Use of Artificial Intelligence and big data analysis in control and diagnosis of complex systems

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1	**Example of an Industrial Complex System**
2	Use of AI and Big Data Analysis for Modelling and Control
3	Use of AI and Big Data Analysis for Anomaly Detection and Life-time Prediction

Oerlikon covers a broad range of surface technologies

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Surface treatments

NITRIDING

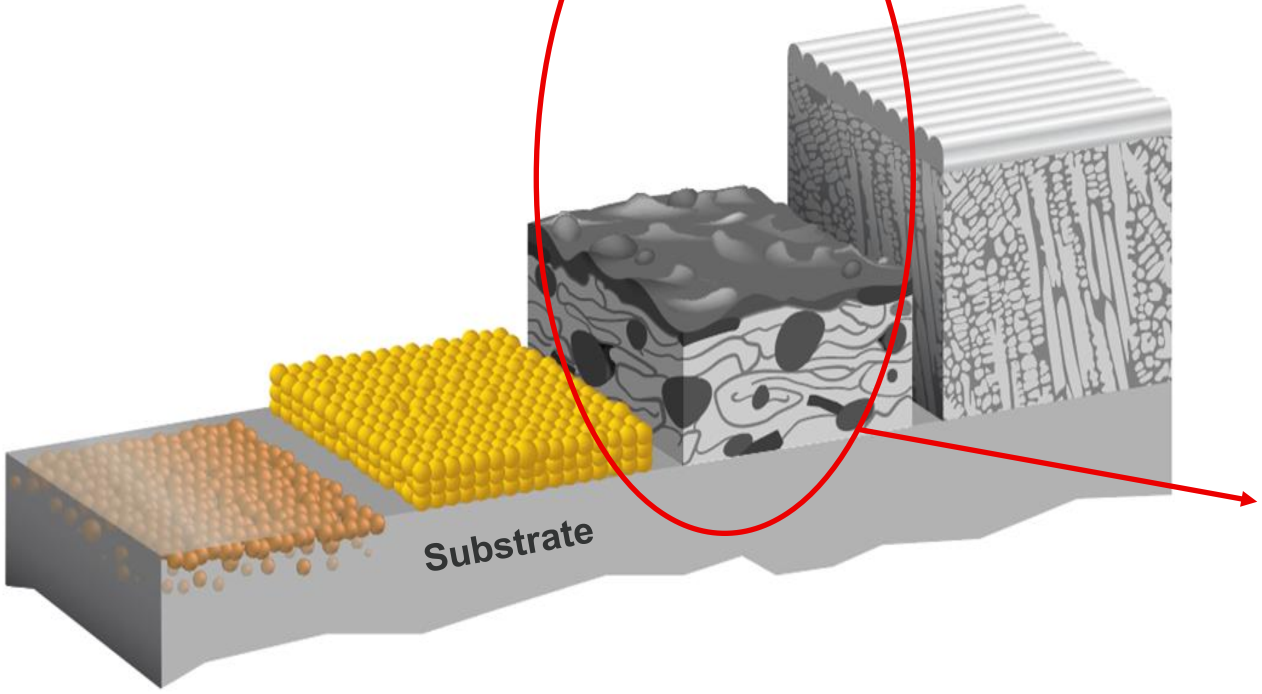
- Plasma Nitriding

THIN FILM COATING

- PVD
- CVD

THICKER LAYER COATING

- Thermal Spray
- Laser Cladding
- PTA



Thermal spraying techniques are coating processes in which melted (or heated) materials are sprayed onto a surface. The "feedstock" (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame).
Thermal spraying can provide thick coatings (approx. thickness range is 20 microns to several mm, depending on the process and feedstock), over a large area at high deposition rate

Thermal Spray System: An Example of a Complex Industrial System

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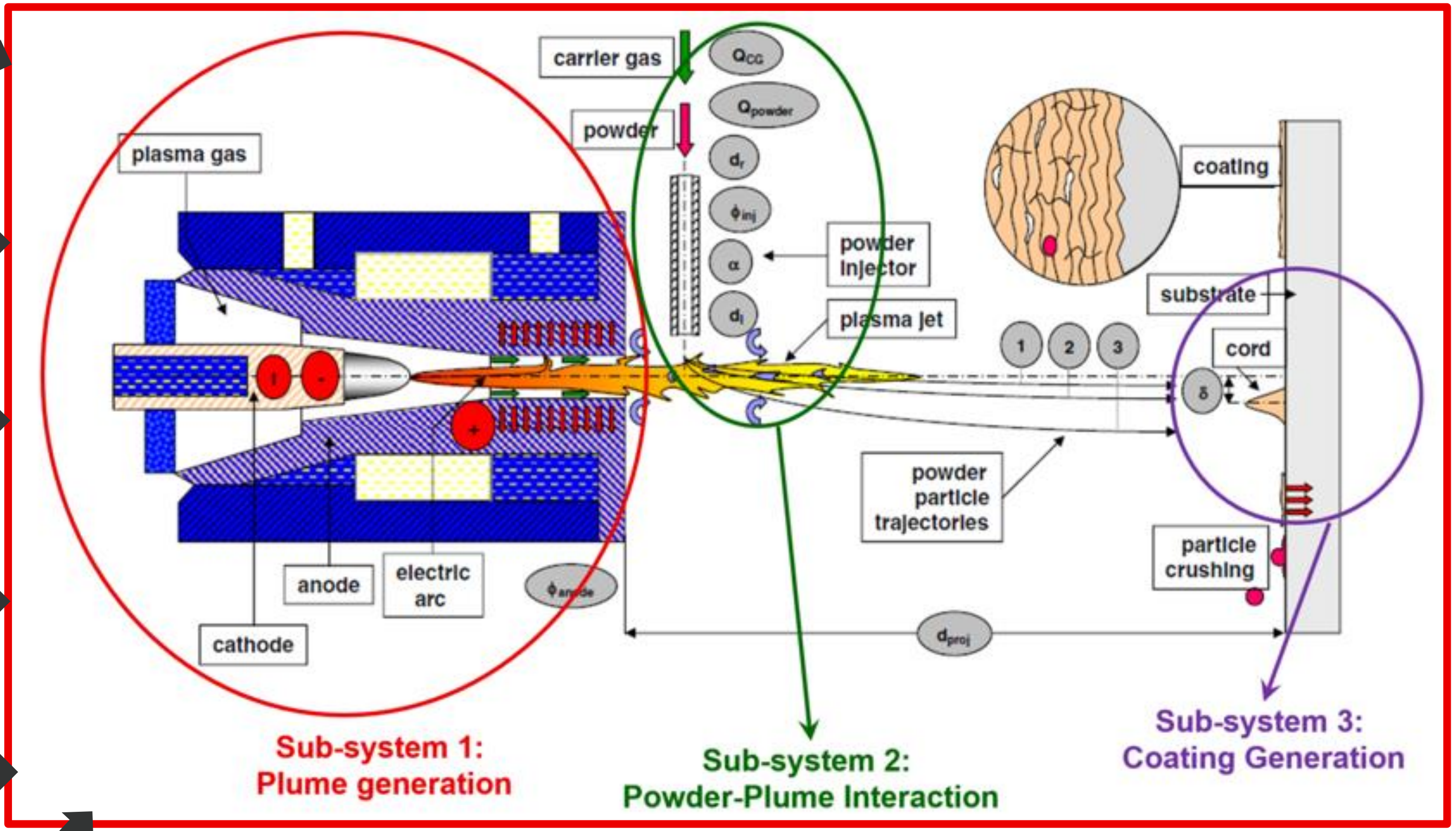
Gas Management Center: Control the flow of process gasses

