Sensor-Based Data Space

CRITICAL INFRASTRUCTURE MONITORING

USE CASE: SUBSTATION TRANSFORMER

Time Series Application

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OUR SMART SENSORS: EMBEDDED EDGE / PRE PROCESSING

CRITICAL INFRASTRUCTURE

Systems, facilities, and assets that are essential for the functioning of a society and its economy.

Their disruption or destruction could have severe impacts on public safety, national security, economic well-being, and/or public health.

Protecting critical infrastructure is crucial for ensuring the stability, security, and resilience of a society.

Governments, private sector organizations, and international entities often cooperate in projects typically involve risk assessments and catastrophe simulation, investment in security measures, contingency planning, and improving coordination.

- 1. Energy: Power plants, electrical grids, oil and gas pipelines.
- 2. Transportation: Airports, seaports, railways, highways, bridges.
- 3. Water: Water treatment plants, dams, reservoirs, wastewater treatment facilities.
- 4. Communication: Telecommunications networks, internet infrastructure, broadcasting stations.
- 5. Healthcare: Hospitals, medical facilities, pharmaceutical manufacturers.
- 6. Financial Services: Banks, stock exchanges, payment systems.
- 7. Food and Agriculture: Farms, food processing plants, distribution networks.
- 8. Government: Government buildings, emergency response agencies, defense installations.
- 9. Emergency Services: Fire departments, police stations, emergency medical services.
- 10. Information Technology: Data centers, cybersecurity infrastructure, critical software systems.

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- **1. Energy: Power plants, electrical grids, oil and gas pipelines.**

OUR USE CASE IS THE TOP PRIORITY!

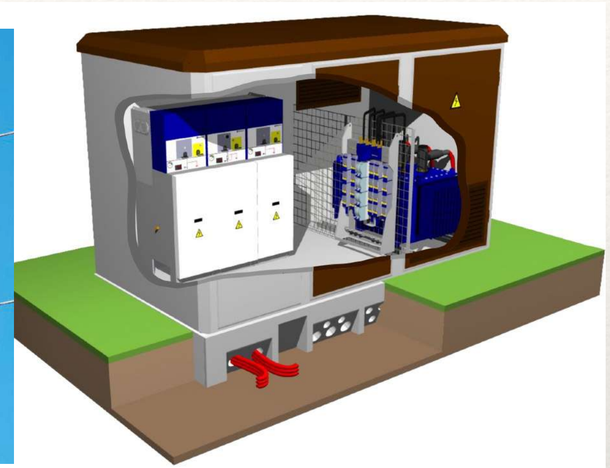
WHY SUBSTATION TRANSFORMER CENTERS?

- Substation Transformer Centers play a key role in the GRID System, stepping down the voltage of electricity as it travels from power plants to end users
- Transformer Centers are not monitored today. They need a complex combination of different sensors. There is no solution in the market.
- Utility companies worldwide will invest billions in their transition to Smart Grids over the next 10-15 years
- There are 28 million Substation Transformer Centers in the world

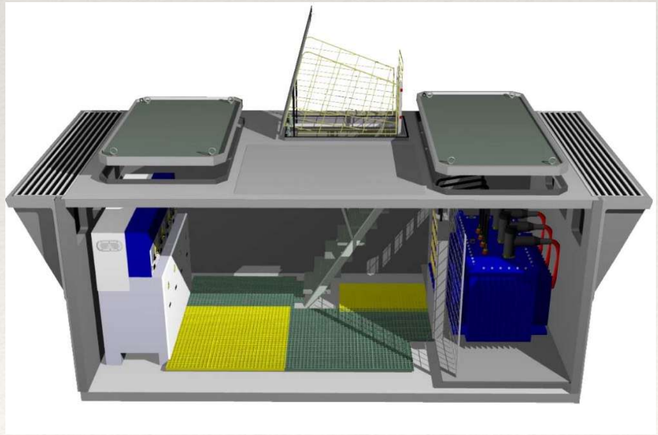
Alteria has a unique turnkey sensor based monitoring system…

….that will become a market reference.

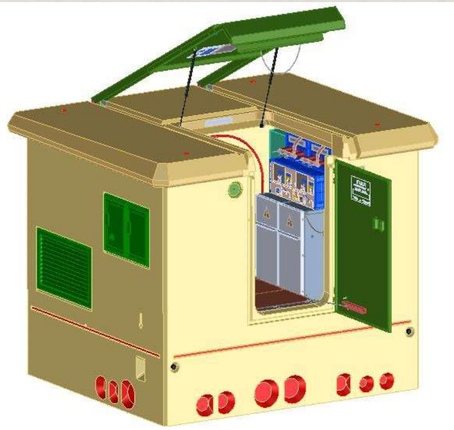
POLE TS



MODULAR TS



UNDERGROUND TS



SEMIBURIED TS

PROJECT BACKGROUND

- Conscious of the Smart Grid challenges ALTERIA started in 2018 the development of sensor combination to create a Substation Transformer Center Digital Twin.
- Late 2019 we were awarded with an **IBERDROLA** challenge to develop a sensor system to monitor transformer centers.
- After the pandemic the **IBERDROLA** challenge was enriched and re-launched internationally in 2022, and ALTERIA won the challenge again, now amongst 38 proposals to perform a PoC.
- In late 2023, **EDP** awarded ALTERIA with a challenge to provide sensorization of substation transformer centers in two PoCs: One for primary and One for secondary centers.

- https://www.iberdrola.com/innovation/international-startup-program-perseo/wireless-sensors-transformer-centres
- https://espana.edp.com/en/news/energy-starter-selects-nine-startups-innovative-proposals-electricity-grids-0

TIPS

- The Substation Transformer Centers are the heart of the distribution grid.
- The technology has evolved very slowly over the last 100 years. The moment is now.

SENSOR TECHNOLOGY OVERVIEW

SMART SENSORS

❖ Definition: Smart sensors are *advanced platforms with onboard technologies*, like pre-processing, intermediate storage, diagnostics and DFU/OTA (Direct Firmware Update/ Over the Air Update)

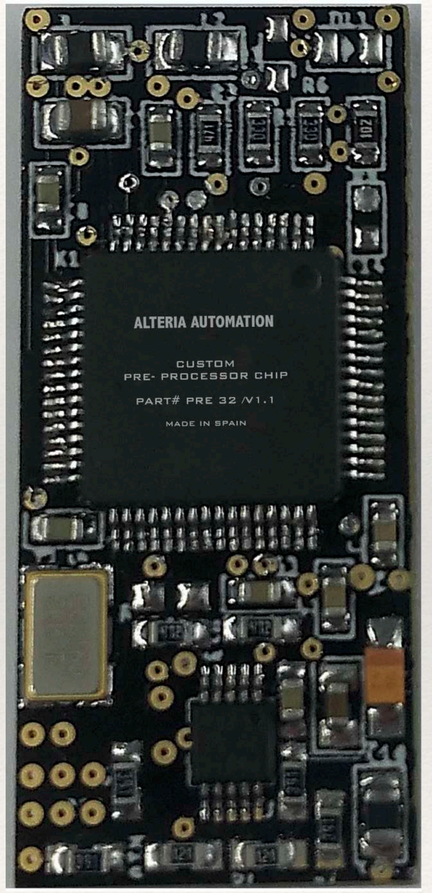
❖ What they do: Smart sensors transform traditional *analog signals into true digital insights*.

❖ The Difference: The pre-processing capabilities, its power, flexibility and adaptability to a particular task.

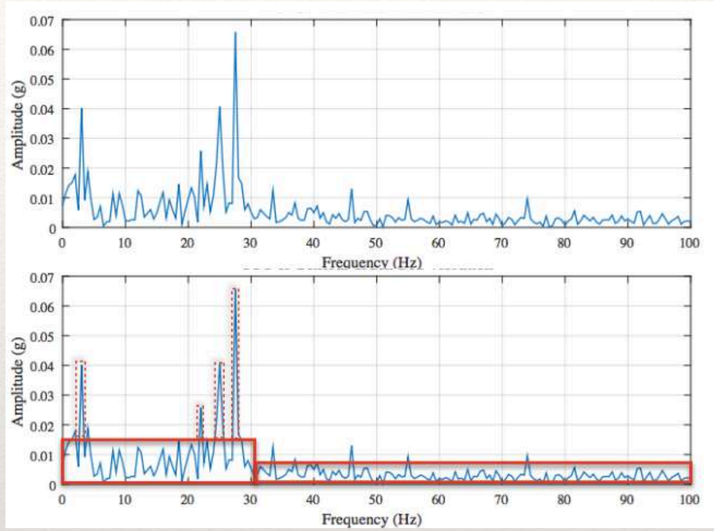
❖ A.I. Ready: Newly developed Embedded computing capabilities allow A.I on the EDGE. Miniaturization and low power have strengthened substantially over the last years, thereby enabling powerful data pre-processing at the EDGE.

