Use of machine learning techniques for muography applied to industrial applications

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MUON systems

IFCA Instituto de Física de Cantabria

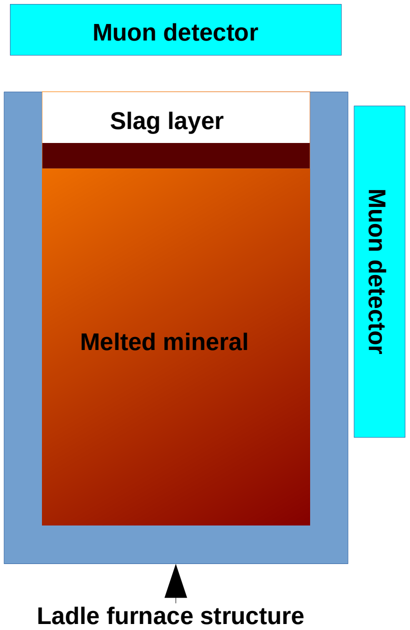
Muography in the industry

- Muography is a new Non-Destructive Testing (NDT) technique that might be exploited in the industry
  - Preventive maintenance of equipment (estimation of the degradation)
  - Quality control of the production process (measurement of liquid interfaces, tolerances, etc)
  - Risk assessment and evaluation (continuous monitoring of structural integrity)
- Large variety of different problems and issues in the industry but some general common points:
  - Relatively large and dense objects (from ~ 50 cm to several meters, iron, steel, etc)
  - In most cases not possible to have any physical access to the object when the factory is in production
  - Relatively harsh environment in terms of dust, temperature and space or time restrictions
- Muography has some unique properties that can be very useful for these applications
  - Large power of penetration (no problem to deal with several meters of steel)
  - No need to physically “touch” the object → it can be applied while the equipment is in production
  - Allows a continuous monitoring of several (typically large structures)
    - Very helpful to detect sudden changes in the production process or anomalies in the equipment

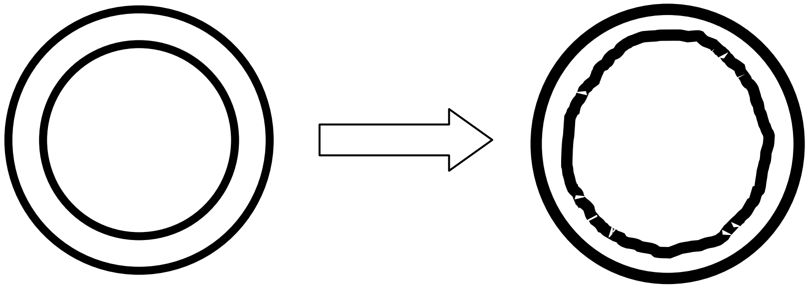
Industrial problems with reduced complexity

- There is one interesting point to be highlighted for most industrial problems
  - The nominal geometry and composition of the equipment/problem is usually very well known
  - Only small variations with respect to the nominal position are targeted
  - This allows to reduce the complexity of the problem to only a (small) set of parameters
- This fact opens the possibility to exploit parameter inference and/or simple IA-based methods
  - No need to "reconstruct" the object, enough to model the possible variations

Ladle furnace: parameter of interest is the position of the slag-mineral interface



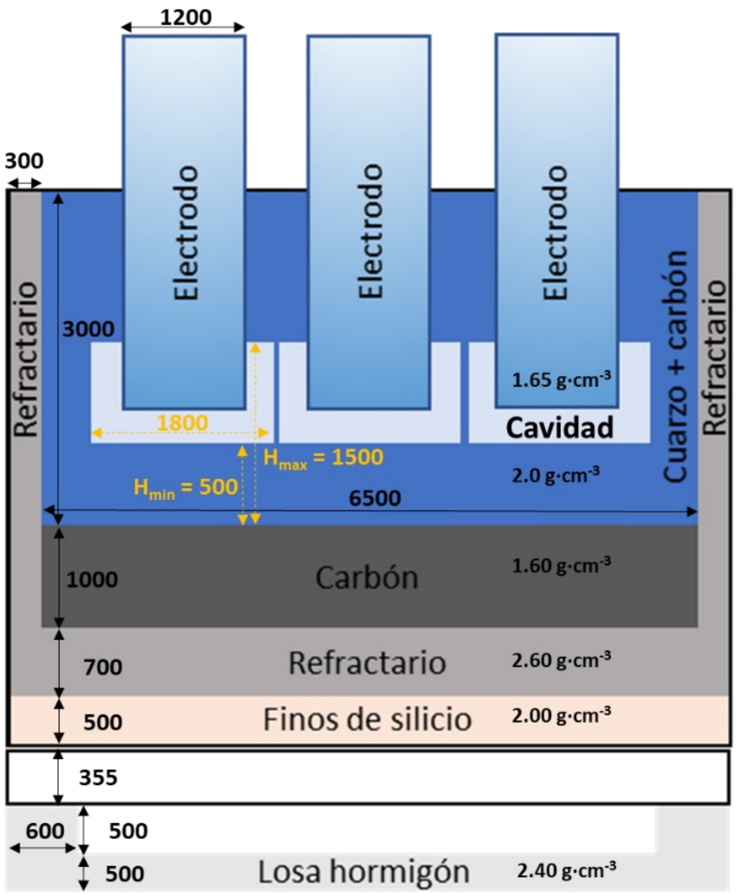
Degradation of pipes: parameter(s) of interest is the thickness of the pipe