Power Supply: Control the electrical current and power delivered to the gun

Chiller: Control the Flow and temperature of water to cool down the gun

Ventilation System: Extract the dust from the booth

Robot System: Control the movement and position of the gun



Powder Feeding System: Control the flow of the powder injected to the plume

Thermal Spray Parameters

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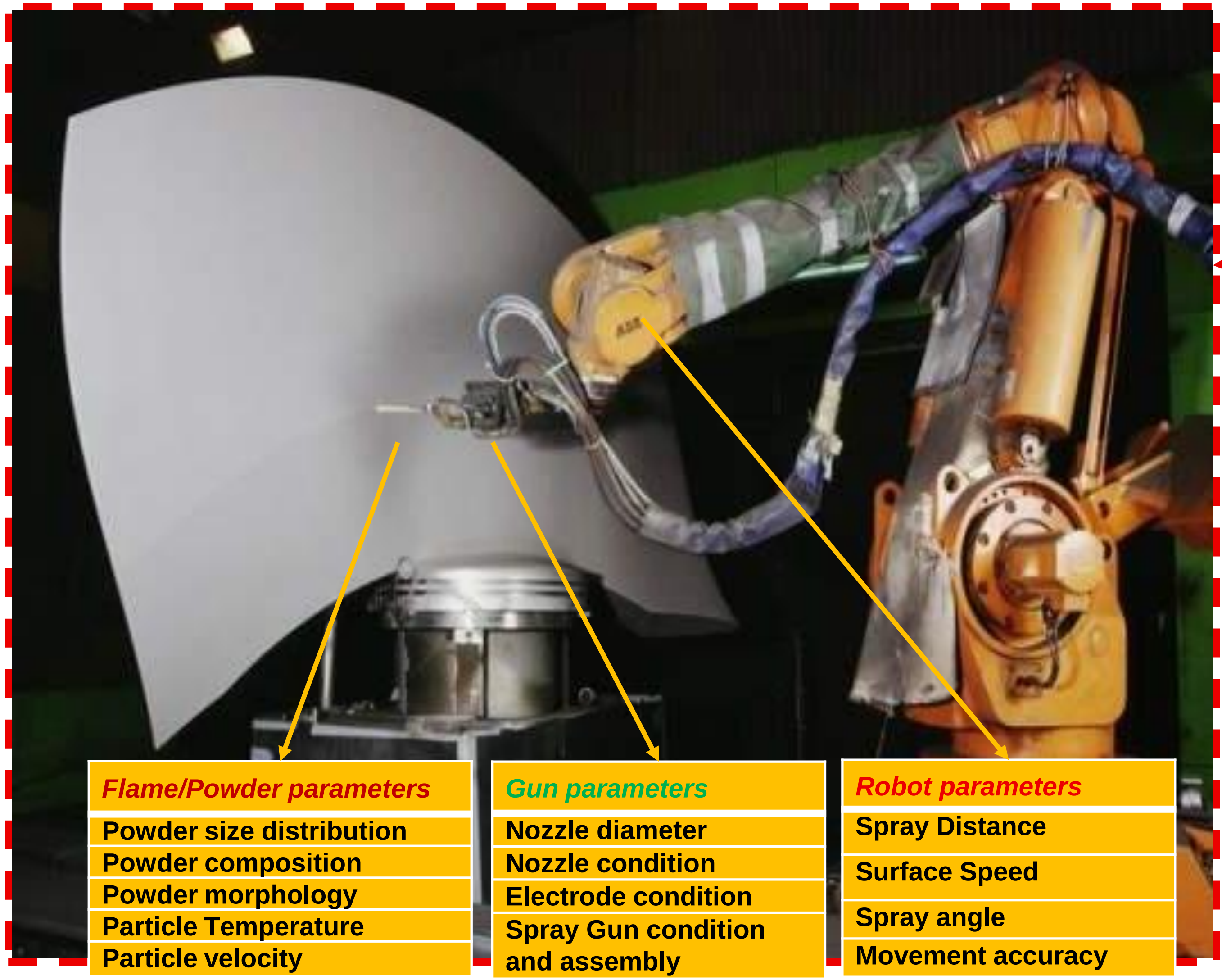