❖ Embedded EDGE: Is the next great technological step towards:

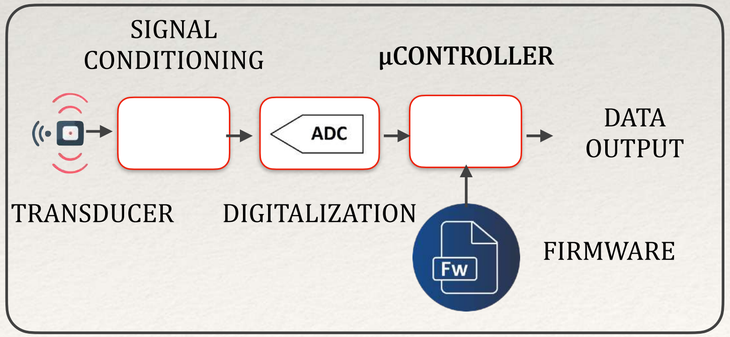
1.- Minimizing garbage data with *Feature Extraction*
2.- Improving A.I. models by *eliminating noise over relevant data*
3.- Eliminating uncertainty/false positives with *Sensor Fusion*
4.- Improving A.I. models by *eliminating noise over relevant data*



SMART SENSOR PRE-PROCESSOR REAL SIZE IS ONLY 35 x15 mm



FEATURE EXTRACTION



SMART SENSOR LAYOUT

REAL - TIME ACQUISITION

DIFFERENT TECHNOLOGY OPTIONS

☑ Embedded edge or Pre-processing **(OUR WAY!)**

The image on the right side is showing **a real Acoustic Energy Ultrasound sensor used for partial discharge**

Advantages

Pre-processing provides a lighter payload **avoids clogging** the server **with irrelevant data**

Only relevant data is useful to **create predictive models**

Pre-processing is better performed **using feature extraction methods** as pre-processing can discard valuable physical variable environmental information such as background noise.

What is inside

○ Using commercial sensors or cameras, data acquisition hardware, PC computers and storing raw data **(EXPENSIVE, UNRELIABLE, COMPLEXITY)**

The image on the right side is showing **a real substation transformer data acquisition rack, used to monitor partial discharge**.

Problems

Heterogenous data integration of standalone equipment ,not designed for unnatended operation

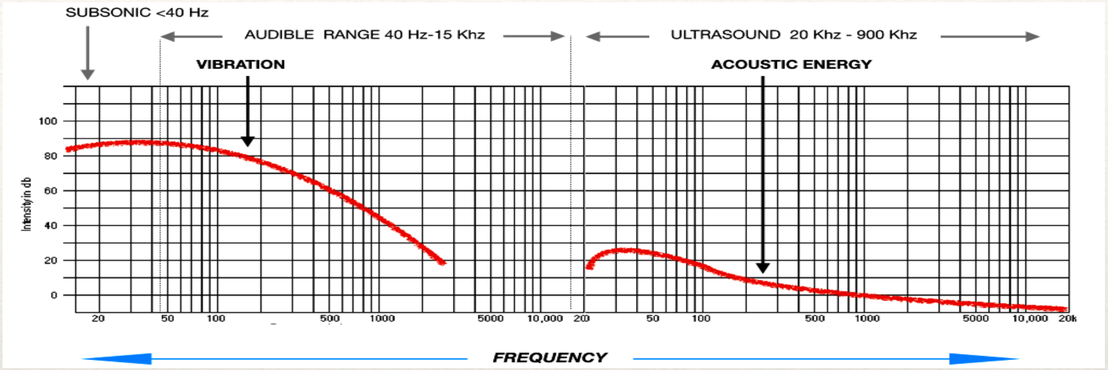
Expensive commercial hardware!

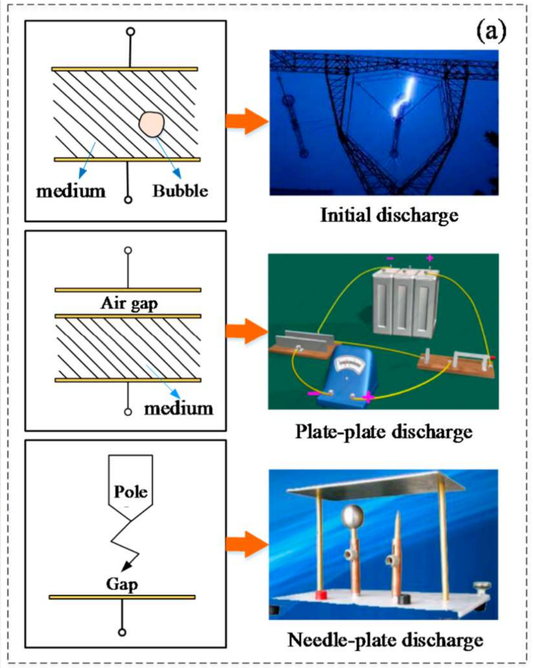
Large **footprint, Frankenstein integration** of different equipment, messy wiring, reliability issues, bulky!

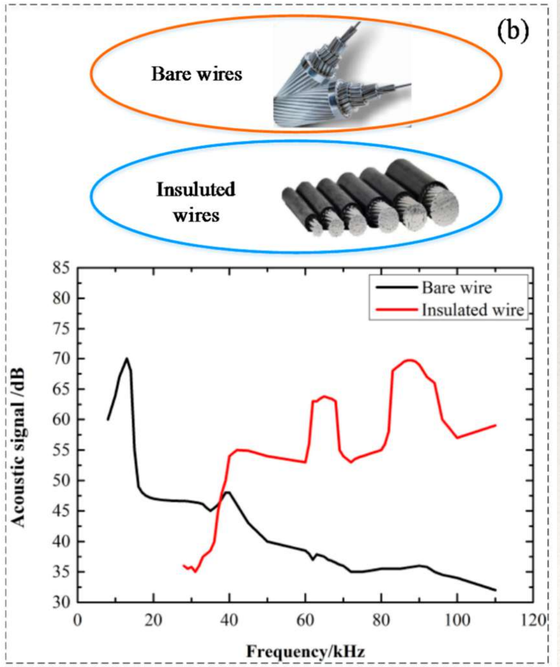
Very large **storage space required** at database. Too much irrelevant data fouls the creation of predictive models

1.- ACOUSTIC ENERGY (ULTRASOUND)

- How it works: **Ultrasound** spectral analysis over non-audible frequencies
- Definition: Acoustic energy is the **transient elastic waves** within a material, caused by deformation and the **release of localized stress energy**
- Advantage: Earliest warning. Research has reported that Acoustic energy sensors are more sensitive to early faults than other sensors, while immune to interference
- Cost: Affordable today thanks to modern electronics
- Payload: Bandwidth hungry. Needs embedded edge pre-processing often
- Applications: **Transformer partial discharge, Electrical switchgear faults, terminal tightness and rust, Corona arcing on HV cells**