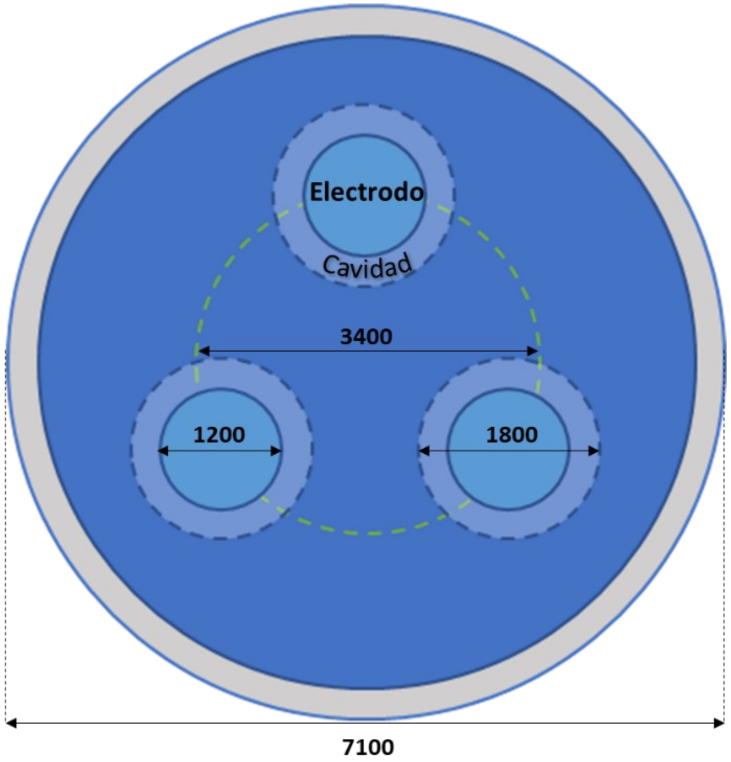


Can use the average thickness of the wall, or the model can be made more complex by using a polygon fitting the inner surface of the pipe

Another example: Electric arc furnaces

- Consider the example of the stability and efficiency of an electric arc furnace in foundries
- Many factories have issues estimating the exact position of the electrodes in the mixture
  - They suspect that small oscillations of the electrodes are responsible for efficiency losses
  - A precise knowledge (~cm) of this position would allow to correct for the effect





Regression for geometry characterization (I)

