Pressure measured in relation to vacuum is absolute pressure, and pressure measured in relation to standard atmospheric pressure is relative pressure. We differentiate between gauge pressure and underpressure. The unit for pressure is Pa = N /m^2. Pressure is measured from 0.1 Pa to 10^8 Pa and a pressure below 133 Pa is considered to be vacuum, and below 0.1 Pa high vacuum. Vacuum measurement converters are special devices called vacuum gauges. However, pressure measuring is basically force measuring.

In practice, there are many devices which measure pressure by measuring displacement, force and pressure balancing (manometers). Therefore, diaphragms (membranes) and bellows with resistance, inductance, capacitance and piezoelectric transducers are used.

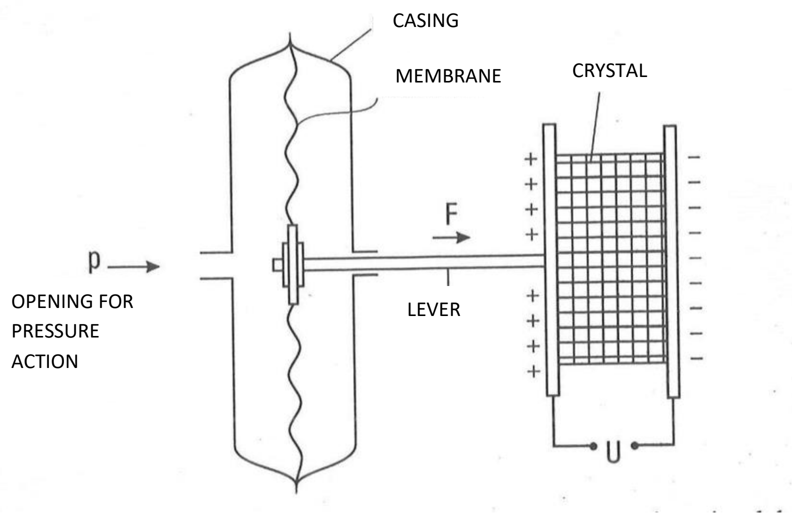


Figure 12. Principal view of the piezoelectric converter for pressure measurement

Capsules with a membrane which moves under pressure are used quite often. The membrane movement acts on the piezoelectric crystal, so voltage occurs due to force. Hence, by measuring the voltage, pressure is indirectly measured. The crystal may withstand large loads and thus, high pressures can be measured. If a crystal is built into a gas engine block as a spark plug, then changes in the pressure can be measured during the four-stroke cycle. This is how pressures are measured in hydraulics, pneumatics, cannon barrels and gun barrels, explosions and at supersonic speeds. If the moving lever acts on the moving capacitor plates instead of the quartz, then this is the capacitance method of pressure measurement. With the inductance method, the lever moves the iron core, and with the resistance method, the potentiometer slider moves.

1.3.4. Measuring liquid levels

Liquid level measurement is widely applied. Usually the volume information is more important than the level information, but it can also be easily calculated using the container dimensions. The amount of fuel in vehicle tanks is measured, as well as in power plants, refineries or water tanks. Many methods of measuring liquid levels and converting that data into electrical signals have been developed. Some of those methods are:

- mechanical float method,

- resistance, capacitance and inductance method,

- radioactive method,

- optical method,

- ultrasound method,

- piezoelectric method (pressure sensor).

1.3.4.1. Capacitance method

For this method, two dielectrics are placed between two electrodes – air and liquid whose level is to be measured. The two electrodes are immersed in the liquid, or one electrode is immersed and the other is the container.

Formula for capacitance: $C_1 = \varepsilon_1 \frac{S_1}{d}$, $C_2 = \varepsilon_2 \frac{S_2}{d}$

The immersed electrodes act as two parallel capacitors: $C = C_1 + C_2$

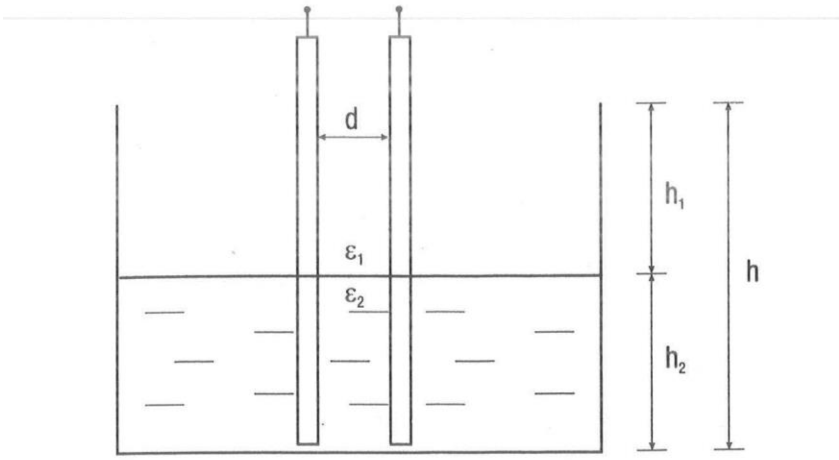


Figure 13. Display of the capacitance way of measuring the liquid level

1.3.4.2. Ultrasound method

This is the latest method for measuring liquid levels and it is suitable for large liquid containers. There are no movable parts and the measuring device is separated from the liquid.