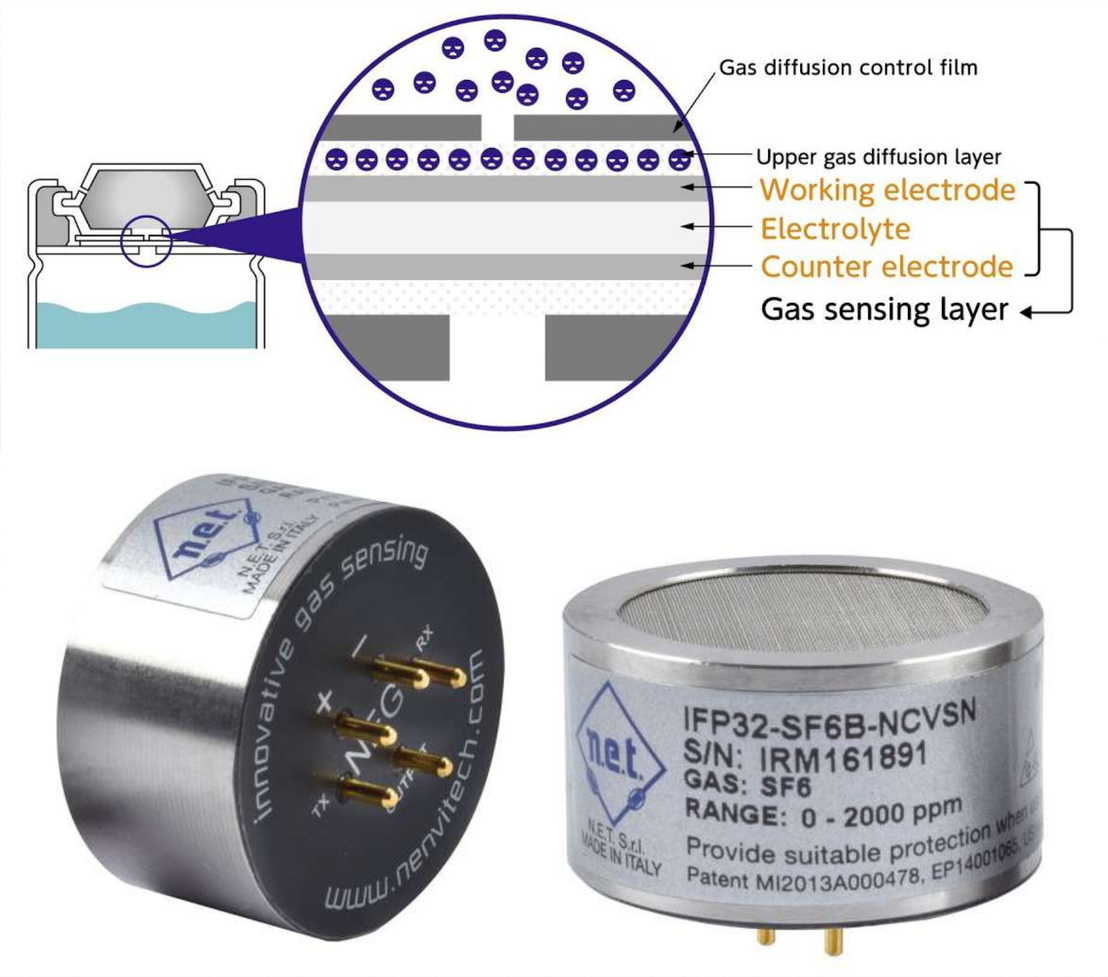






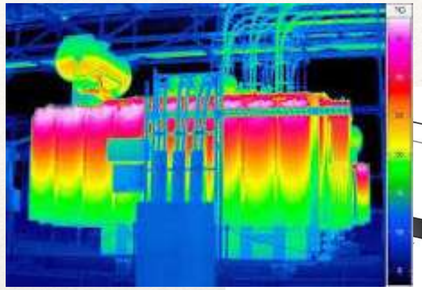
2.- GAS & ARTIFCIAL NOSE SENSORS

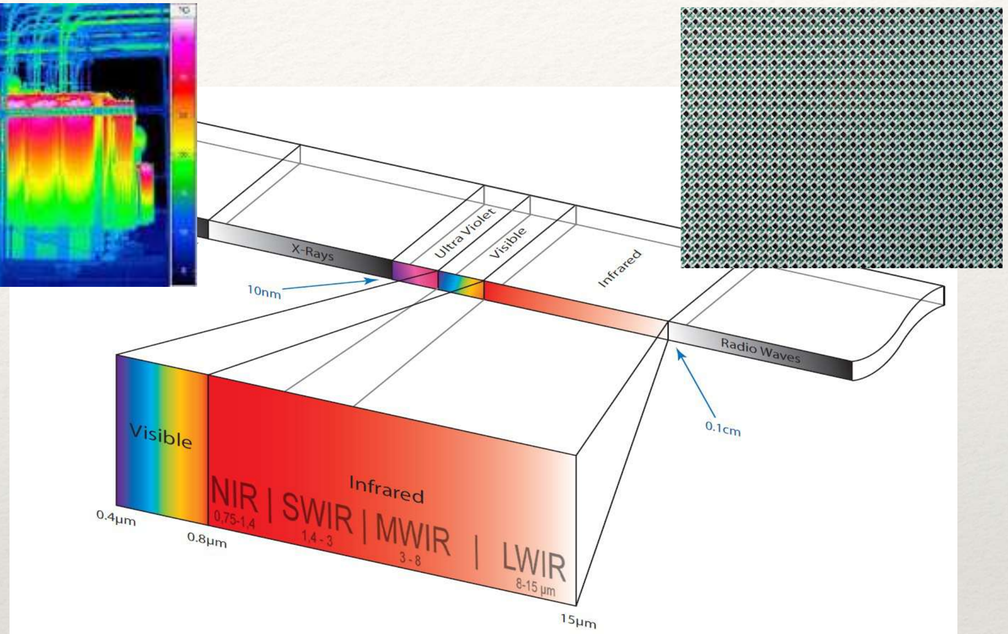
- How it works:
  - **Electrochemical gas transducers are sensible** and react t**o the presence of a certain gas**, while passing a small electrical current
  - **NDIR** (Non Dispersive Infra Red) **gas transducers** work by measuring the **light absorbed in the presence of molecules of a certain gas**
- Physical variable: Gas concentration in ppm or µg/m^3
- Advantage: Clear and **reliable indication of the fault**
- Cost: Medium/Low
- Payload: Low. Data output is only two bytes
- Applications: **Electrical switchgear faults (SF_6 gas isolation leaking), Corona arcing on HV cells (O_3 gas detection)**



3.- THERMAL INFRARED IMAGING

- How it works: **Non-contact Infrared thermocouple transducers** form a rectangular array that delivers thermal imaging without using a video data format
- Definition: The infrared spectrum (780 nm – 1,400 nm wavelength) is called ***thermal infrared*** **and makes a perfect picture of heat generation**
- Advantage: A picture is worth a thousand words. **Imaging is the best information available** with the right processing tools it can detect almost everything physical.
- Cost: Infrared thermocouple transducers proposed **are much cheaper than Infrared cameras**
- Payload: IR thermocouple arrays deliver data that is not bandwidth hungry like cameras that output video signals
- Applications: **Intrusion detection, electrical distribution panel faults, terminal tightness, short circuits, transformer heat and fire detection.**