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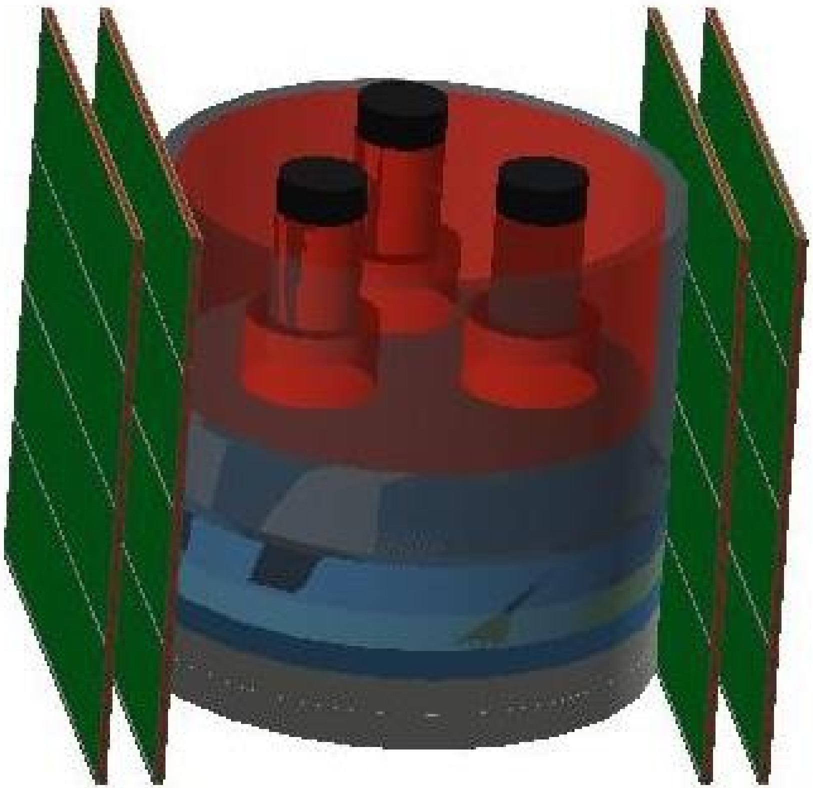
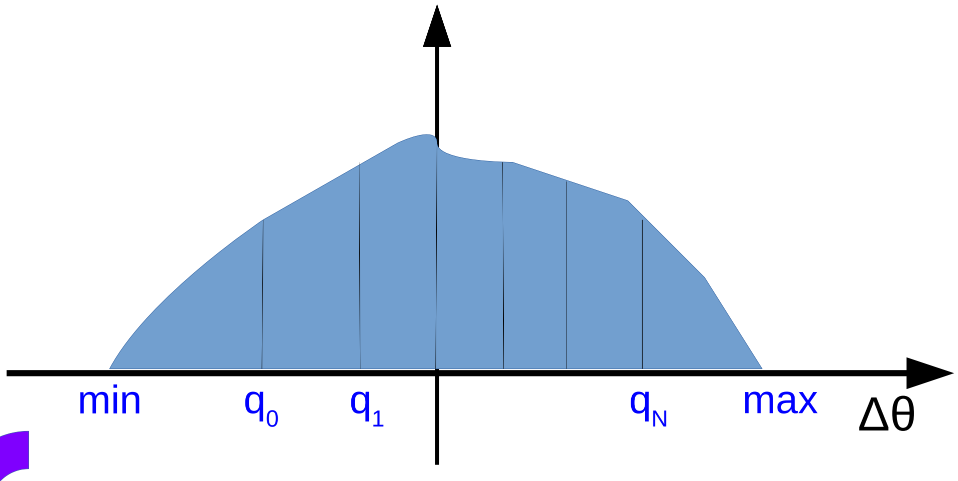
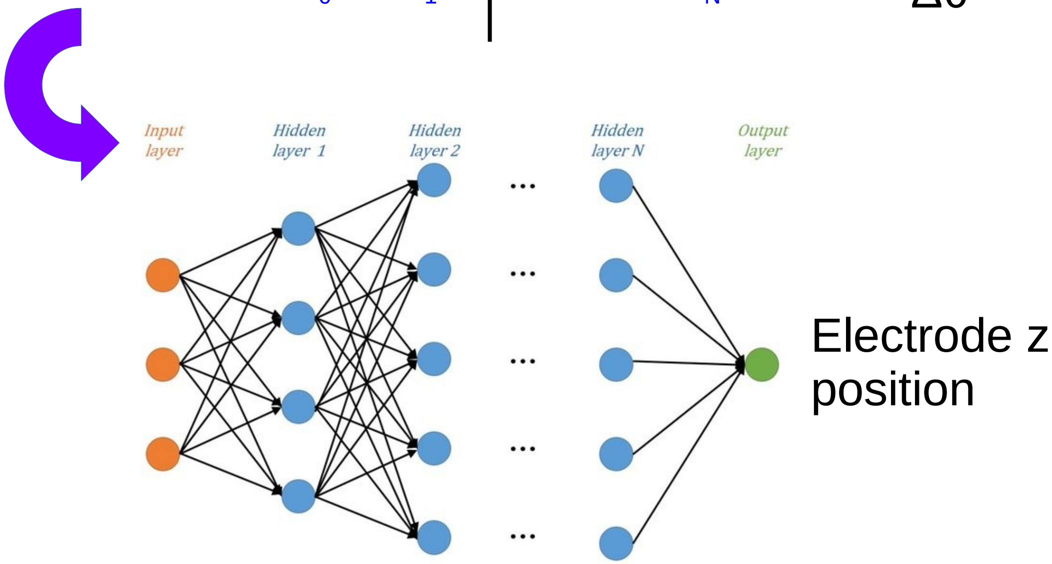
- Built a GEANT4-based model of a furnace with different values for the position of the electrodes
- Artificial Neural Network performing regression on the position of the edge of the electrode in the mix
- ANN using as input data the n-quantiles (+min and max) of the angular scattering distributions