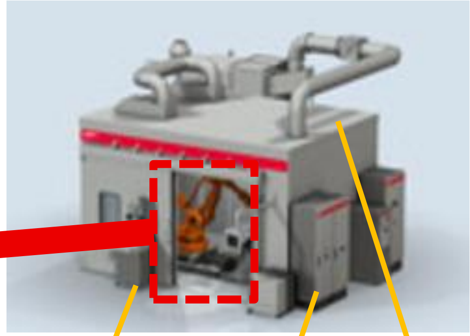

Controller parameters
- Gun Current
- Gas or Liquid fuel flow
- Primary gas flow
- Secondary gas flow
- Shroud gas flow
- Gun Current

Flame/Powder parameters
- Powder size distribution
- Powder composition
- Powder morphology
- Particle Temperature
- Particle velocity

Gun parameters
- Nozzle diameter
- Nozzle condition
- Electrode condition
- Spray Gun condition and assembly

Robot parameters
- Spray Distance
- Surface Speed
- Spray angle
- Movement accuracy

Feeder parameters
- Carrier gas flow
- Powder Feed Rate
- Injector diameter
- Powder injection angle
- Number of Powder Ports
- Carrier gas flow

Booth/Chiller parameters
- Water Inlet Temp
- Cooling Power
- Water Conductivity
- Water flow
- Booth ventilation

It is estimated [1] to be 50 to 60 different influencing parameters. Considering all 5 steps of coating process, the number is estimated to be even greater, up to 150 [2]. Deviations in these parameters can result in significant process variations, reducing process repeatability and reproducibility.

1. P. Fauchais, "Understanding plasma spraying", *J. Phys. D: Appl. Phys.*, vol. 37, no. 9, pp. R86–R108, May 2004, doi: 10.1088/0022-3727/37/9/R02.
2. C. Brunet and S. Dallaire, "The importance of particle size distribution on the plasma spraying of TiC", *Surf. Coat. Technol.*, vol. 31, no. 1, Art. no. 1, Jul. 1987, doi: 10.1016/0257-8972(87)90149-6.

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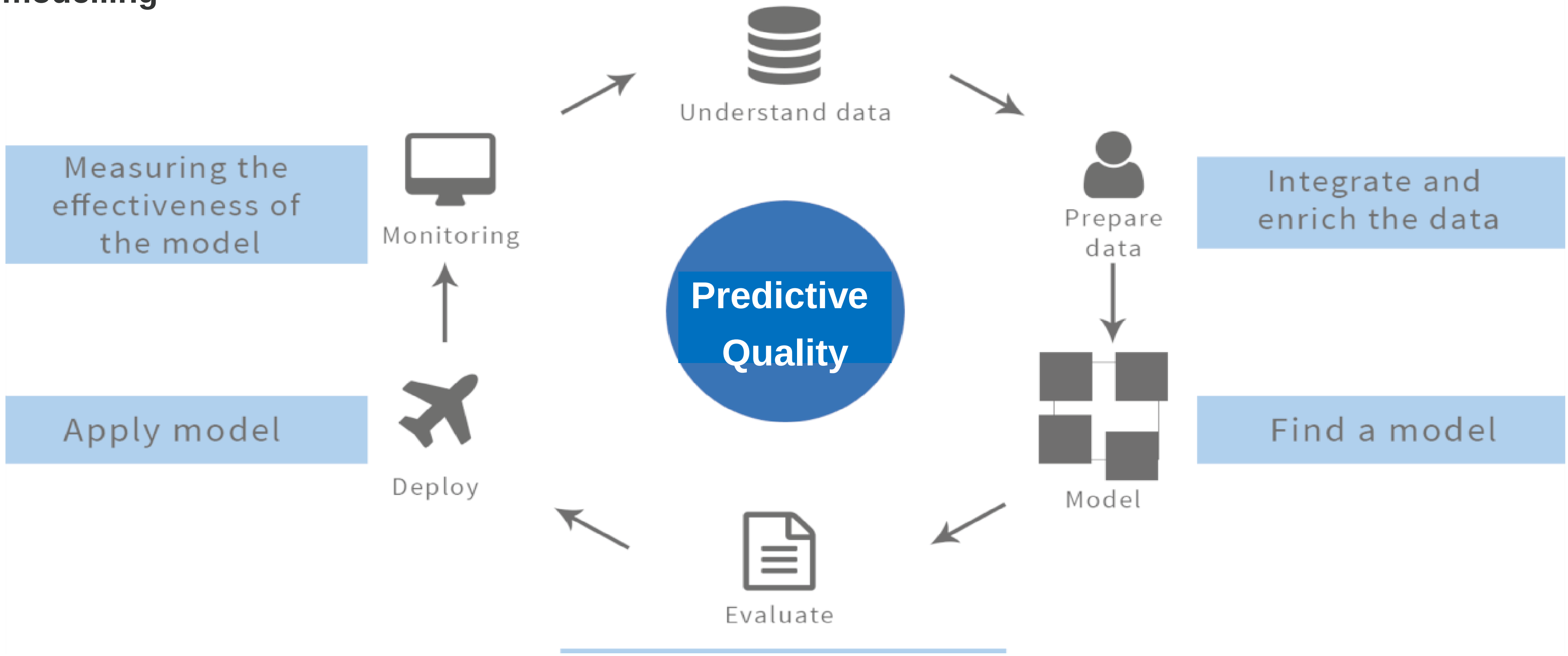
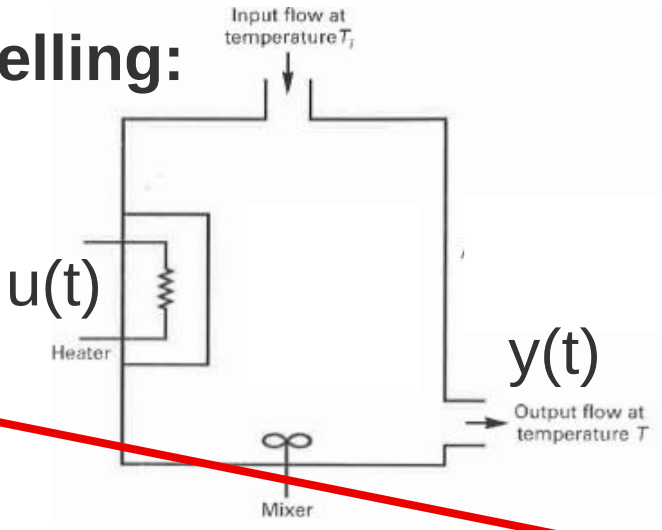
Use of Data Analytics in Control: for example Coating Quality Control