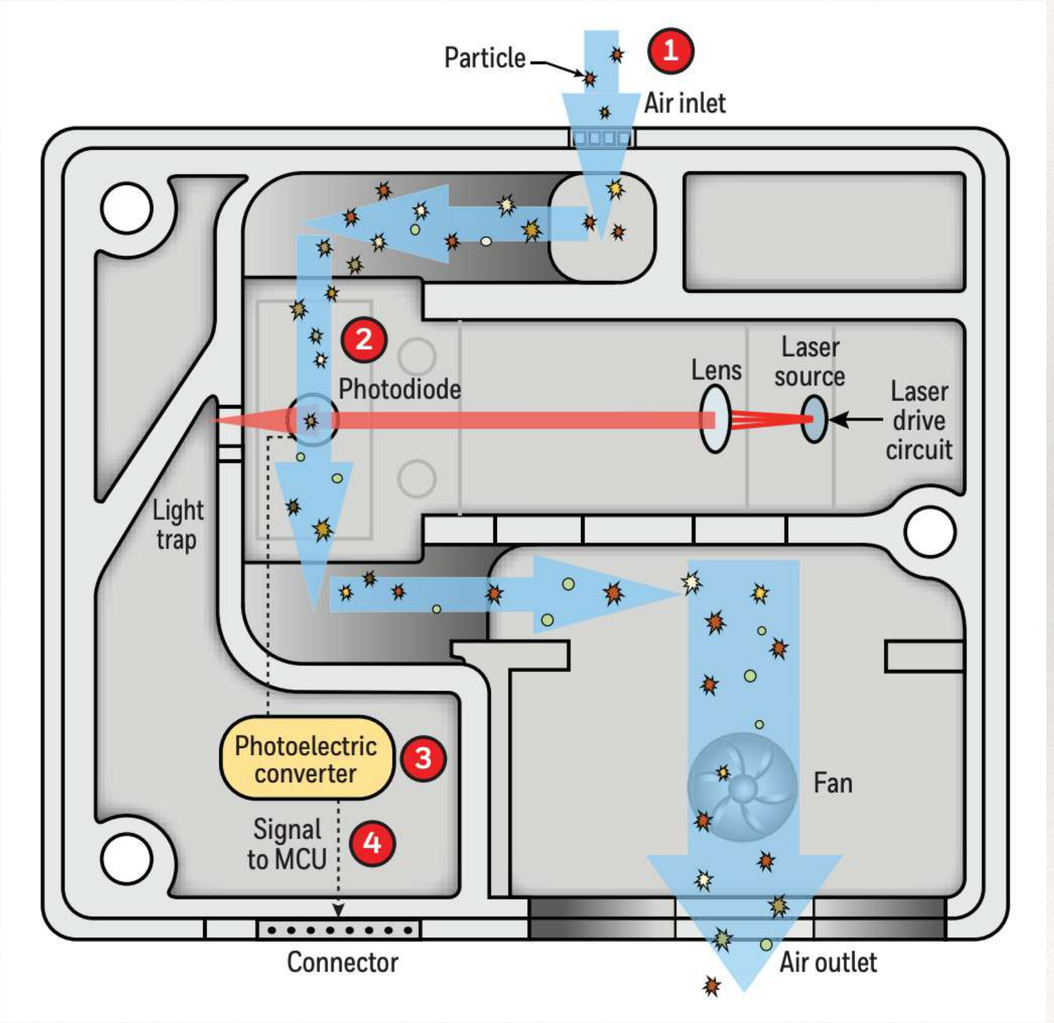




NIR – Near Infrared	0.75 – 1.4 µm	"Thermal Infrared" (Range)
SWIR - Short Wavelength Infrared	1.4 – 3 µm	
MWIR – Medium Wavelength Infrared	3 – 8 µm	
LWIR – Long Wavelength Infrared	8 – 15 µm	
FIR – Far Infrared	15 – 1000 µm	

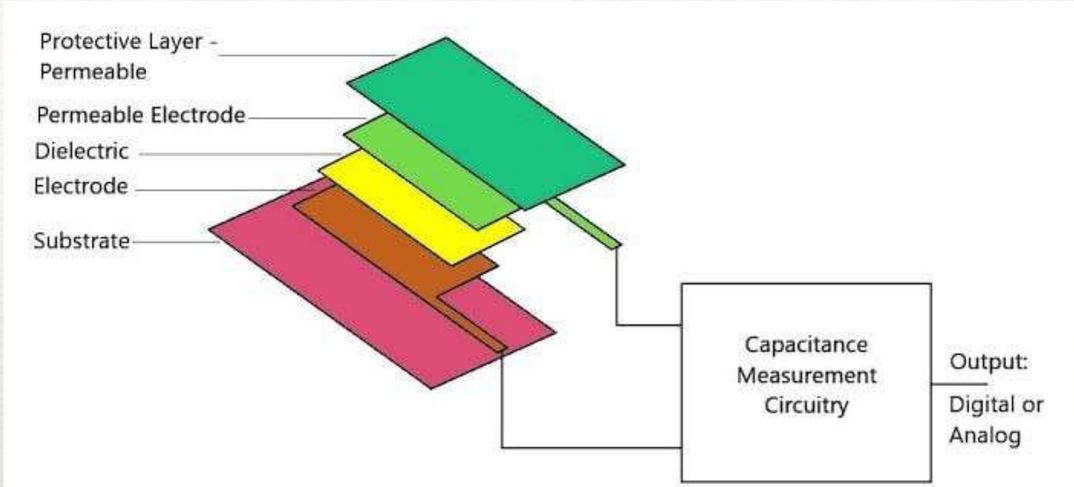
4.- PARTICULATE MATTER

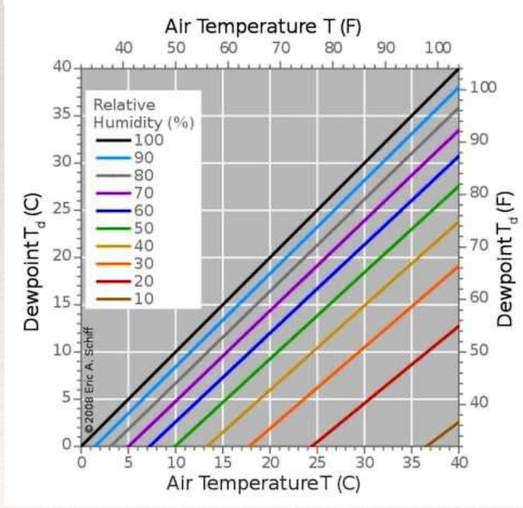
- How it works: Air is passed with the aid of a small fan into dark chamber where **a small Laser beam illuminates the dust** and the reflection is detected by a photodiode
- Technology: The PM sensor uses a laser scattering principle. In the end, equivalent particle diameter and the number of particles with different diameter per unit and particle **volumetric concentration is calculated**
- Advantage: Provides a q**uick assessment of the environment**, discriminates between particle size
- Cost: **Low cost**
- Payload: Low data through output
- Applications: **Fire and smoke detection, non selective gas detection, Open doors and dust ingress to the substation**



5.- HUMIDITY & TEMPERATURE

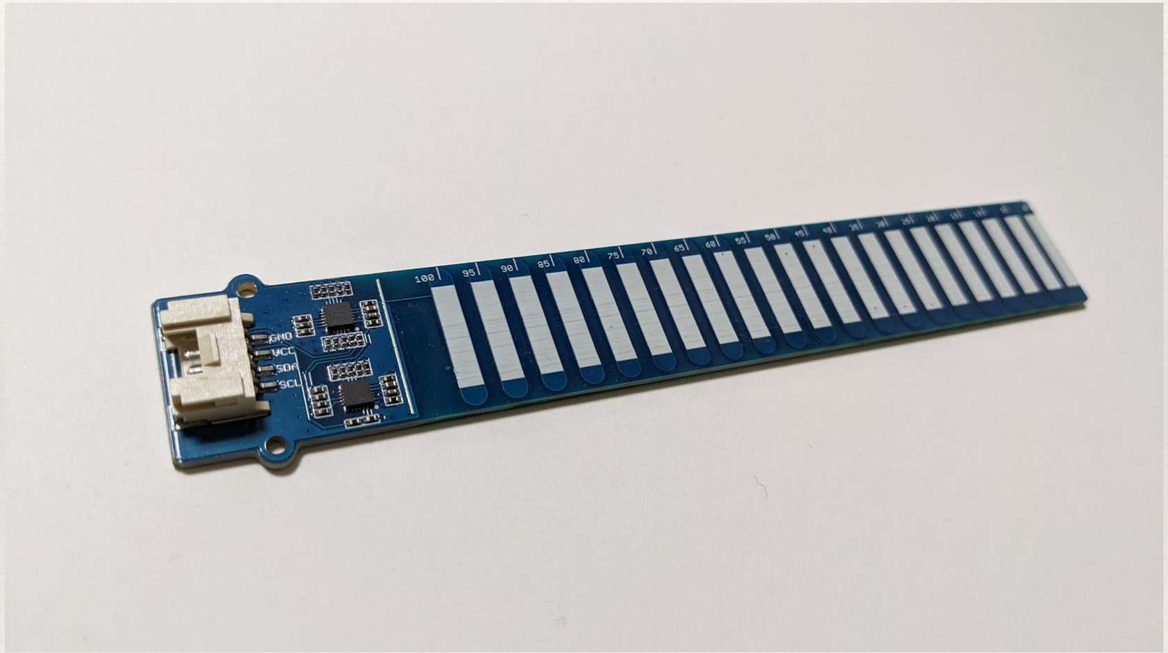
- How it works: **Humidity is sensed by capacitance variation** using moisture-sensitive dielectrics. A temperature sensor corrects the humidity measure given
- Definition: **Humidity sensors use MEMS technology** (Micro Electro Mechanic Systems) that are built with microscopic devices and moving parts. They merge nanoscale and nanotechnology
- Advantage: Provides **early report of water issues**
- Cost: **Low cost**
- Payload: Low data though output
- Applications: **Water roof leaks, flooding, environmental assessment, and dew point**