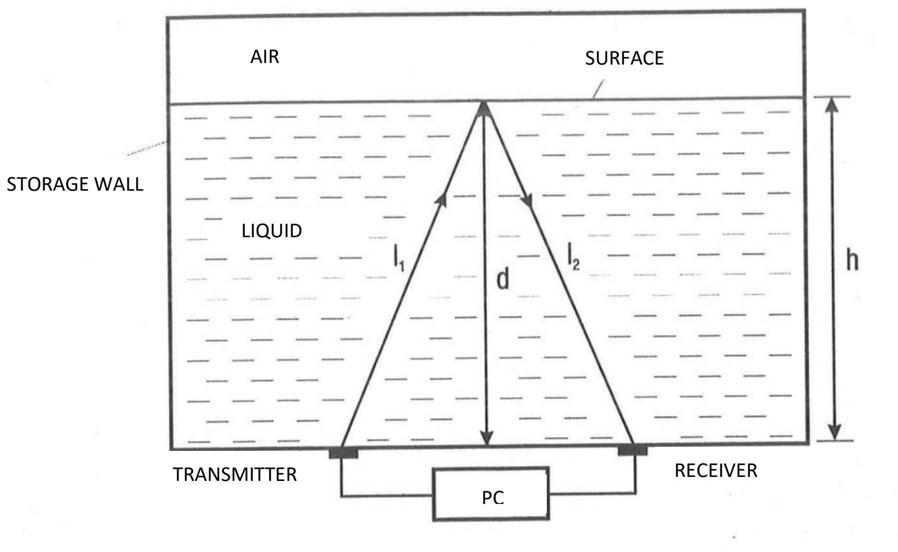


Figure 14. Display of the liquid level measurement with the ultrasound

The ultrasound generators are piezoelectric. The device is similar to a sonar for measuring the depth of water below a ship. The time between sending and receiving ultrasound (mechanical) waves is measured. The wave propagation speed through the liquid has to be known. Wave reflection occurs on the surface of the liquid.

The formula for calculating the ultrasound wave path is: $l = v\,t$, $l = l_1 + l_2$

where: v – known wave speed (different for every liquid), l – wave path for calculating the unknown value h (level), t – signal travel time.

It is easy to calculate triangle height d from the known circumference of the isosceles triangle. The scale is calibrated in meters for height or in m^3 for volume. The containers are usually round. The electronic device shows the final result so the operator does not have to calculate it. Remote measurement is usually used.

1.3.5. Fluid flow rate measurement

Fluid is a common name for liquids and gases. Mass flow rate is measured in kg/h, kg/min, kg/s and volume flow rate in m^3/h, m^3/min, m^3/s. Flow rate measurement is frequent in practice in refineries, gas pipelines, oil pipelines, water supply facilities, power stations, vehicles, chemical industry, mining, etc. It is a very extensive field of work and it is difficult to provide an overview of the measurement methods. There are hundreds of designs and I will demonstrate two.

1.3.5.1. Ultrasound method

Here, two pairs of receivers and transmitters are used (Figure 15). The diameter of pipe D and the distance d are known. The fluid flow rate v is unknown. The speed of the emitted ultrasound (mechanical) wave c is known. The Doppler effect occurs: the wave speed in the direction of fluid motion is greater than the wave speed in the opposite direction. The time required for both waves to pass through the pipe is measured, and the difference is proportional to the flow rate. If sinusoidal waves are transmitted, a delay occurs in the form of phase shift. Time measurement is the most precise type of measurement and in modern electronics, the device for doing that is small and affordable. The computer converts the data and gives a final display of speed, or sends this data via a remote transfer device to the supercomputer. Since the waves do not travel tangentially with the motion of the fluid, but are inclined, the horizontal wave component must be considered. The flow can then be measured using ultrasound converters in various areas, from the blood flow in blood vessels to oil pipelines. These converters have great characteristics, such as no flow disturbance, high accuracy, fast response, flow rate measurement for different fluids, linearity, no moving parts which wear out, etc.

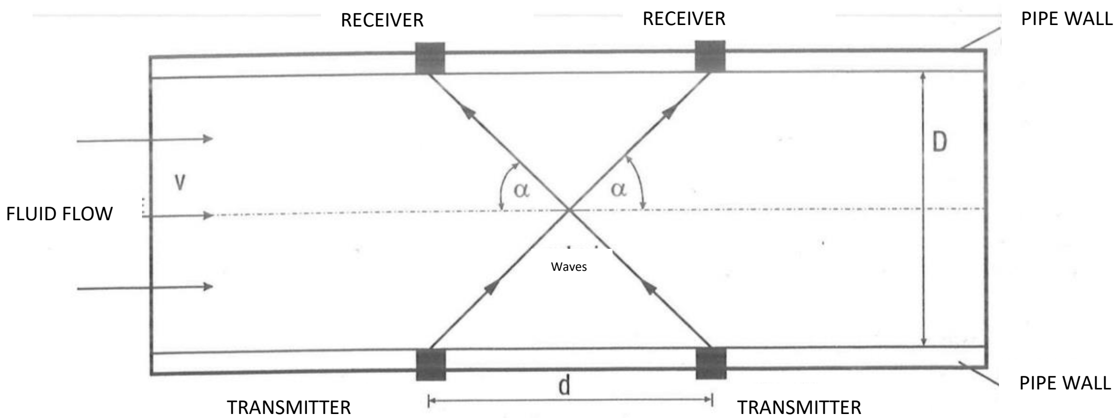


Figure 15. Diagram of the ulstrasonic flow measurement converter

1.3.5.2. Electromechanical method

For this method, a propeller is placed in the pipeline, and a magnet is placed at the top of the arm. There is a coil along the side of the pipeline in which, due to electromagnetic induction, a pulse is induced every time a magnet passes by. That voltage pulse increases and is shaped in a Schmitt trigger. Pulses are counted by an electronic counter. Their number is proportional to the number of propeller rotations and that speed defines the volume flow rate. More frequently, a turbine is placed in the pipe instead of a propeller and the fluid motion turns the turbine blades with small magnets at the tips. (Figure 16)

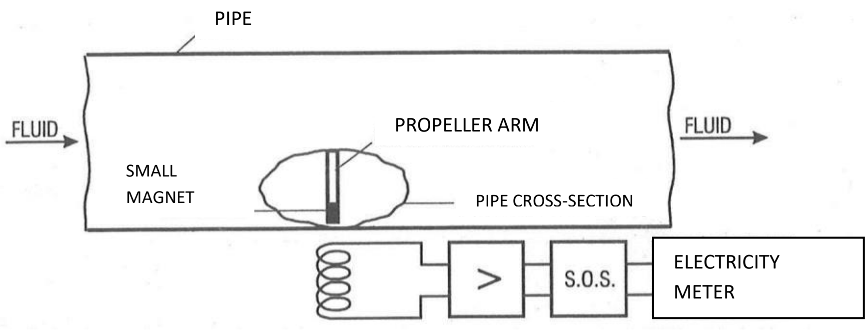


Figure 16. Diagram of measuring the flow with the propeller

1.3.6. Temperature measurement

Heat is one of the forms of energy in nature and temperature is the measure for defining the thermal state of an object. There are several temperature scales. The most important ones are the Celsius relative scale in °C and the Kelvin absolute scale in K. The Fahrenheit scale in °F, the Réaumur scale in °Re and the Rankin scale in °R are also used. Heat transfers from an object to another object in three ways:

a) **by conducting**
b) **by flowing** or convection in fluids
c) **by radiation** in the form of electromagnetic waves

Almost all physical changes related to the change in temperature are used for temperature measurement. A large number of methods and an even greater number of designs have been developed. I will demonstrate the most important measurement methods.