Three methods for system modelling:

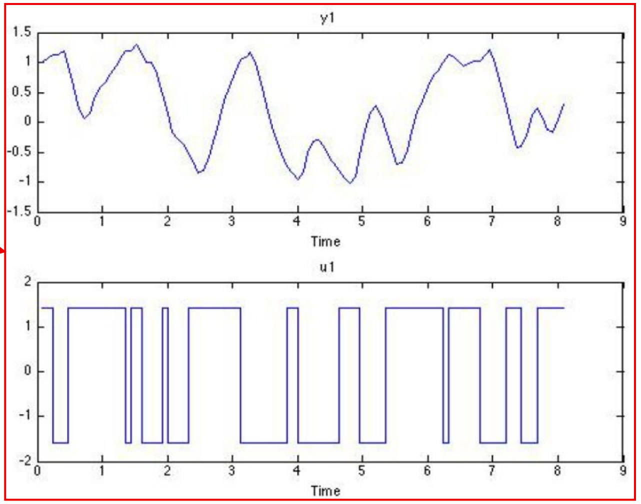
- Mathematical modelling
- Computational modelling
- Data modelling



A Simple Example of Data Modelling:
Identify a model for a Hairdryer



Data Collection
This system fans air through a tube which is heated at the inlet. The input signal u(t) reflects the power of the heating device. The output signal y(t) reflects the temperature of the air coming out.



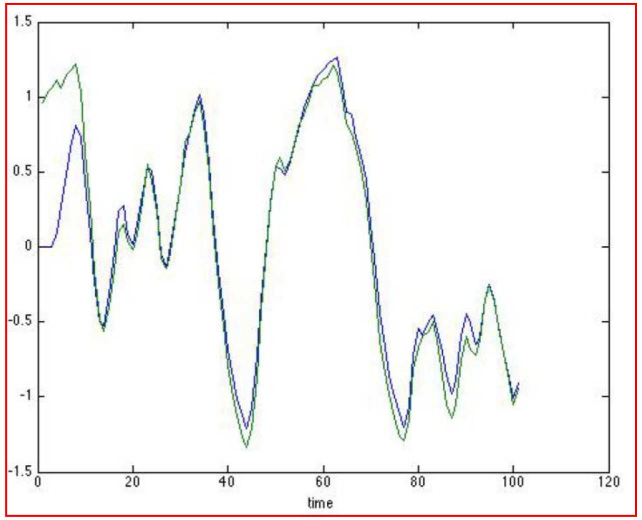
Model Selection
Inspection of input-output suggest the following parametric ARX model relating input to output signals, where {a1 a2, b1, b2} are to be estimated based on the collected data as given before

$$y(t) + a_1 y(t-1) + a_2 y(t-2) = b_1 u(t-3) + b_2 u(t-4)$$

Parameter Estimation
Using packages such as MATLAB, the parameter of the ARX model can be estimated.

```
>> model = arx(z2, [2 2 3]);
```

Model Validation
The actual and estimated outputs are compared, and model accuracy is assessed.



TS Modelling Approaches

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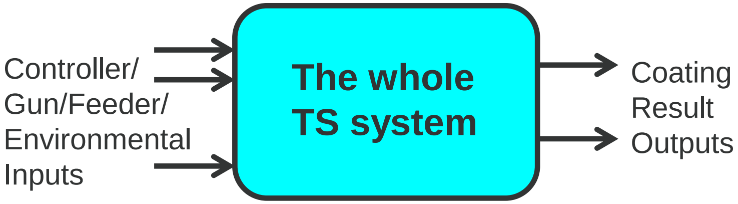
Modeling the whole system as one black box

- Less number of experiments

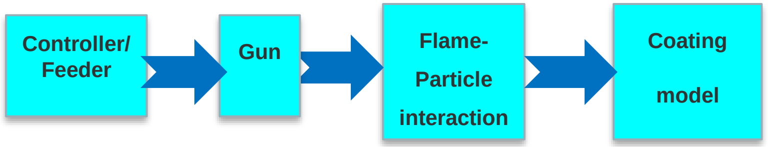
- Cannot determine the effect of each sub-system
- Higher number of inputs
- Less model accuracy



Modeling each sub-system

- More knowledge about each system
- More accurate modeling
- More possibility to re-use a model in other cases

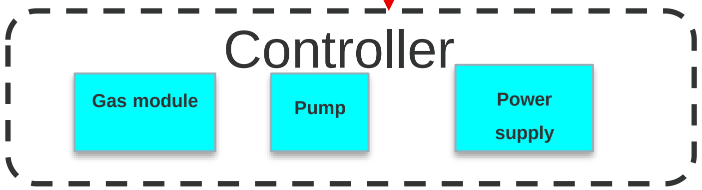
- Higher number of experiments
- Some internal outputs might not be measurable