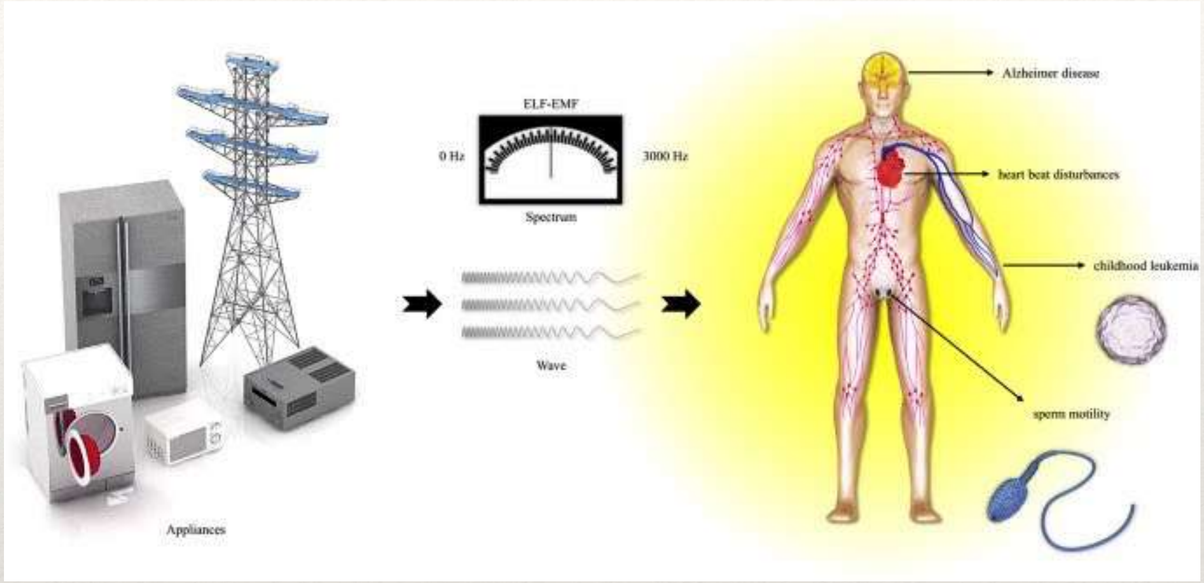
6.- FLOODING

- How it works: **Water is sensed by contact points** built corrosion resistant metals
- Technology: Flooding sensors **use capacitance measuring technology** to provide accurate detection of water presence
- Advantage: Provides confirmation of water ingress, some designs provide **water level information. Automated pump-out action is possible** to avoid further damage
- Cost: Low cost
- Payload: Low data though output
- Applications: **Water roof leaks, storm flooding, rain ingress**

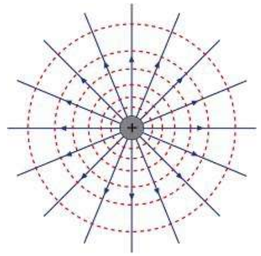


7.- ELECTRICAL AND MAGNETIC FIELDS

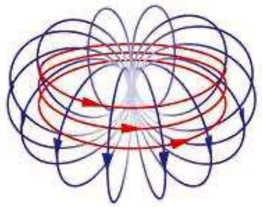
- How it works: Electric fields and magnetic fields intensity **are measured by specific sensors**. Embedded-edge **preprocessing provides immunity to noise and interference** present at the substation
- Technology:
  - **Electric fields** are detected where **voltage is present**.
  - **Magnetic fields** are the detected where electrical **current is flowing** and creates induction
- Advantage: Provides a great **safety measure to the maintenance personnel**. Awareness of electrical shock risk
- Cost: Low cost
- Use: **Sensor is worn by the worker**. Not installed at the substation. Sensor reports wirelessly to data platform
- Applications: **Detection of magnetic fields indicates the transformer is under load. Detection of electrical fields indicates voltage is present, and electric shock risk is still possible**



DETECTION OF 50Hz ELECTRIC FIELD:
ELECTRICAL SHOCK PREVENTION

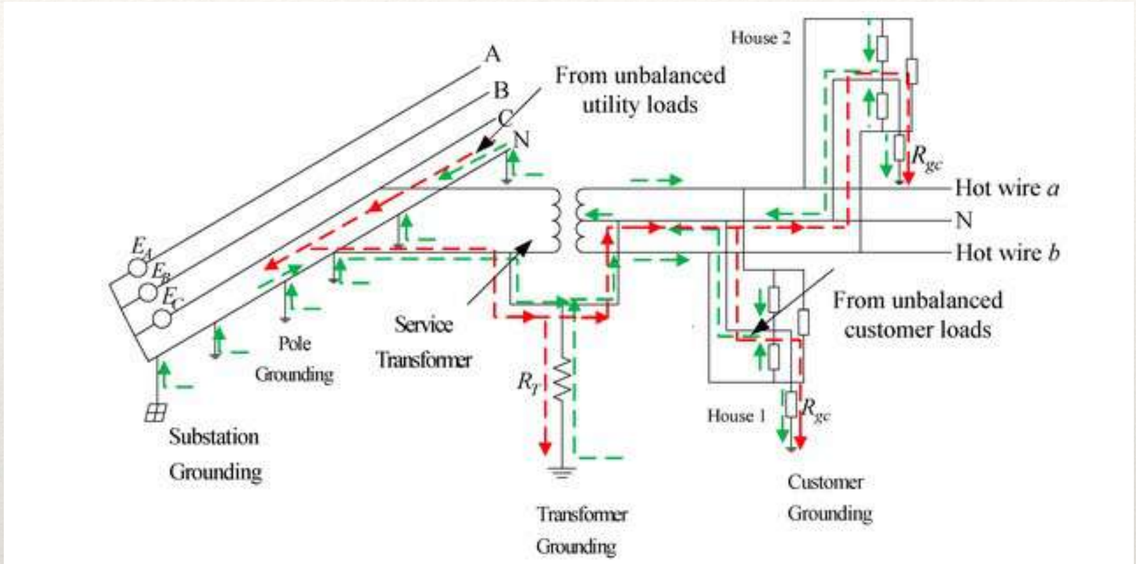


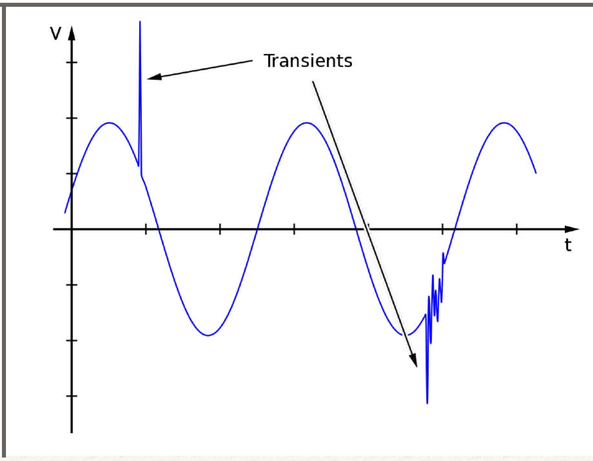
DETECTION OF 50Hz MAGNETIC FIELD:
HIGH ELF EXPOSURE PREVENTION



8.- CURRENT AND VOLTAGE

- How it works: **Hall effect current sensors monitor** AC a DC currents and **transient spikes** up to 1 MHz or 1µS.
- Definition: Hall effect **sensor detects** the presence and **magnitude of a magnetic field using the Hall effect**. The output voltage of a Hall sensor is directly proportional to the strength of the field
- Advantage: **Non intrusive**. Clamps over wires
- Cost: Medium cost
- Payload: High, if the sensor is intended to monitor shorts spikes. **Embedded edge pre-processing possible**
- Applications:
  - **Measurement of Current and Voltage spikes with a Wideband response from DC to 1 MHz and beyond.**
  - **Ground faults at the substation by monitoring Neutral to Earth potential (NEV)**





Sensor Side

I.- ENVIRONMENTAL

TEM/HUMIDITY | GAS | FLOOD

II.-OPERATIONAL

EARTH FAULT | CURRENT | A.E. USOUND

III.- HAZARDS

THERMAL | EMF | PARTICULATE

SENSOR NODE

SENSOR DATA
WIRELESS OR WIRED

Server Side

DATA FROM OTHER SYSTEMS (A.P.I.)