1.3.6.1. Measurement methods based on heat radiation

Based on the physical knowledge on black-body radiation, devices for measuring high temperatures have been developed. They are called pyrometers. The electromagnetic radiation spectrum depends on the temperature of the radiating body. There are multiple designs: optical pyrometers, which work based on Planck's law, and radiation pyrometers, which work based on the Stefan–Boltzmann law. They are used for both industrial and scientific purposes.

1.3.6.2. Measurement methods based on a thermoelectric phenomenon

Based on the Seebeck effect, a thermocouple (thermoelement) has been developed. It is a device which directly converts heat into electrical energy with a small efficiency coefficient (η=1%). For thermovoltage:

- two different materials (usually metal alloys) are used,
- one end of the lines has to be firmly connected (metering junction), and the other end is the reference junction where voltage is measured,
- the metering junction is at a different temperature than the reference junction.

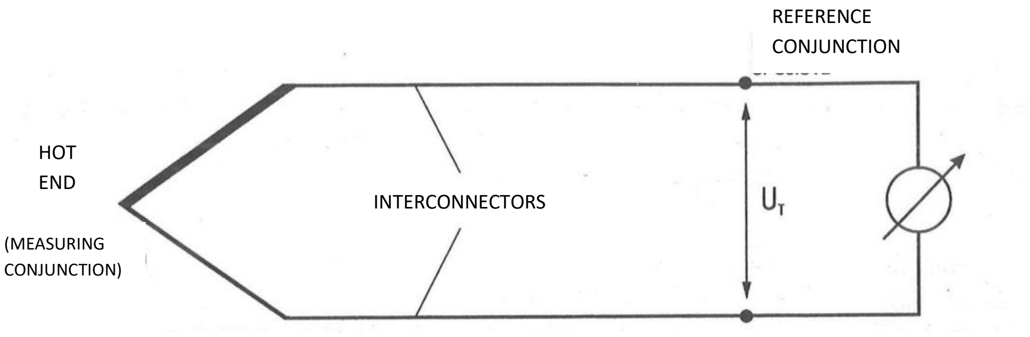


Figure 17. Principal view of the termocoule mode of operation

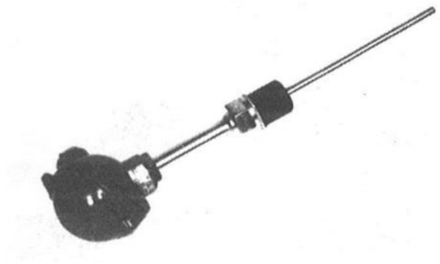


Figure 18. Temperature measuring probe (resistive or thermoelectric sensor)

1.3.6.3. Measurement methods based on change in electrical resistance

Resistance converters have a sensor which changes the amount of electrical resistance with the change in temperature. They may be made of metal or semiconductors. Materials for metal wire resistors are copper, tungsten, nickel and platinum. Layered designs are created by vapour deposition of platinum on ceramics. Metal designs have a large measuring range from -265°C to 1100°C, depending on the type of material. Semiconducting designs are non-linear resistors. They can be thermistors (NTC – negative temperature coefficient and PTC – positive temperature coefficient of electrical resistance). The measuring area of a thermistor is smaller than for metals, but their accuracy is high and the time constant is very small, i.e. the inverter dynamics are very good. NTC and PTC probes are frequently used for measuring the temperature of windings of electrical machines for protection. Carbon metering elements are used for measuring the lowest temperatures, from 1 K to 20 K.

1.3.7. Measurement methods based on change in dimensions

Volume, i.e. the length of the wire and poles, depends on temperature changes. The dependency of object dimensions on temperature changes is tested for every material and the data are shown in tables. The change in object dimensions is called dilation. The change in dimensions of metal, liquids and gases is used in practice. A bimetal metering element or a thermobimetal is commonly used for simple applications. This is being done with a dilation sensor. It consists of two strips made of different metal alloys (usually INVAR). It is important that the materials have different coefficients of thermal expansion. They are firmly connected. One end is fixed, and the other one is movable. The movement depends on the temperature. Spiral or helicoidal designs may be constructed instead of a linear strip in order to achieve greater rotation. The measuring range is from -185°C to 400°C, and the measuring error is about +/- 1%. They are suitable for simple temperature regulations, e.g. in a refrigerator or in an apartment.

1.2. Remote measurement and control

In practice, the measurement data often have to be remotely transmitted, which also applies to control signals. Examples of short distance transmission are signals in vehicles and buildings, while long distance transmission refers to power systems, space exploration, weather data, military equipment, railway systems, etc. Remote measurements are also called telemetry, and the process of collecting, transmitting and processing measurement data is called acquisition. Data can be transmitted using wires or wirelessly.

Traditional transmission uses electrical signals which are transmitted through copper wires. The downsides are price, size and the amount of copper lines, as well as the strong impact of interference. All external electric and magnetic fields act as interference. That is why many protective measures have been developed, such as shielding, grounding, transposed lines or line routing. Today, copper wires are considered to be an old-fashioned solution for transmission. Modern solutions transmit signals in the form of light using optical fibre cables. These are glass fibres, usually made of flint glass, which have very little attenuation and are flexible. Moreover, fibre shield is a clear material of a low fracture index. Assumably, fibre cables will completely replace copper lines in the future.