Modeling each module of each sub-system

- More knowledge about each component
- More accurate modeling
- More possibility to re-use a model in other cases

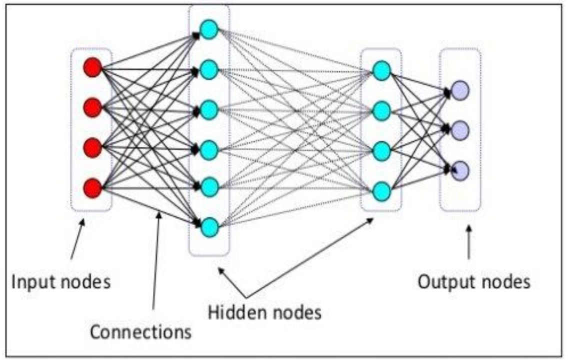
- Higher number of experiments
- Some internal outputs might not be measurable
- Complicated process



AI modelling of Thermal Spray Coating

Approach 1: Neural Network

Inputs: A, G1, G2, Gc, Pf, Pd, Pa, Ps, Pc, Pm, Ac, Sd, Ss, Sa



Intermediate Outputs: Acoustic, Particle T and V, Gun Hardware state, Gun voltage

Outputs: Sr, Sp, Hr, Th, Ad, Rs, DE

- Computationally efficient for huge data sets

- Data-hungry approach
- Not accounting for noise in data

AI modelling of Thermal Spray Coating

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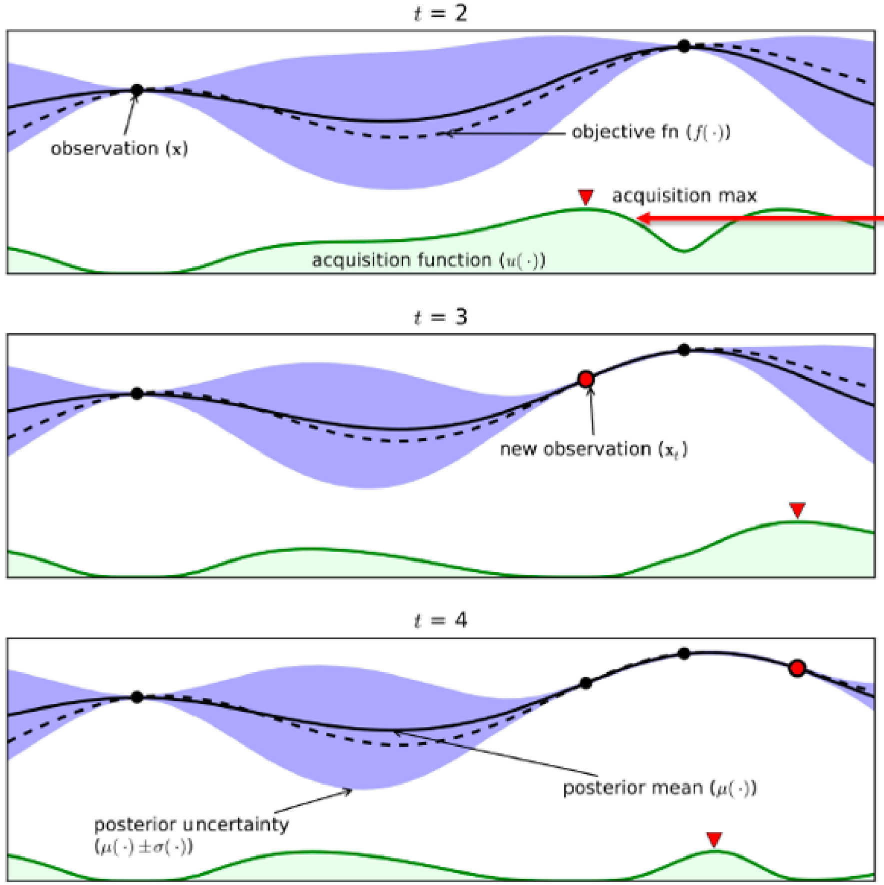
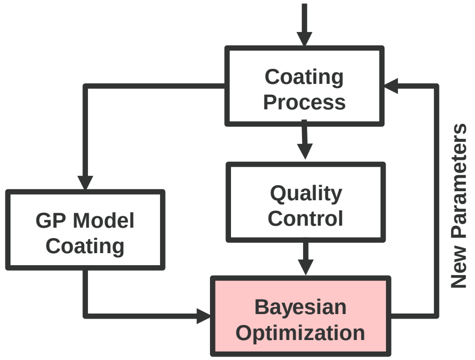
Approach 2: Bayesian Optimization

- x : Input parameters
- S(x) : Stress Index (deterministic function, no modelling)
- c(x) : Constrained outputs (modelled on data with GP)



Acquisition function: Depends on the mean and variance of the queried points from the GP