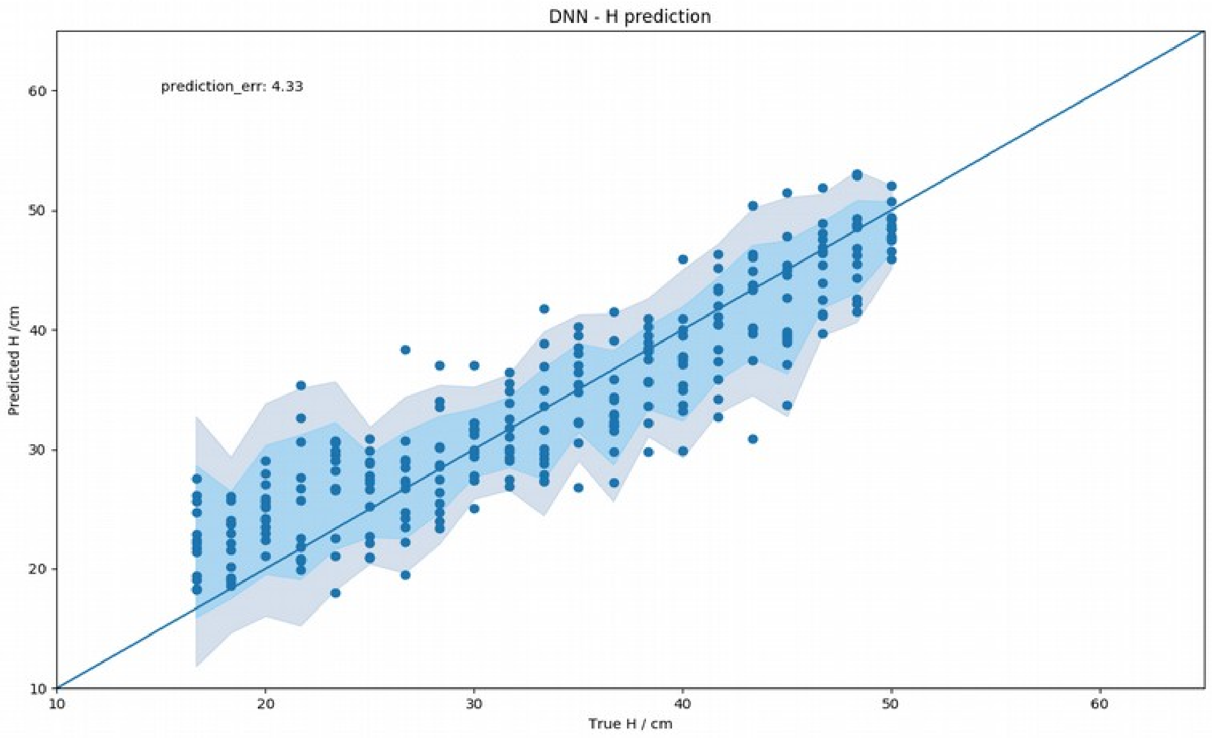






Additional variables + data augmentation

- We introduced also the distribution of the position deviation
- Data augmentation performed defining cross product variables: angle x position, etc
- Quantiles of all distributions are computed and given as input to the DNN

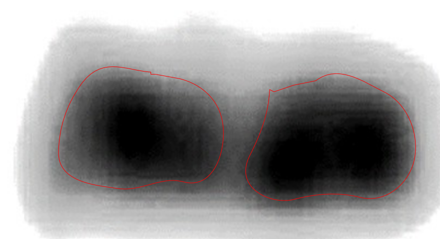


- Encouraging results, a resolution of about 4 cm is achieved (more than acceptable for the problem)

Automation of detection in industrial problems

- Another useful procedure in the industry has to do with the automation of the response
- The aim of this is not so much to reconstruct the geometry but to automate the decision making
- In order to do this we propose to use segmentation techniques to recover objects in images
- Consider the problem of finding cracks in a block of concrete:
  - How do we automatically decide there is a crack in between?