With this technology, signals can be transmitted over long distances as light pulses, without any significant losses. Infra-red beams are used (from 700 to 2000 nm), which have almost the same characteristics as the visible light of wavelength from 400 to 700 nm. Infra-red light emitting diodes (LEDs) or special laser diodes are used for the conversion of electrical signals into light. The receiver and transmitter are designed as a monolithic hermetically sealed element in a metal housing which may be soldered on a printed circuit board with a power supply of 5 V. The transfer capacity of optical fibre cables is very large.

In addition to these two methods using lines, wireless data transmission is important as well and it is essential for ships, planes, spacecrafts, rotary objects, etc. For this method of data transmission, radio waves, directed microwave connections (optical visibility), laser connections, acoustic connections (ultrasonic and infra-red) are used. It should be emphasized that satellite communication is increasingly important (telephone, radio, TV, navigation, etc.) and that usually electromagnetic microwaves are used.

Data may also be transmitted using fluid pressure in pipelines. Hydraulic signals are important for moving objects, while pneumatic signals are important in the chemical industry because of flammable and explosive environments. Pneumatic signals, due to attenuation in pipes, may only be used at a distance of max. 100 meters. The speed of air pressure propagation is approximately the same as the speed of sound. For a line (pipe) of 150 m, the signal delay exceeds 10 s. The final propagation speed may be considered actual dead time and pipe attenuation a time constant.

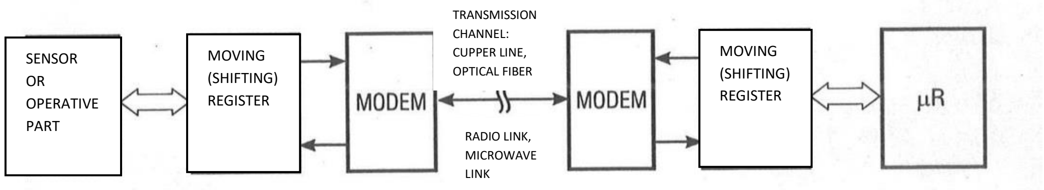


Figure 19. Long distance digital data transfer

2. Internet of Things - Introduction

Since its inception, the Internet has undergone a revolutionary development. Nowadays we are living in a period of time, when the interconnection by the world wide web is going through another significant part which is the interconnection of not only people, but also any other conceivable things. Thanks to the Internet of Things, as this part of the Internet is often being referred to today, intelligent solutions are possible and we can monitor, assess and influence the behavior of the intelligent applications.

Let us imagine a smart house which includes a lot of intelligent applications. From sensors monitoring temperature, humidity or air quality, up to the control elements which can regulate the environment of the house on the basis of optimum settings or on the basis of commands from an inhabitant of the house. Thanks to the intelligent interconnection of all these applications, it is possible to see what the condition of the monitored value is and one can also influence what will be done with the environment of the house. For example, we can remotely affect the time and the amount of heating and lighting in relation to their unexpected return home.

Thanks to the Internet of Things, the devices connected mutually to the Internet can communicate with each other, send data and receive commands.

2.1. Internet of Things - Practical Applications

Using the Internet of Things - IoT (sometimes referred to as the Internet of Everything - IoE), not only people are interconnected with eachother, but also people and things as well as the actual things are interconnected.

The practical applications of the Internet of Things are inexhaustible and every day manufactures come up with new groundbreaking solutions. For instance, one of the solutions deals with the issues of parking. When parking lots are guarded by an automatic detection system, summary reports and parking statistics can be processed automatically.

Another application provides for monitoring of lighting amount, temperature or air quality at schools. Here, the respective detectors send the measured data to the central system for evaluation and on the basis of the result of the measurement, the respective response can be invoked. For example, in the form of selected indication in the respective room or by automatic modification to the conditions using the air-conditioning and automated lighting system.

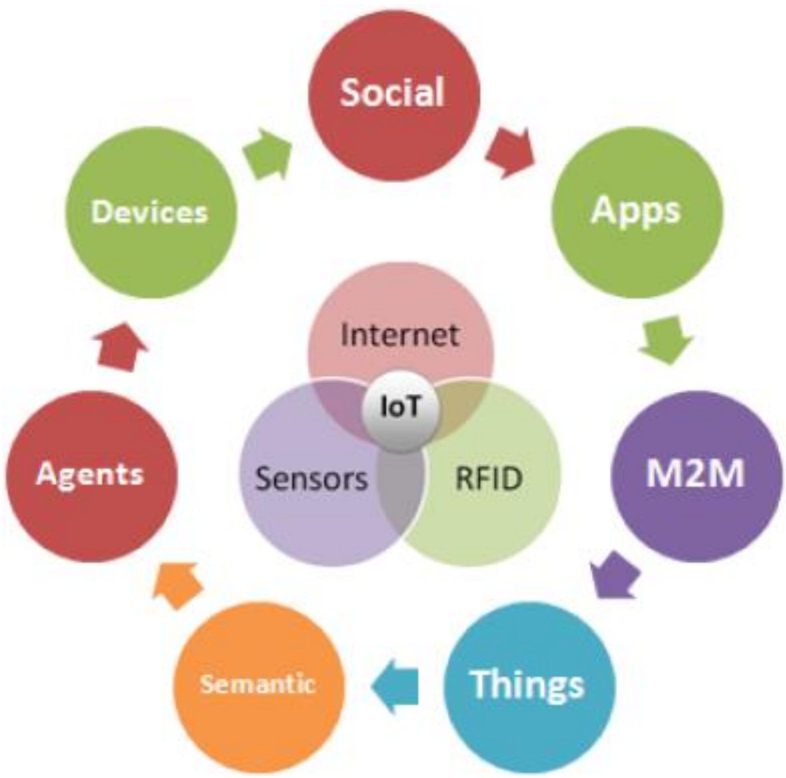
In addition, household guard systems containing various detectors are also very useful applications. Thanks to the Internet connection, they are able to provide not only detection of infringement, but also the sending of a report to the central system, including the photo of the intruder.