Cloud Server

DATABASE

- Real-Time: Monitoring process based on data from sensors
- Warnings & Alarms: Unlimited threshold levels can be set up to create automated alarms
- Traceability: Data is stored on a database and can be used to create predictive models based on trends
- Predictive Maintenance: Actions can be made using A.I. tools
- Process Automation: Water pumps, extinguishers, Switches can be operated from system
- Security: Data is encrypted and secure protocols in place

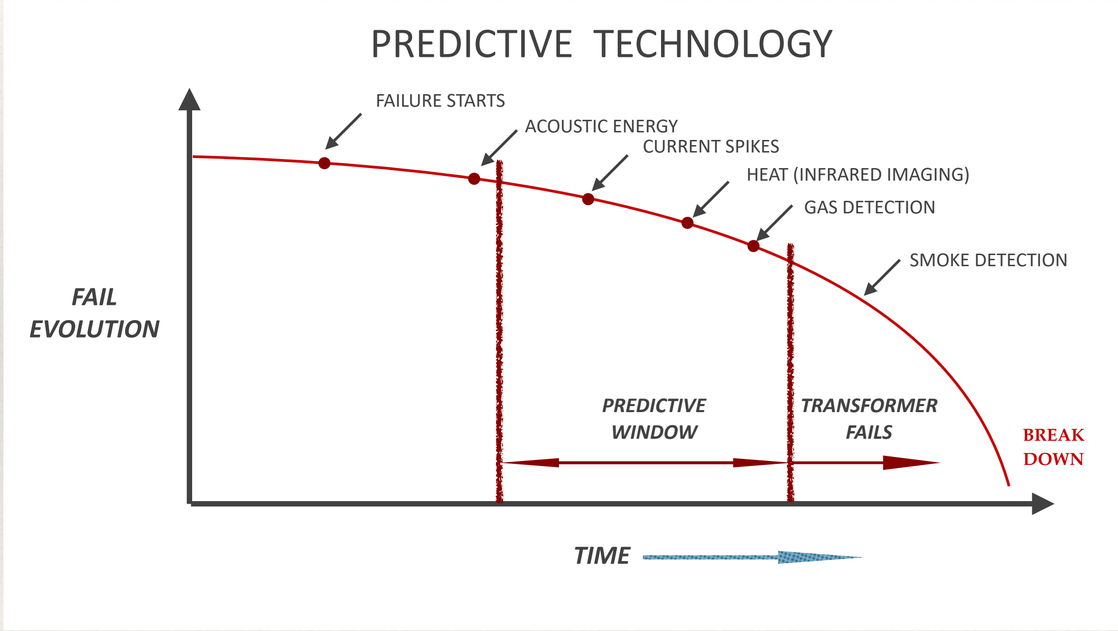
GRAPHIC USER INTERFACE (G.U.I.) DATA VISUALIZATION

HISTORIAN CLIENT
ANALYZING SENSOR DATA FROM SERVER DATABASE

UNDERSTANDING THE SENSOR INSIGHTS

ALTERIA has the know-how for a deep intuitive understanding of sensor use.

- Acoustic Energy (Ultrasound)
  - Measures stray energy such as insulation leaks, material stress such as terminal tightness, and electrical energy disturbances such as H.V. corona and partial discharges
- Current spikes
  - Measures electrical high frequency spikes and energy disturbances
- Heat (Infrared Imaging)
  - Measures extreme energy disturbance, such as abnormal heat and fire, measures also intrusion
- Gas
  - Ozone O_3 gas is created by H.V. Corona, SF6 gas is used on switchgear, leaks need to be detected and reported
- Smoke
  - Smoke is early detected by Particulate Matter sensor as soon as material starts to overheat, well before flame starts



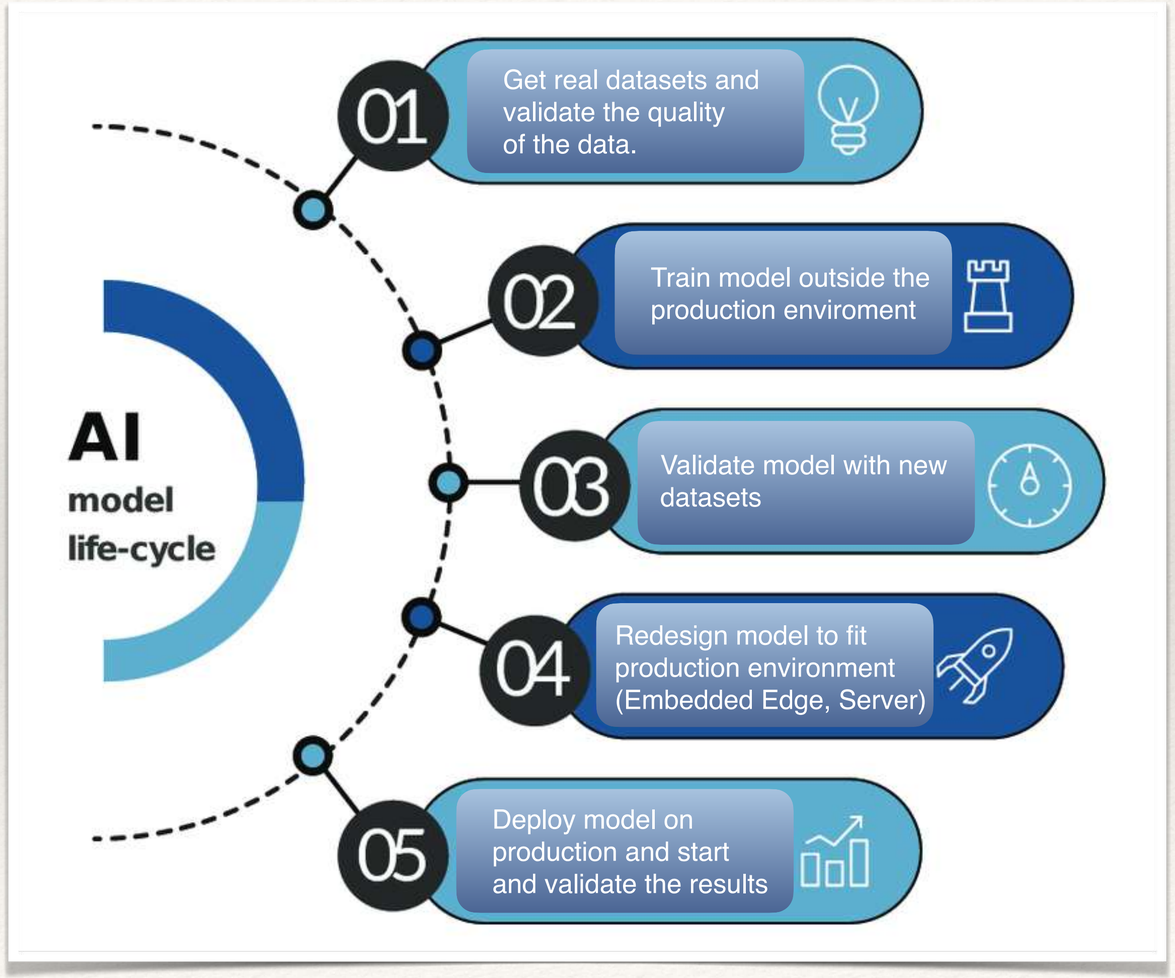
CONDITION CATALOG

- This is a **first proposal of a condition catalog** to perform substation real-time monitoring
- The proposal has to be discussed with the IDE maintenance department to include their **experience with the most common substation problems**
- The **real-time remote monitoring** of the conditions shown is possible **with just nine different sensors**
- To provide a good coverage inside the substation **more than one sensor unit of each type might be needed**
- **Electric and magnetic fields hazard** monitoring is **not included** in this condition catalog **as** in our proposal **is a device worn by the technician**

CONDITION	SENSOR	DETECTION USE	AVAILABLE
FLOOD	5.- HUMIDITY 6.- FLOODING	Flood is detected by high humidity and water detection at the floor	☑
PARTIAL DISCHARGE	1.- A.E. (ULTRASOUND) 8.- CURRENT SPIKES	Partial discharge is detected by ultrasound acoustic energy and high frequency current spikes	☑
OVERHEATING FIRE	3.- INFRARED IMAGING 4.- PARTICULATE MATTER	Heat and fire is detected by infrared imaging and the particles generated	☑
ISOLATION LOSS	2.- GAS (SF_6)	Isolation loss is detected by Sulfur hexafluoride gas leaking	☑
CORONA, ARCING	2.- GAS (O_3) 1.- A.E. (ULTRASOUND) 8.- CURRENT SPIKES	Corona dsichargs are detected by the generation of ozone gas, current spikes an ultrasound acoustic energy.	☑
TERMINAL TIGTHNESS	1.- A.E. (ULTRASOUND) 8.- CURRENT SPIKES	Loose terminals are detected by ultrasound acoustic energy and current spikes	☑
ROOF LEAKS	5.- HUMIDITY	Roof leaks are the detective by high humidity	☑
SMOKE	4.- PARTICULATE MATTER	Smoke is detected by particulate sensor	☑
INTRUSION	3.- INFRARED IMAGING	Human or animal intrusion is detected by infrared imaging	☑
ENVIRONMENTAL	5.- TEMPERATURE 5.- HUMIDITY 4.- PARTICULATE MATTER	Environmental anomalies inside the substation are detected by a combination of environmental sensors	☑
EARTH FAULT (NEV)	9.- CURRENT SENSOR	Earth fault or high impedance is measured by monitoring the neutral to earth potential (NEV)	☑