POCA based image



POCA based image

Automation of detection in industrial problems

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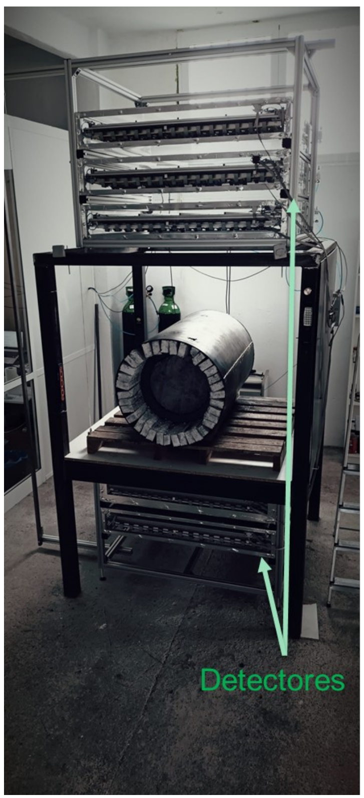
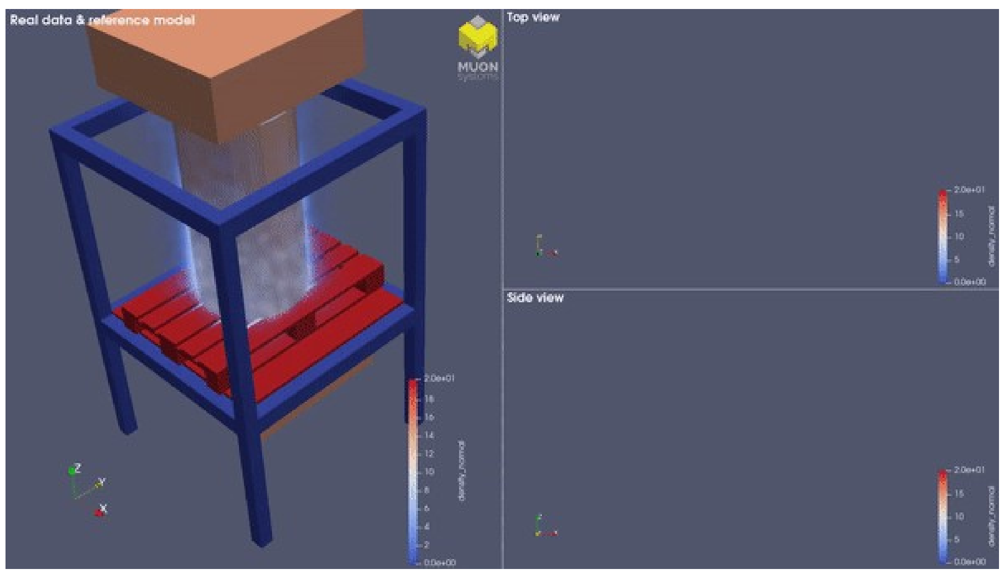
- Not only the automated detection is interesting also the geometry (surface/volume) of the objects
- We have applied segmentation to the problem of the measurement of a silicon melting furnace


Hardware
1m^2 modular detectors

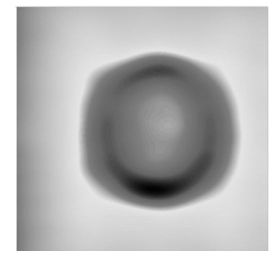
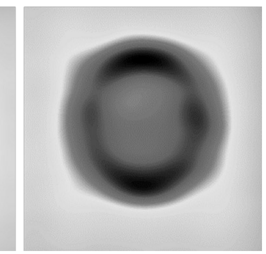