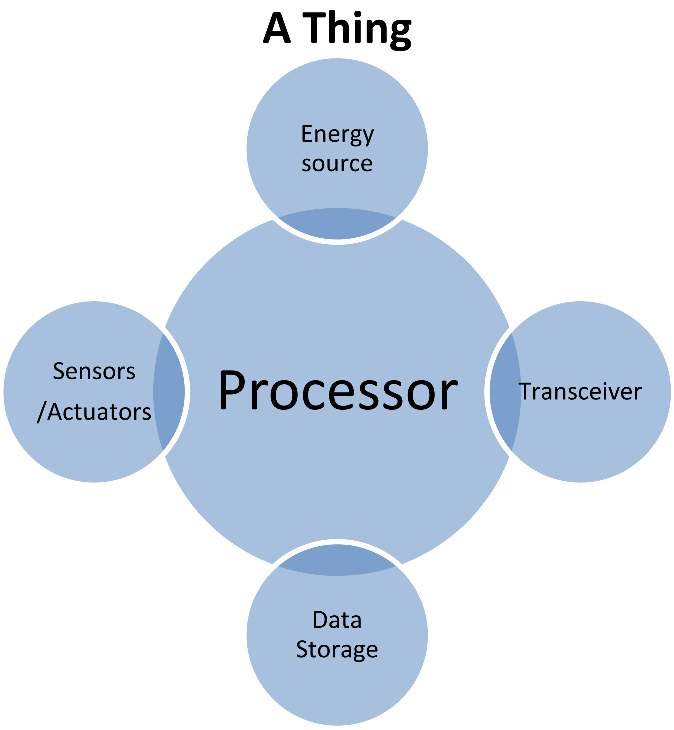
A certainly uncommon use of the Internet of Things is an application detecting repletion of hives with honey. It continuously sends data to the central system and performs its evaluation, representation and communication. Other applications are intended for automatic street lighting at dusk or dark. Here, the interconnection of individual lamps using the wireless network helps to detect failures and conditions and as a result, they save energy significantly.

Nowadays we can find a really great amount of useful applications which simplify and make positive contribution to the life of people and it can be expected that the tendency of this development will still continue. With increasing public popularity of smart applications using the Internet of Things, these tendency will be more and more significant.

In line with its development, the majority of the governments in Europe, Asia, and the Americas now consider the Internet of Things as an area of innovation and growth. Although larger players in some application areas still do not recognise the potential, many of them pay high attention or even accelerate the pace by coining new terms for the IoT and adding additional components to it. Moreover, end-users in the private and business domain have nowadays acquired a significant competence in dealing with smart devices and networked applications.

As the Internet of Things continues to develop, further potential is estimated by a combination with related technology approaches and concepts such as Cloud computing, Future Internet, Big Data, robotics and Semantic technologies. Of course, the idea as such is not new but becomes now evident as those related concepts have started to reveal synergies by combining them.





Examples of IoT Devices

Humans
- wearable devices
- in-body devices
- health and wellness
- disease management

Homes
- home controllers
- security systems

Retails
- self-scheckouts
- inventory optimisation

Industry
- operation efficiency
- equipment optimisation
- health and safety
- construction

Offices
- energy management
- productivity
- mobile working

Cities
- smart meters
- environment monitoring
- resource management
- infrastructure control

Vehicles
- autonomy
- real-time routing with traffic control
- maintenence

2.2. IoT device Definition

An IoT device is a piece of equipment with the mandatory capabilities of communication and optional capabilities of sensing, actuation, data capture, data storage and data processing. The device collects various kinds of information and provides it to the information and communication networks for further processing. Some devices also execute operations based on information received from the information and communication networks.

1. Fundamental characteristics

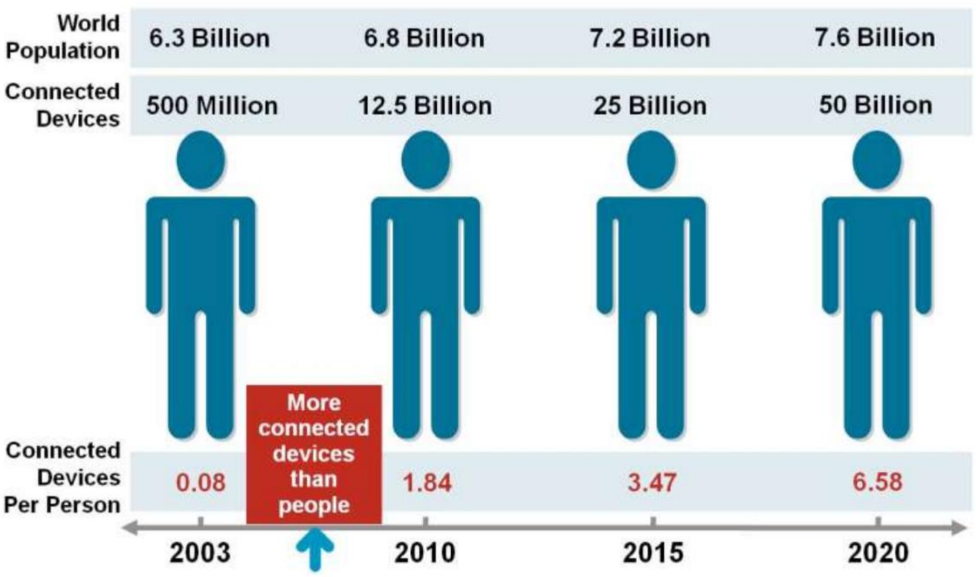
• Interconnectivity: With regard to the IoT, anything can be interconnected with the global information and communication infrastructure.

• Heterogeneity: The devices in the IoT are heterogeneous as they are based on different hardware platforms and networks. They can interact with other devices or service platforms through different networks.