PREDICTIVE MODEL CREATION

- A.I. based ***models can not created*** upon data ***from libraries or simulations***
- A.I. based models ***have to be created over real data*** from sensors
- A.I. models shall be ***built upon relevant data,*** not based on irrelevant data (noise)
- Too much ***irrelevant data fouls the models***
- Predictive ***models have to be created over real-time data*** and not from partial data from samples



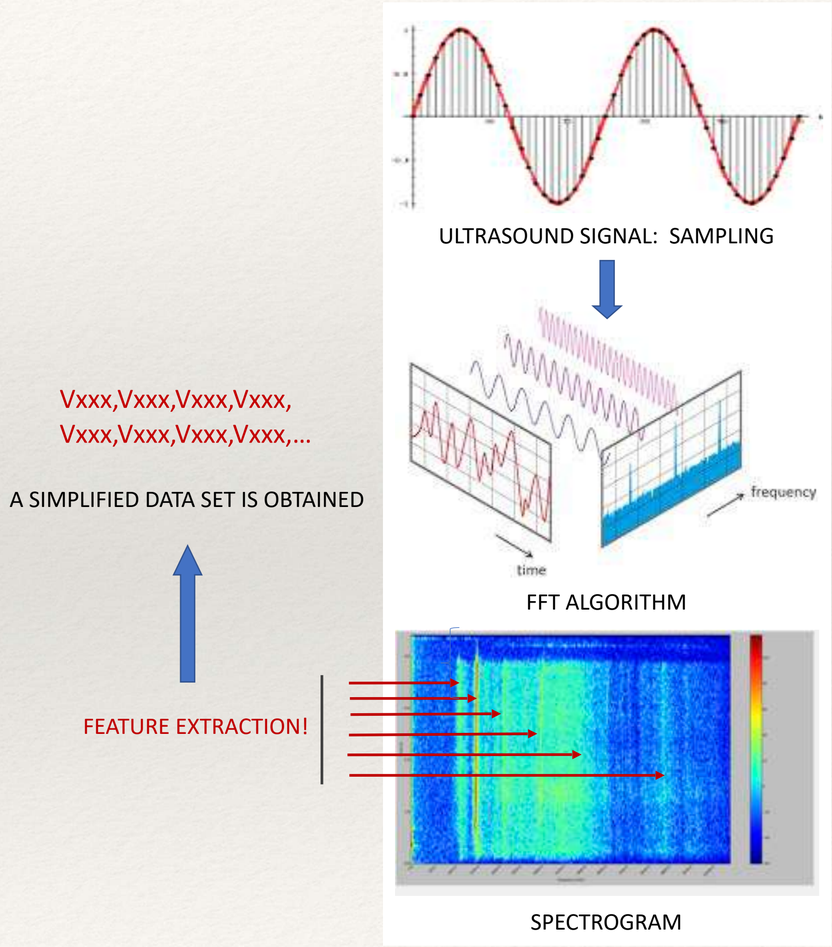
1.- FEATURE EXTRACTION

Feature extraction is a process of dimensionality reduction by which an initial set of raw data is reduced to more manageable groups for processing.

A characteristic of these large data sets is a large number of variables and values that require a lot of computing resources to process.

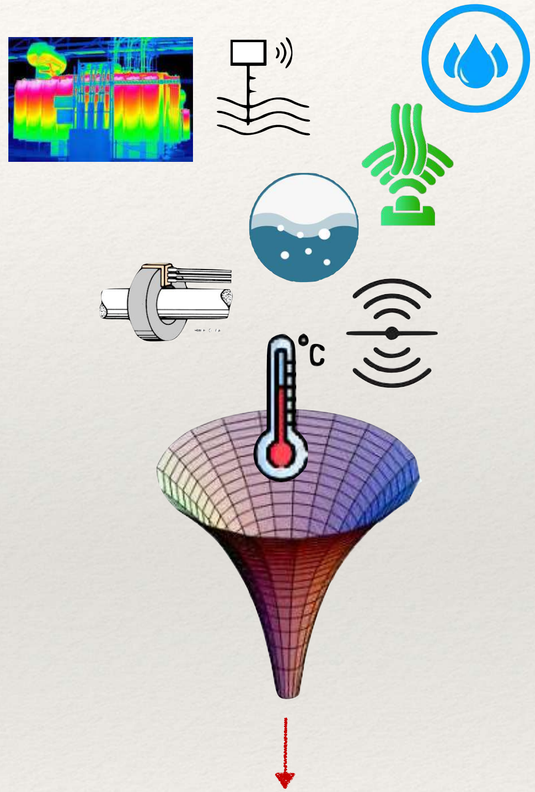
On the example shown:

- The analog continuous ultrasound **signal is digitized**
- Sampled at even time intervals
- A Fast Fourier Transform **(FFT)** algorithm **translates the signal from the time domain into the frequency domain**
- A waterfall spectrogram output is obtained
- A hard-coded or Neural network trained **algorithm performs the Feature Extraction**
- **A simplified low payload dataset is obtained** that truly represents the physical variable
- **Creating models from a simplified dataset** works better **because the irrelevant information is not processed**



2.- HOMOGENIZATION

- Data homogenization **is the process of bringing all data into a common geospatial framework** to ensure consistency of data, integrity of analysis and validity of results
- The process can be idealize as a funnel where **data from different sensors reading different physical variables is fed from different formats, being homogenized and structured** into a consistent data string.
- That complex process is done using **C/C++ running under R.T.O.S.** (Real-Time Operating System) **on an embedded system microprocessor**
- The **process uses algorithm and feature extraction techniques** described before to reduce dimensionality
- **Data string is forwarded to a server where is re-structured** using a declarative human-readable language understandable to the database such as Json
- **Data is stored** using new variable definitions **on a non-Sql database**



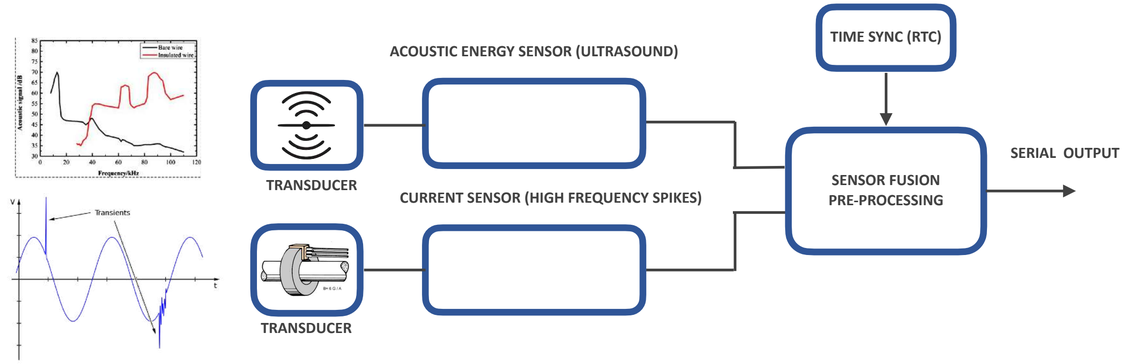
FORWARDED DATA STRING

TEMxxx,HUMxxx,ULTxxx,PMxxx,FLDxxx,GSFxxx,GOOxxx,IRIxxx,CSPxxx…

3.- SENSOR FUSION

- Sensor Fusion is the **process of combining different sensor data** (and other available data) in a way that the **resulting combined information has better accuracy,** to the reality than would be possible when these data are used individually
- **Sensor Fusion was born in the aerospace** industry to read data from sensors along with time synchronization for instrumental navigation purposes
- **Sensor fusion can be used** today on many applications **combining sensor data to create a condition catalog** that helps to generate very accurate predictive models
- In the example shown on the image rigth, **data from different sensors is used to detect partial discharge** from the transformer accurately by **combining acoustic energy** ultrasound information **with** high frequency current **spike transients**.