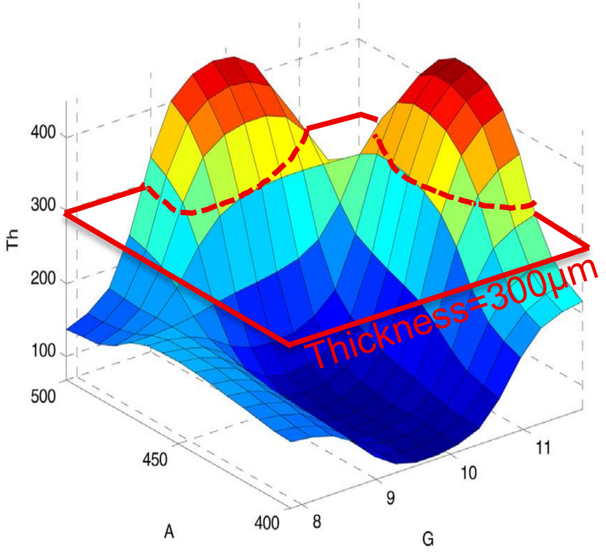


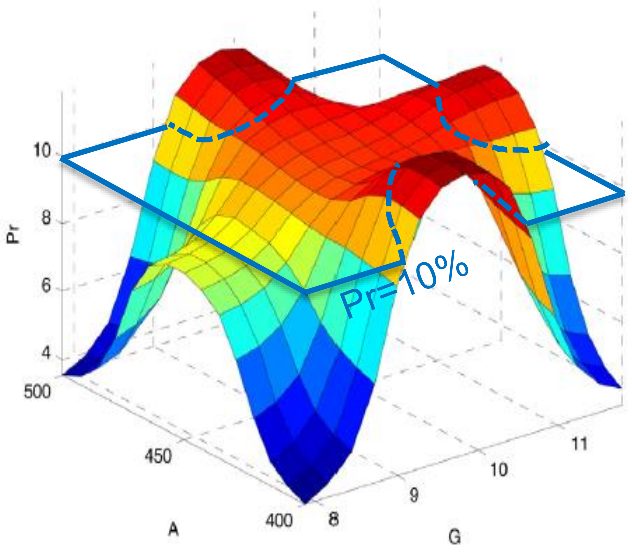
- Less data needed to design the optimum parameters
- Accounts for noise in data

- Computationally expensive for huge data sets

Benefits of Data Models

- Use the experimental data to develop a Big-data model of the coating system from input parameters to coating charactristics.
- Once the model is built, it can be used to:
  - Predict the coating charactristics using input parameters
  - Develop new parameters to achieve a specified coating
  - Learn about the effect of each parameters on the coating





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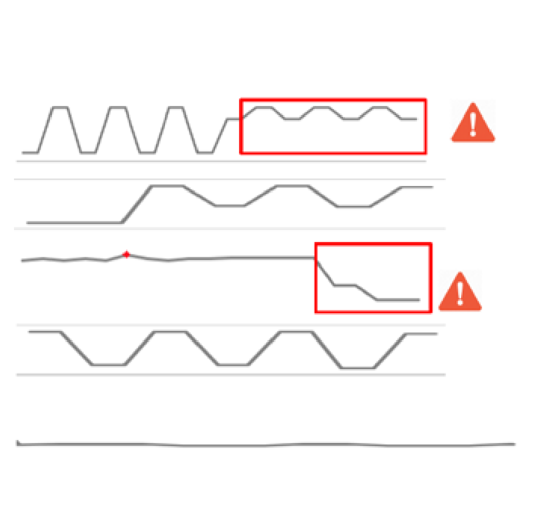
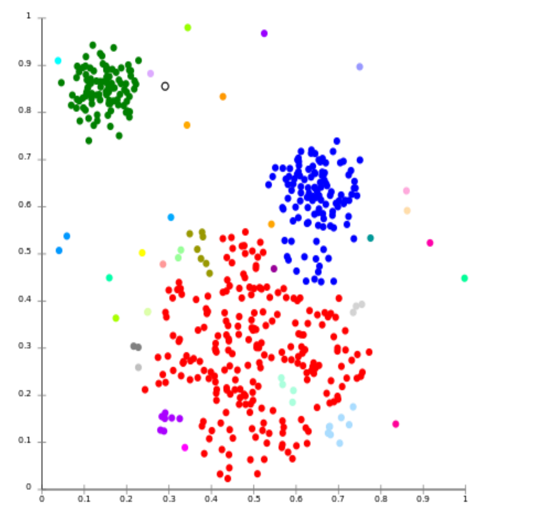
Deep Data Analysis for Anomaly detection and Hardware Life-time Prediction

AI can be used to perform three types of analysis on Machine signals:
1- Alert creation when signal shape is distorted
2- Clustering Normal and Abnormal cases
3- Predicting Hardware Life-time