Furnace hearth

Measure of the wall refractory:
1cm resolution
15 min exposure

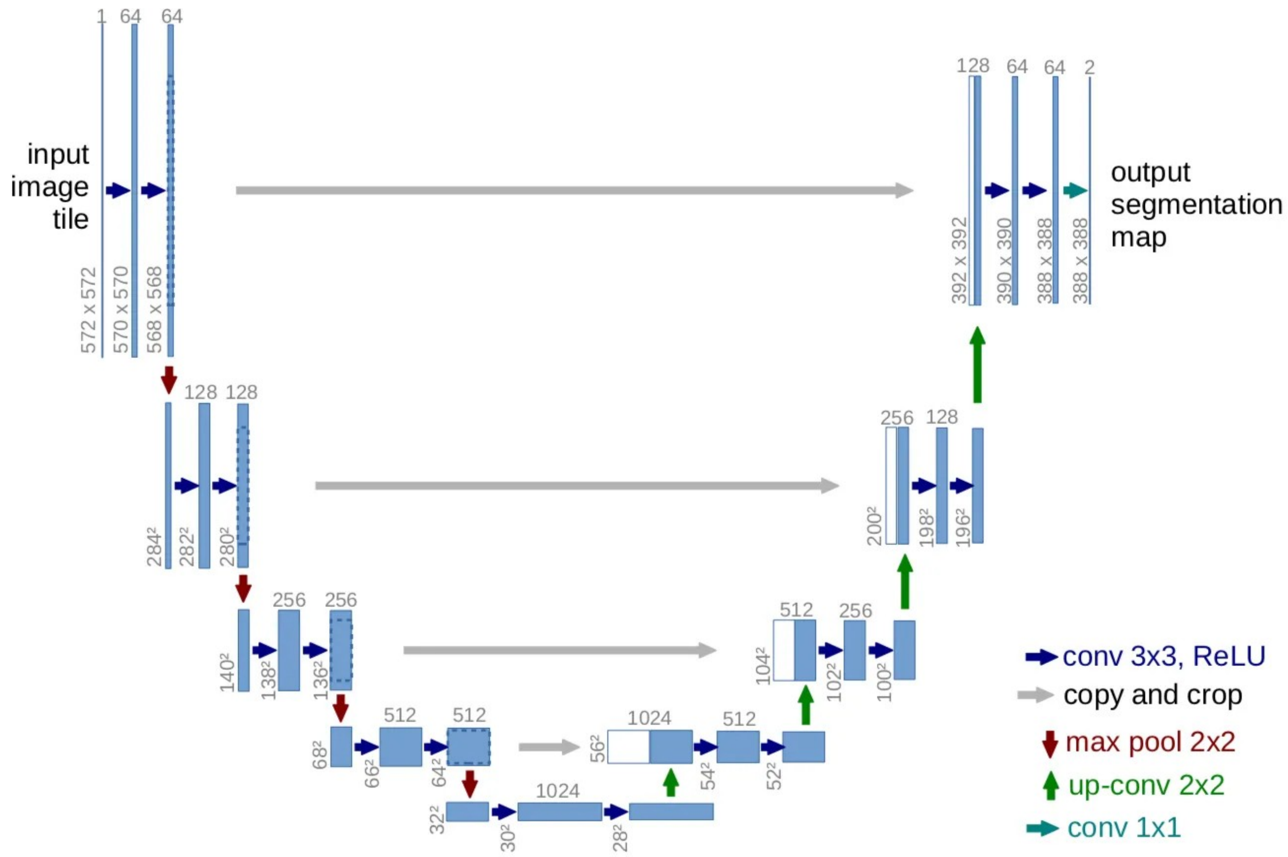


Real data 3D reconstruction of a silicon melting furnace

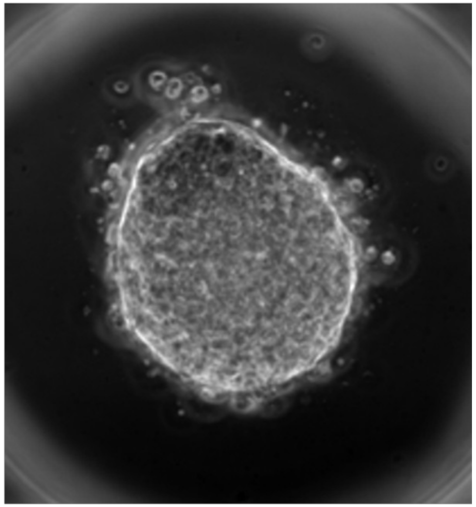



First segmentation approach: a U-NET

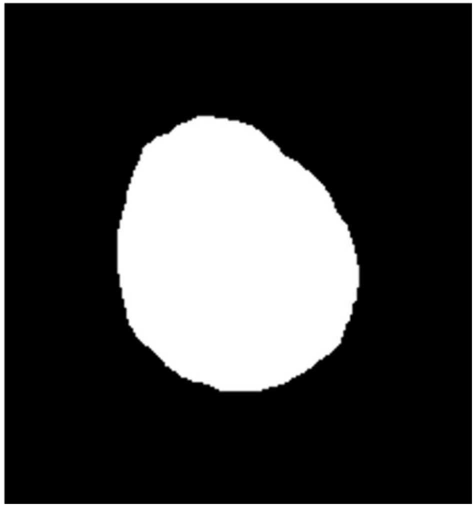
- This kind of architecture has been proposed in order to produce segmentation masks
- A picture is given as input to the network and it produces a mask with pixels associated to a class
- The network has a classical convolutional part and a symmetric upsampling part