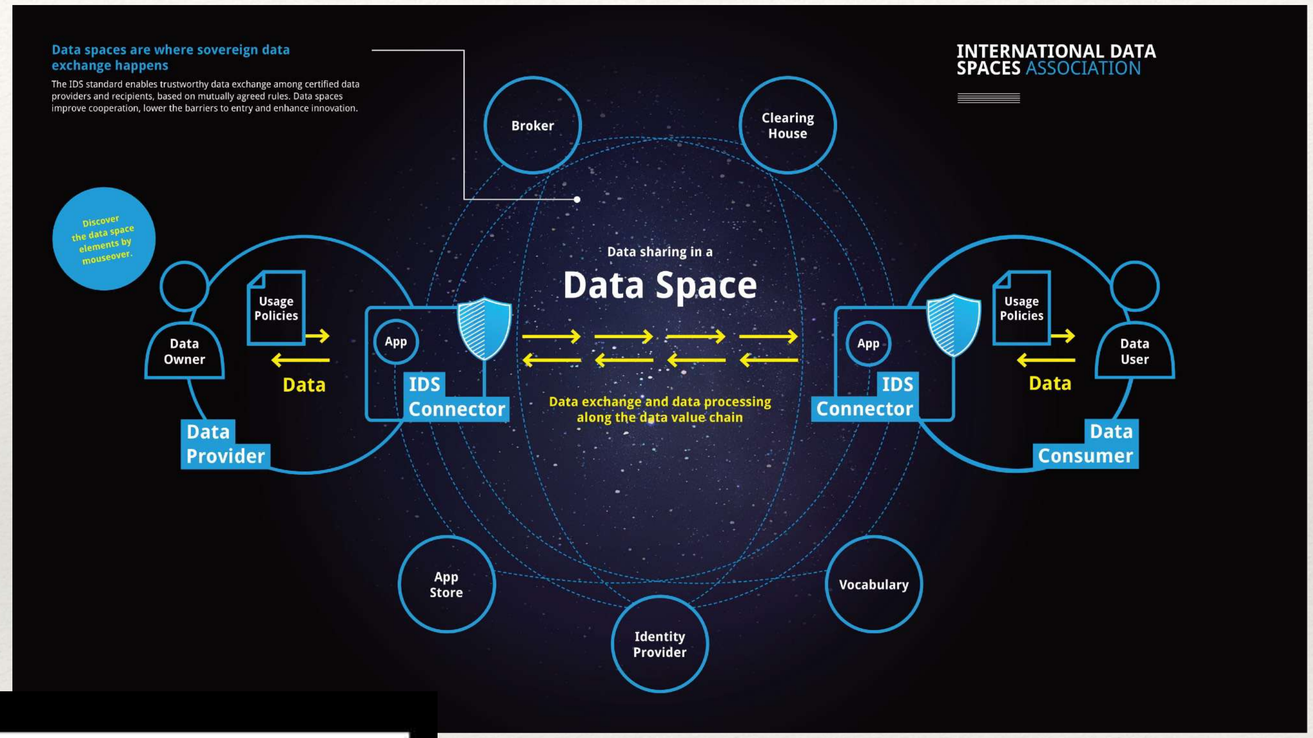
EXAMPLE OF EMBEDDED-EDGE SENSOR FUSION PRE-PROCESSING



Acoustic energy emission is Matched with current high frequency transient spike sensor data to detect more accurately partial discharge events

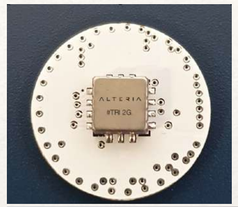
INFRASTRUCTURE DATA SPACE

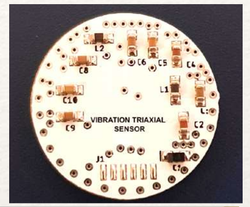
- Critical infrastructure needs **Real-time data**
- **Time-series data**. 1 Sensor 200k samples/s
- Use of **Feature Extraction** provides up to 98% dimensional reduction
- **Data homogeneization** (discrete/non-discrete)
- **Data governance and cybersecurity** a top issue
- Project consulting **International Data Spaces** (IDS)

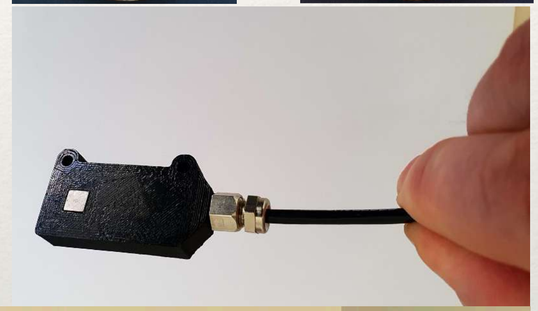


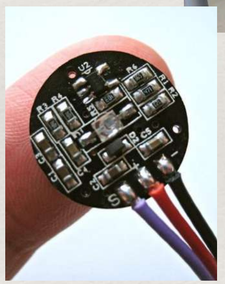
CAPABILITIES & AWARDS

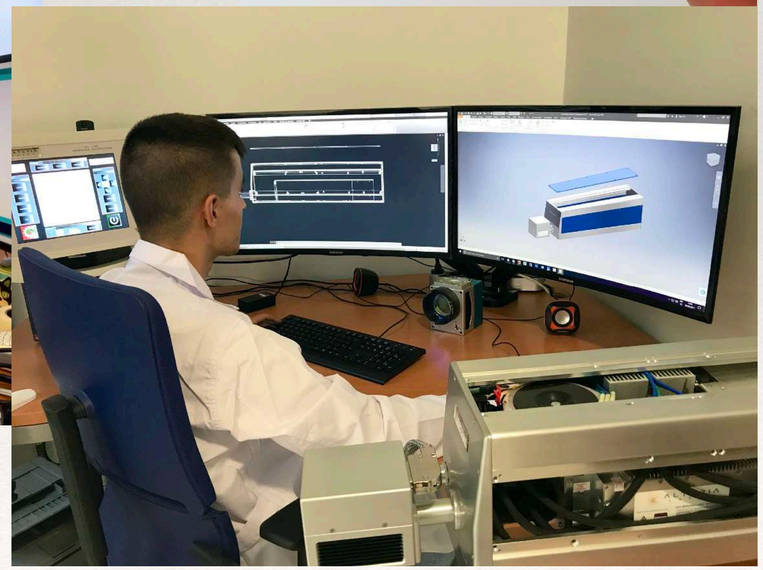
- “SILENSE” Ultrasound (ECSEL 2017-20)
- “PORTASENSE” Predictive Maintenance (CDTI NEOTEC 2018-20)
- “ION UVC” Air Disinfection (INNO4COV-19 2021)
- “SIMULAIR-COV19” (HUBCAP 2021)
- “COPDM” Smart Wearable (DIGI-B-CUBE 2021)
- “LOGISDA” Asset Tracking (MINCOTUR 2021)
- “PLANTAR” Farming Sensors (PENTA 2020-22)
- “AEROSENSE” Smart Wearable (GALACTICA 2022-23)
- “LASERPEST” Farm to Fork (HORIZON EUROPE 2023-25)
- “AVANZA5G” UNICO I+D 5G 2022 (MINECO 2022-25)
- PERTE CHIP 2023 (CEDETI 2024/25)











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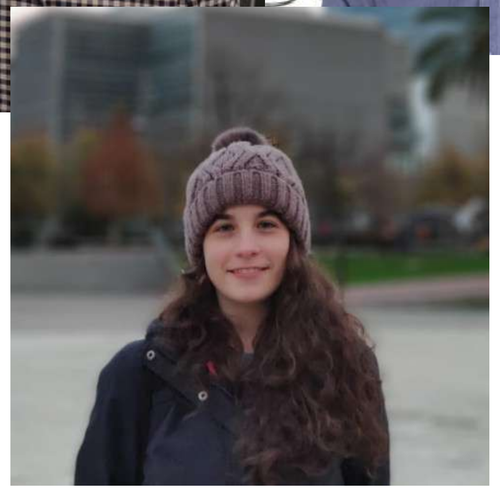

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