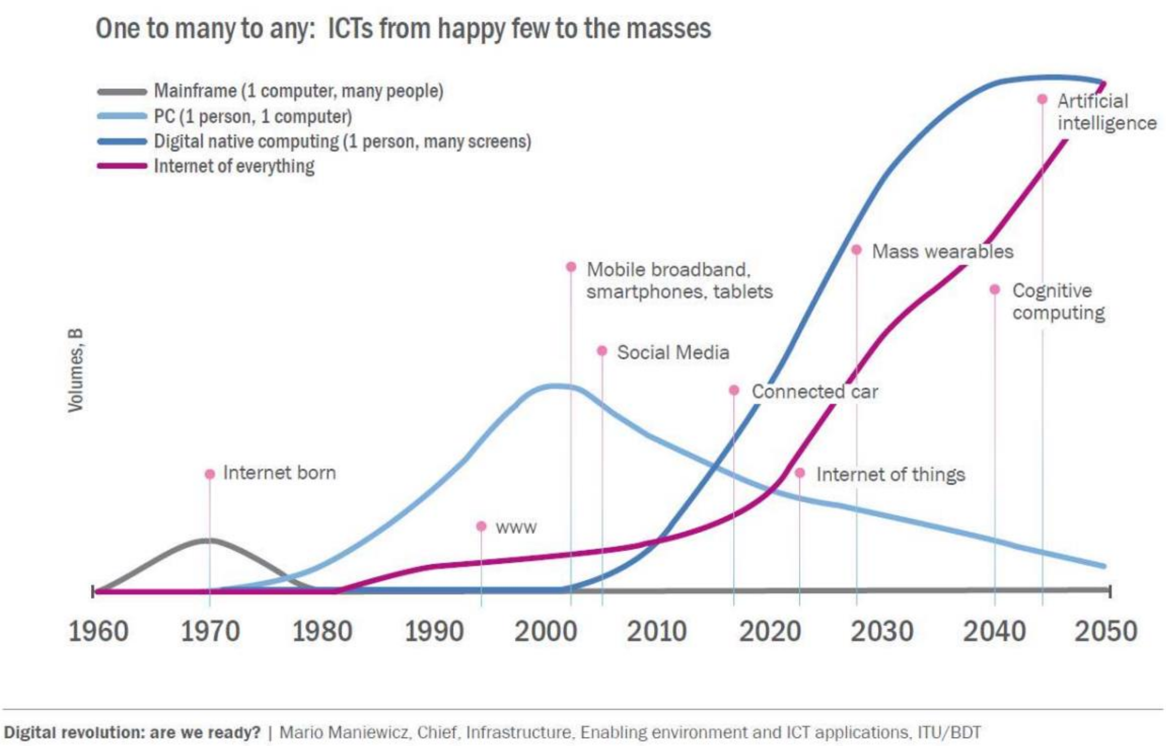
• Dynamic changes: The state of the devices change dynamically, e.g., sleeping and waking up, connected and/or disconnected as well as the context of the devices including location and speed. Moreover, the number of devices can change dynamically.

• Enormous scale: The number of devices that need to be managed and that communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. The ratio of communication triggered by devices as compared to communication triggered by humans will noticeably shift towards devicetriggered communication.

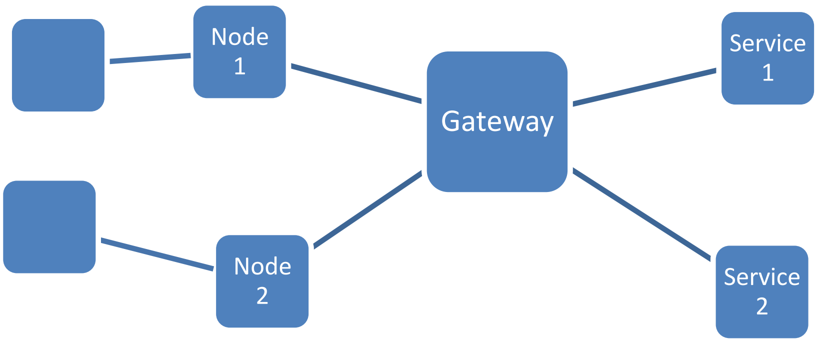
Predictions:



Source: Cisco IBSG, April 2011



2. IoT Architecture



3. The technologies enabling the Internet of Things

Technology	Definition	Examples
Sensors	A device that generates an electronic signal from a physical condition or event	The cost of an accelerometer has fallen to 35 cents from 1,75 EUR in 2006. Similar trends have made other types of sensors small, inexpensive, and robust enough to create information from everything, from fetal heartbeats via conductive fabric in the mother's clothing to jet engines roaring at 10.000 metres.
Networks	A mechanism for communicating an electronic signal	Wireless networking technologies can deliver bandwidths of 600 megabits per second (Mbps) to 1,3 gigabit per second (Gbps) with nearubiquitous coverage.
Standards	Commonly accepted prohibitions or prescriptions for action	Technical standards enable processing of data and allow for interoperability of aggregated data sets. In the near future, we could see mandates from industry consortia and/or standard bodies related to technical and regulatory IoT standards.
Augmented intelligence	Analytical tools that improve the ability to describe, predict, and exploit relationships among phenomena	Petabyte-sized (1015 bytes, or 1,000 terabytes) databases can now be searched and analyzed, even when populated with unstructured (for example, text or video) data sets. Software that learns might substitute for human analysis and judgment in a few situations.
Augmented behavior	Technologies and techniques that improve compliance with prescribed action	Machine-to-machine interfaces are removing reliably fallible human intervention into otherwise optimized processes. Insights into human cognitive biases are making prescriptions for action based on augmented intelligence more effective and reliable

2.3. Network connectivity planning

Key aspects when considering network connectivity:

• Range - are you deploying to a single office floor or an entire city?

• Data Rate - how much bandwidth do you require? How often does your data change?

• Power - is your sensor running on mains or battery?

• Frequency - have you considered channel blocking and signal interference?

• Security - will your sensors be supporting mission critical applications?

2.4. IPv6

INFORMATION that sensors create rarely attains its maximum value at the time and place of creation. The signals from sensors often must be communicated to other locations for aggregation and analysis. This typically involves transmitting data over a network.

Sensors and other devices are connected to networks using various networking devices such as hubs, gateways, routers, network bridges, and switches, depending on the application. For example, laptops, tablets, mobile phones, and other devices are often connected to a network, such as Wi-Fi, using a networking device (in this case, a Wi-Fi router).