Input Image

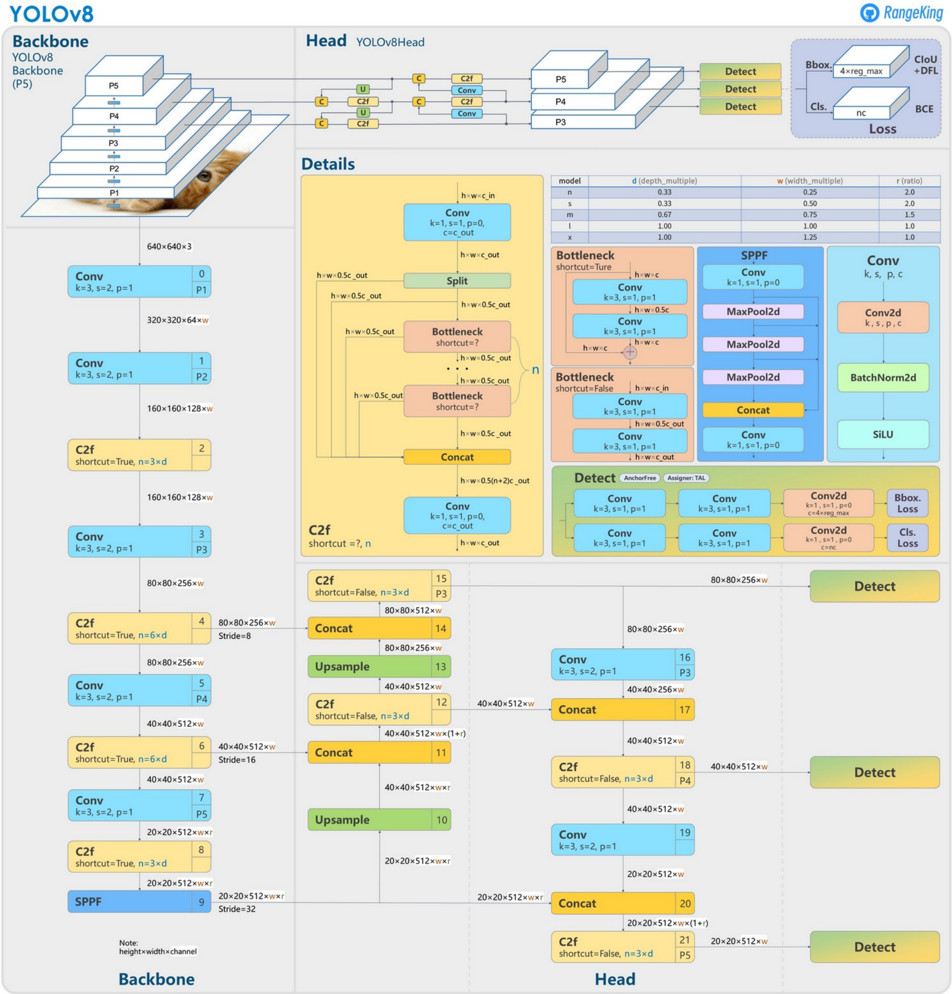


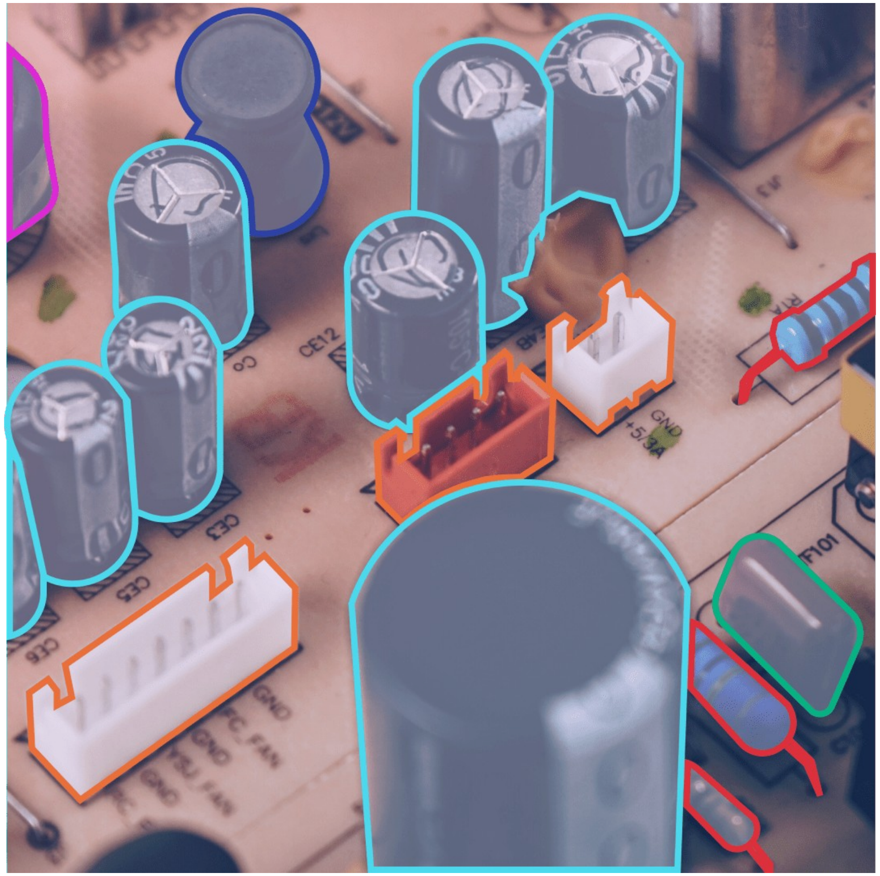
Output Mask



Second segmentation approach: Yolo v8

- Yolo v8 was released in January 2023 including capabilities to perform segmentation
- Complicated and ultra powerful architecture mixing detection + segmentation
  - But easy to use and friendly interface