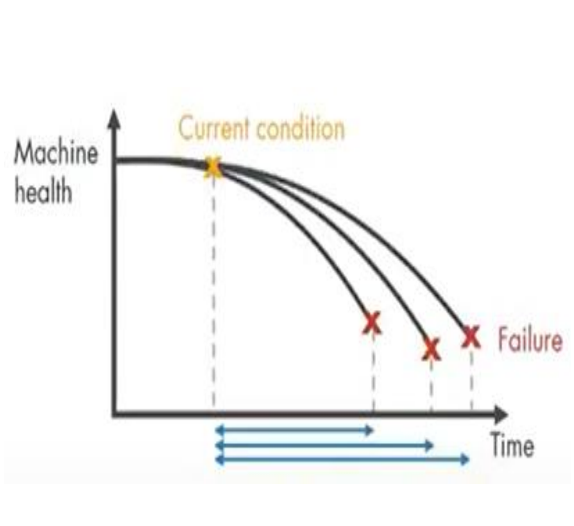
Alert creation



Anomaly Prediction



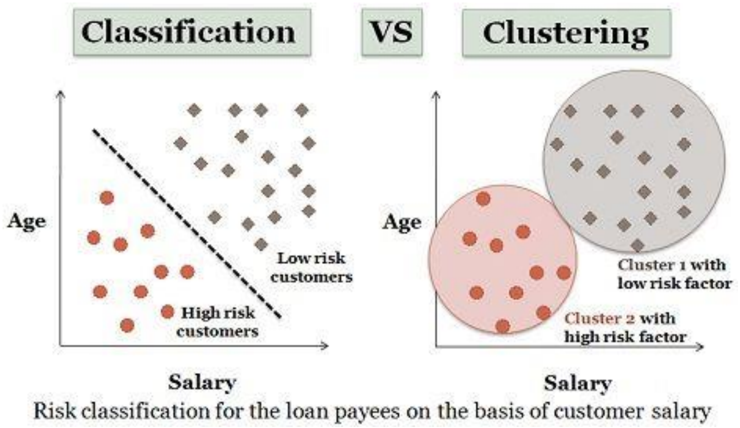
Life-time Prediction



Classification vs. Clustering

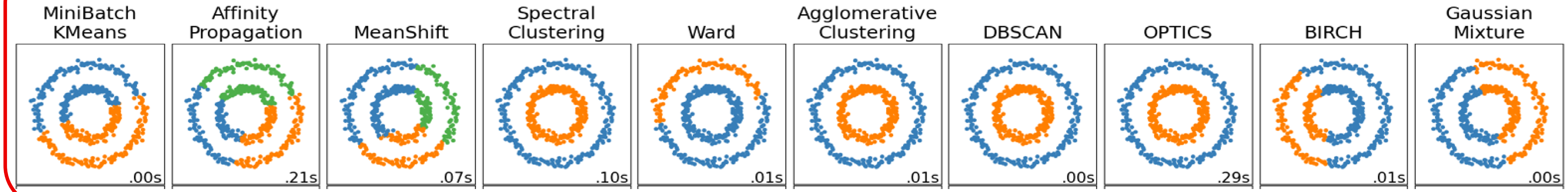
Classification is used in supervised learning technique where predefined labels are assigned to instances by properties.

Clustering is used in unsupervised learning where similar instances are grouped, based on their features or properties.

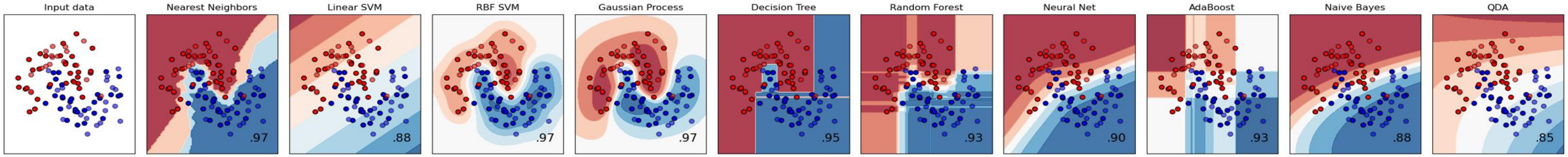


https://techdifferences.com/

Classification



Clustring



https://scikit-learn.org/

Anomaly Detection: Detect unusual behavior of machine signals

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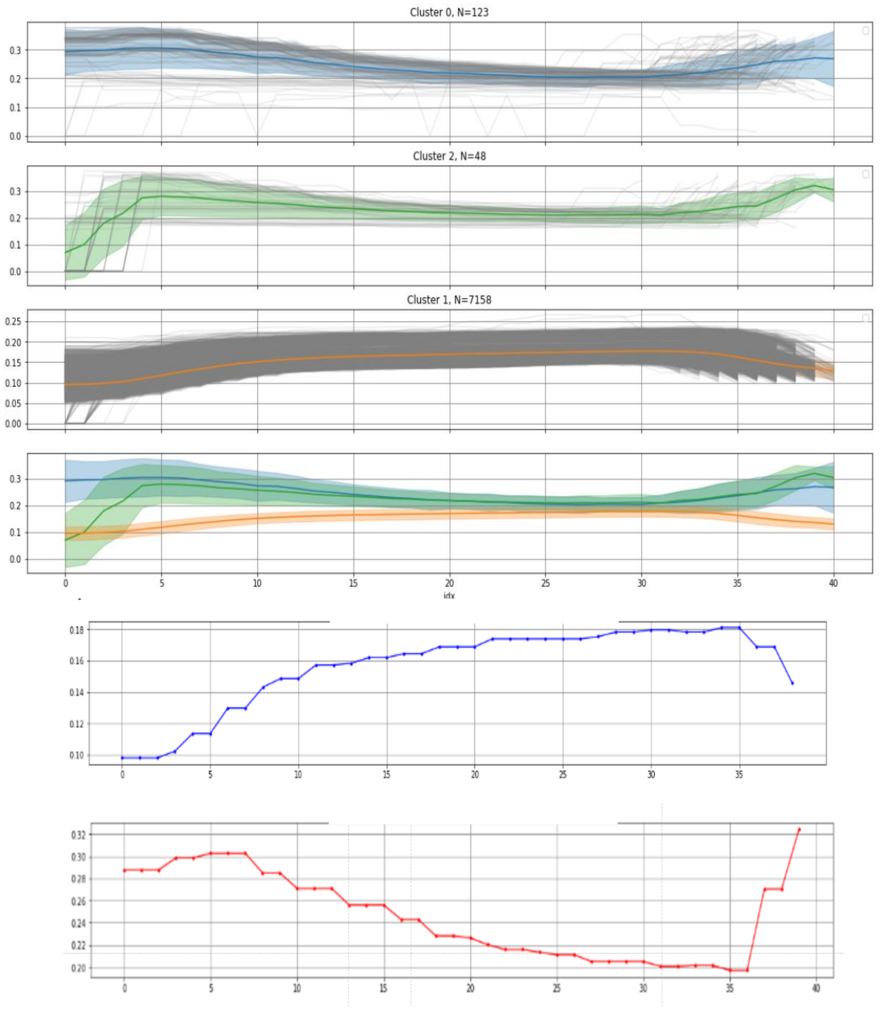
Number of automatically detected abnormal signal using clustring can serve as an indicator for machine performance.