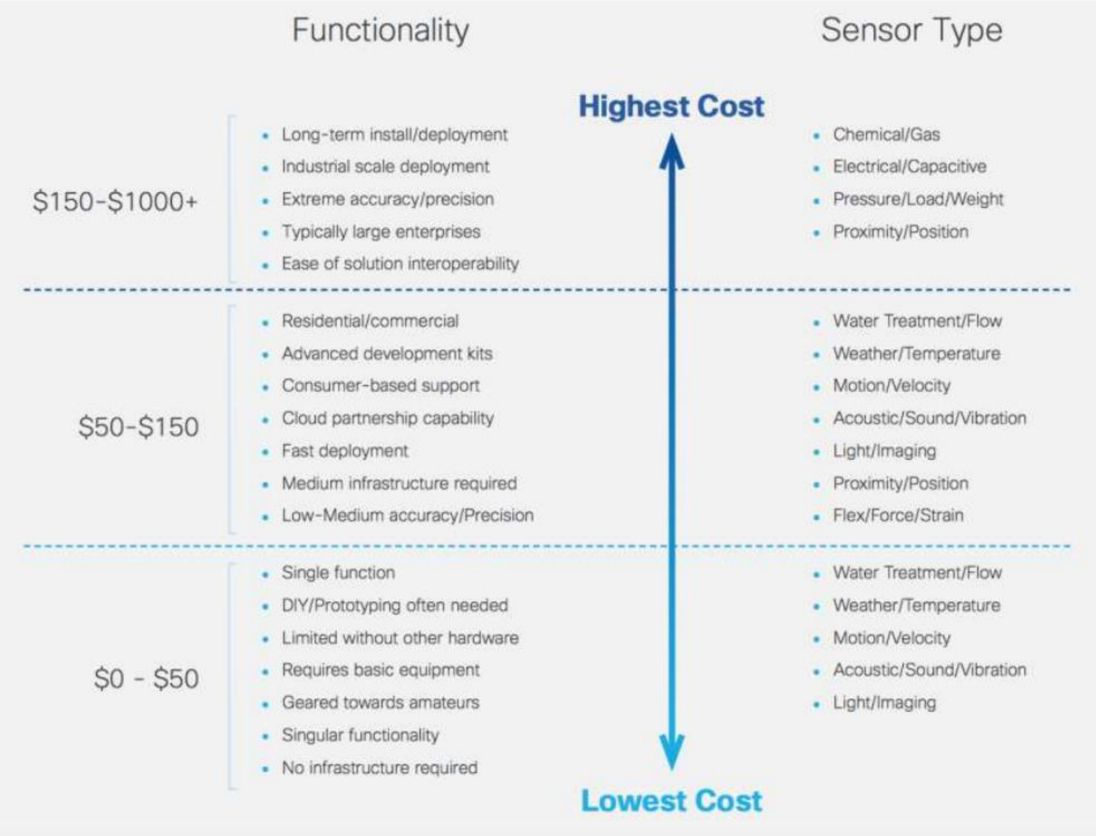
The first step in the process of transferring data from one machine to another via a network is to uniquely identify each of the machines. Hence, the IoT requires a unique name for each of the "things" on the network.

Network protocols are a set of rules that define how computers identify each other. Broadly, network protocols can be proprietary or open. Proprietary network protocols allow identification and authorization to machines with specific hardware and software, making customization easier and allowing manufacturers to differentiate their offerings. Open protocols allow interoperability across heterogeneous devices, thus improving scalability. Internet Protocol (IP) is an open protocol that provides unique addresses to various Internet-connected devices; currently, there are two versions of IP: IP version 4 (IPv4) and IP version 6 (IPv6). IP was used to address computers before it began to be used to address other devices. About 4 billion IPv4 addresses out of its capacity of 6 billion addresses have already been used. IPv6 has superior scalability with approximately 3.4x1038 unique addresses compared to the 6 billion addresses supported by IPv4. Since the number of devices connected to the Internet is estimated to be 26 billion as of 2015 and projected to grow to 50 billion or more by 2020, the adoption of IPv6 has served as a key enabler of the IoT.

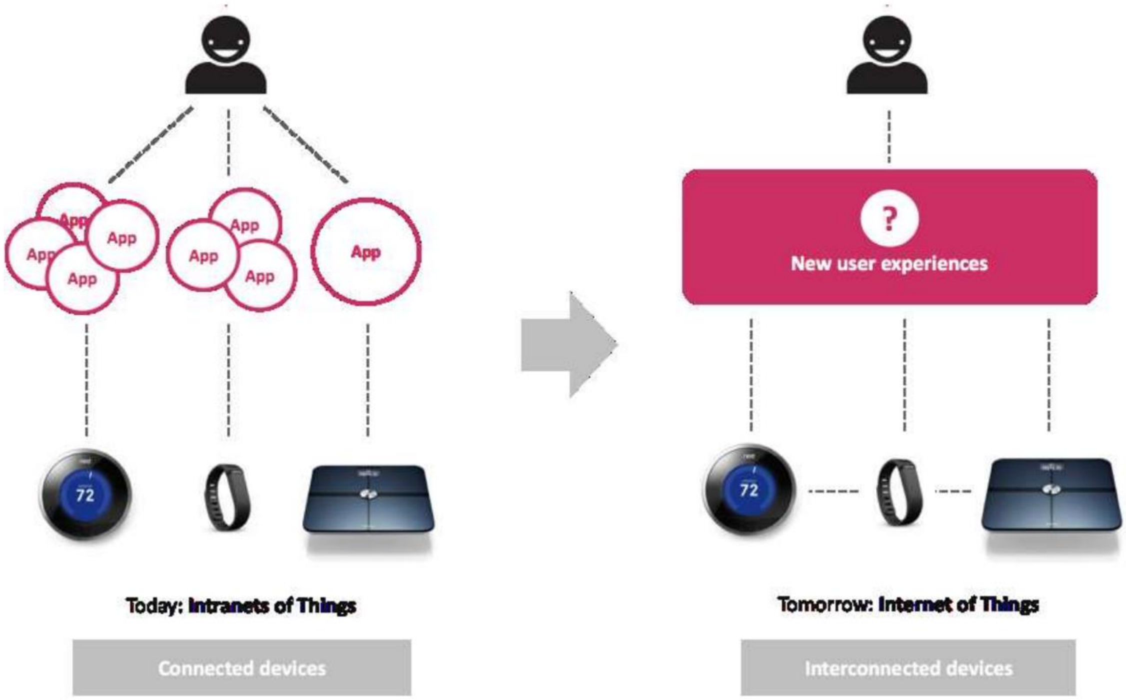
Smart Objects will add tens of billions of additional devices and as there is no scope for IPv4 to support Smart Object Networks, the IPv6 is the only viable way forward:

- Solution to address exhaustion
- Stateless Auto-configuration thanks to Neighbor Discovery Protocol
- Each embedded node can be individually addressed/accessed

Sensors cost/benefit analysis



2.5. What is next?



1. Future Technological challenges

It can be a reflection of five parameters:

Security: IoT already caused security issues that have grabbed the attention of various public and private sector companies of the world. Adding such a big number of new hubs to the systems and the web will provide attackers with a larger platform to invade the system, particularly as many experience the negative effects of security holes. Indications suggested that malware can capture a lot of IoT gadgets being used in basic applications like smart-home devices and closed-circuit cameras and can deploy them against their own servers. A further critical move in security will develop from the way IoT turns out to be involved in our lives. A study proves that cameras connected to the internet will contribute 30% to security concerns. Others are being 15% on house doors, 12% on cars, 10% on TVs, 6% due to iron, 6% on heating systems, 6% on smoke systems, 5% and 5% on an oven and lightening each.

Connectivity: The most significant challenges of the future of IoT would be the device interconnection. This communication will end up resisting the currently existing structure and the technologies associated with it. Presently, a centralized server/client architecture is being utilized to authenticate, authorize and connect several terminals in a network. This model is appropriate only for the current situation and is not scalable to sustain future needs where billions of devices will be part of one network. This scenario will transform the current centralized system into a bottleneck. A large amount of investments and expenditure in maintaining the cloud clusters of servers, which can deal with the humongous quantity of information exchange, are required. Otherwise, the unavailability of servers can lead to a total system shutdown.

Compatibility and Longevity: IoT is developing in a widespread manner. It is incorporating many technologies and will soon advance into a convention. This will pose a serious challenge and will demand the setting up of additional software and hardware in order to establish communication amongst the devices.

Unavailability of standardized M2M protocols, Non-unified cloud services, and varieties in firmware and operating systems among IoT devices are some of the other compatibility issues. Devices working on these technologies will become purposeless in the future as these technologies are likely to become outdated.

Standards: IoT standards are still a work in progress. Standards are well developed and widely adopted in established areas in which IT and operations technology (OT) vendors, practitioners, and standards groups have long operated. However, in new areas, such as low-power wireless and machine-to-machine (M2M) communications, emerging standards are battling it out for dominance. In addition, there are lingering questions about how modern standards can be applied to legacy OT machinery found in manufacturing and other industrial verticals.

But, despite this uncertainty, companies can still turn to a wide range of standards-based IoT solutions—as well as products that use established IT and OT standards—to get IoT projects off the ground and generating real value.

Intelligent Analysis & Actions: The final step in the implementation of IoT is the revelation about the data for analysis. The analysis procedure is based on cognitive technologies and models. There are certain parameters that cause intelligent actions to be incorporated in IOT, some of them being lesser device costs, enhanced device functionality, the machine "influencing" human actions through behavioral-science rationale, deep learning tools, machines' actions in unusual scenarios, information security and privacy and device interoperability.

2. Business challenges

Business chalenges, on the other hand, can be a reflection of three parameters:

Consumer: includes connected devices to IoT such as smart cars, phones, watches, laptops, connected appliances, entertainment equipment and others.

Commercial: devices as inventory controls, device trackers and medical devices.

Industrial: meters, waste water systems, flow gauges, pipeline monitors, manufacturing robots, and other types of connected industrial devices and systems.

3. Social, security, ethical, legal and global concerns

Understanding IoT from the clients and regulators point of view isn't a simple errand for various reasons. IoT data is very sensitive and if leaked, it can give the control of a system in the attacker's hands. Hence we need to shape a strong and reliable technology to secure how IOT data is being used.

References:

Bego, V. : „Mjerenja u elektrotehnici“, Tehnička knjiga, Zagreb, 4. dopunjeno izdanje, 1979.

Biljanović, P. : „Elektronički sklopovi“, Školska knjiga, Zagreb, 1. izdanje, 1989.

Božičević, J. : „Automatsko vođenje procesa“, Tehnička knjiga, Zagreb, 1. izdanje, 1971.

Božičević, J. : „Temelji automatike“, 1. dio: Sustavno gledište i automatika, Automatsko reguliranje, Školska knjiga, Zagreb, 2 izdanje, 1980.

Božičević, J. : „Temelji automatike“, 2. dio: Mjerni pretvornici i mjerenje, Školska knjiga, Zagreb, 8 izdanje, 1991.

Rajić, F. : „Osnove automatike – Mjerenja neelektričnih veličina“, 1. dio, Tehnička škola Ruđer Bošković, Zagreb, 5. izdanje, 1992.

Rajić, F. : „Automatizacija postrojenja za srednje stručne škole“, Školska knjiga, Zagreb, 1. izdanje 2001.

Ravlić, V. : „Automatika“, Velibor Ravlić, Zagreb, 1. izdanje, 1997.

FUTURE AND CHALLENGES OF INTERNET OF THINGS; Falguni Jindal, Rishabh Jamar, Prathamesh Churi, International Journal of Computer Science & Information Technology (IJCSIT) Vol 10, No 2, April 2018

DELOITTE UNIVERSITY PRESS: Inside the Internet of Things (IoT); Jonathan Holdowsky, Monika Mahto, Michael E. Raynor, Mark Cotteleer

INTERNET OF THINGS: CONVERGING TECHNOLOGIES FOR SMART ENVIRONMENTS AND INTEGRATED ECOSYSTEMS; Dr. Ovidiu Vermesan SINTEF, Norway, Dr. Peter Friess EU, Belgium, River Publishers, 2013