Automatically recognize good and bad signal clustuers



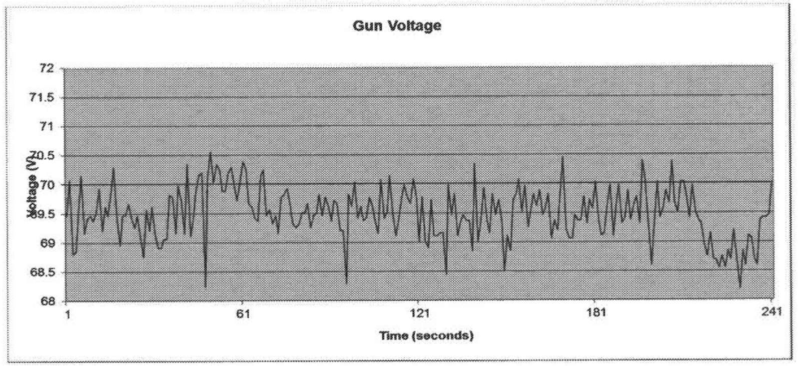
3 clusters:
1 big cluster (**97.4%**) as normal.

- Blue: Normal
- Red: potentially abnormal

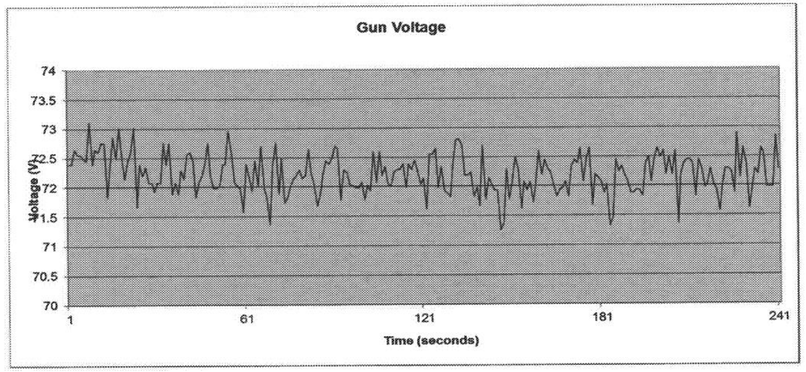
Prediction of hardware status

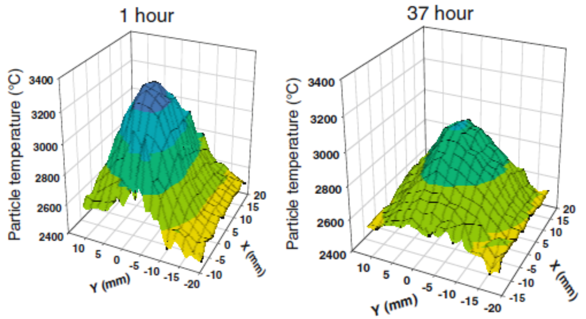
- ✓ One signal that could be used to monitor state of thermal spray process is the high-frequency gun voltage.

Gun Voltage Old Hardware

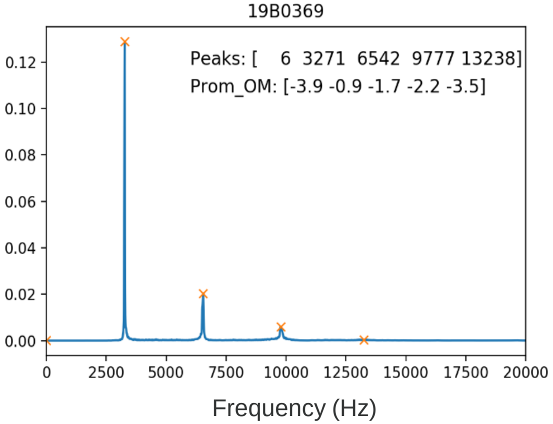


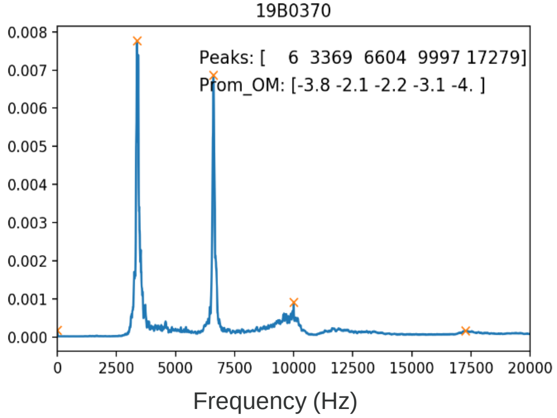
Gun Voltage – New Hardware



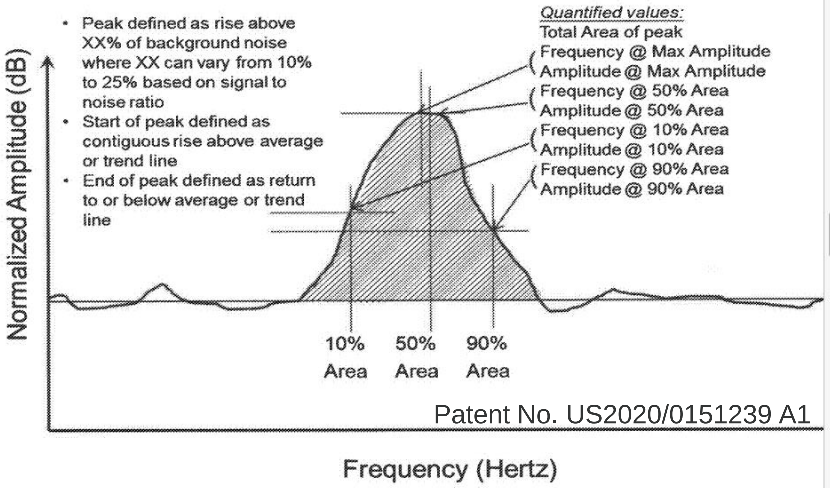


Patent No. US2020/0151239 A1





Frequency Peak Analysis



Patent No. US2020/0151239 A1

- ✓ By training a N.N. with inputs from Frequency Peak Analysis, we can automatically detect if the hardware is new, or it is old and needs to be exchanged.

THANK YOU.

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