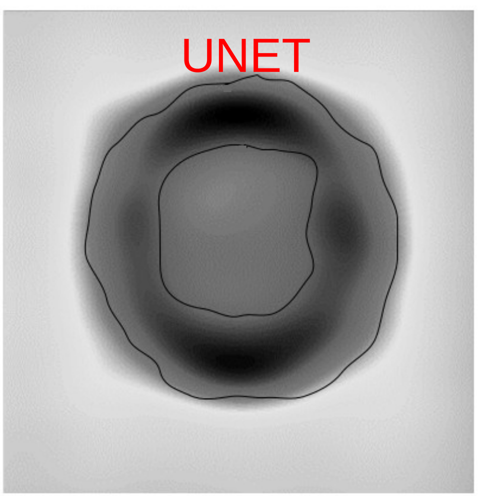


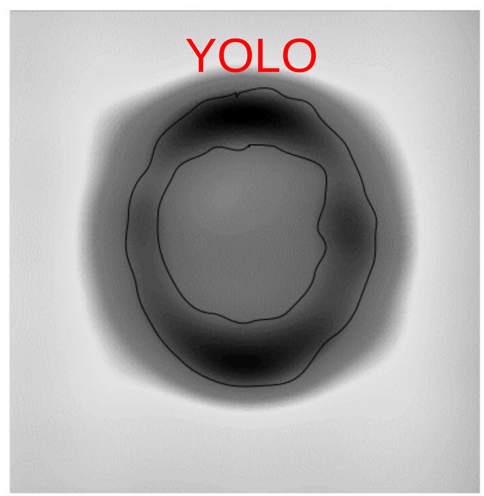


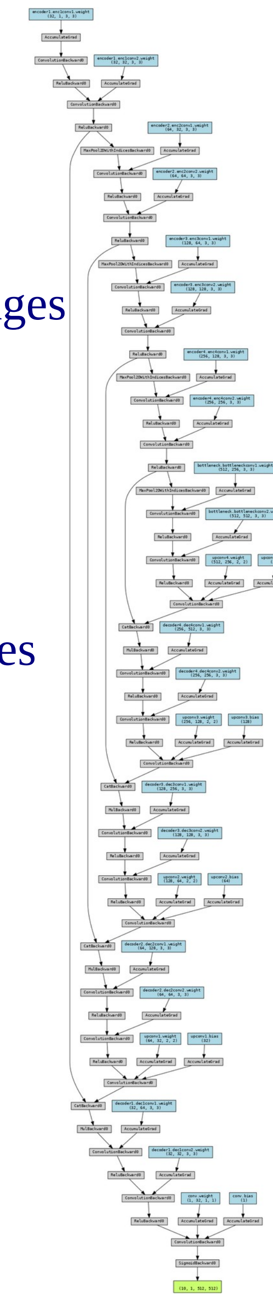
https://ultralytics.com/yolov8

Application to the silicon melting furnace

- UNET architecture taken from the one designed for the LIDC-IDRI dataset
  - It includes pre-training with several thousands of images
- Ultralytics Yolo_v8 also using its own pre-training
- Both models trained only on the last layers of the network using 3000 MC simulation images
  - Using different thicknesses of the furnace
  - Running on GPU G-Force 3090
  - Training time of the order of a few hours in both cases (Yolo taking a bit more)
- Very promising results observed for both systems → waiting to validate with more samples

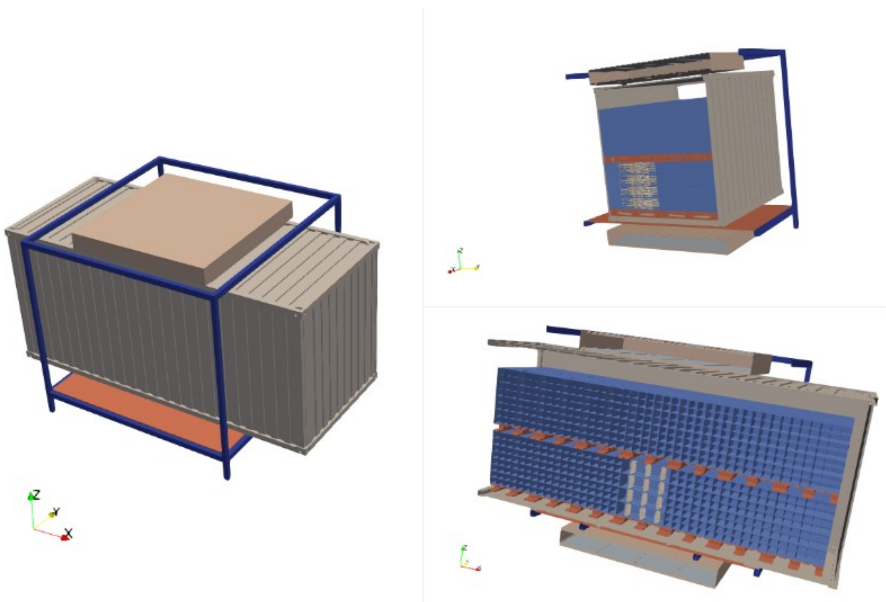


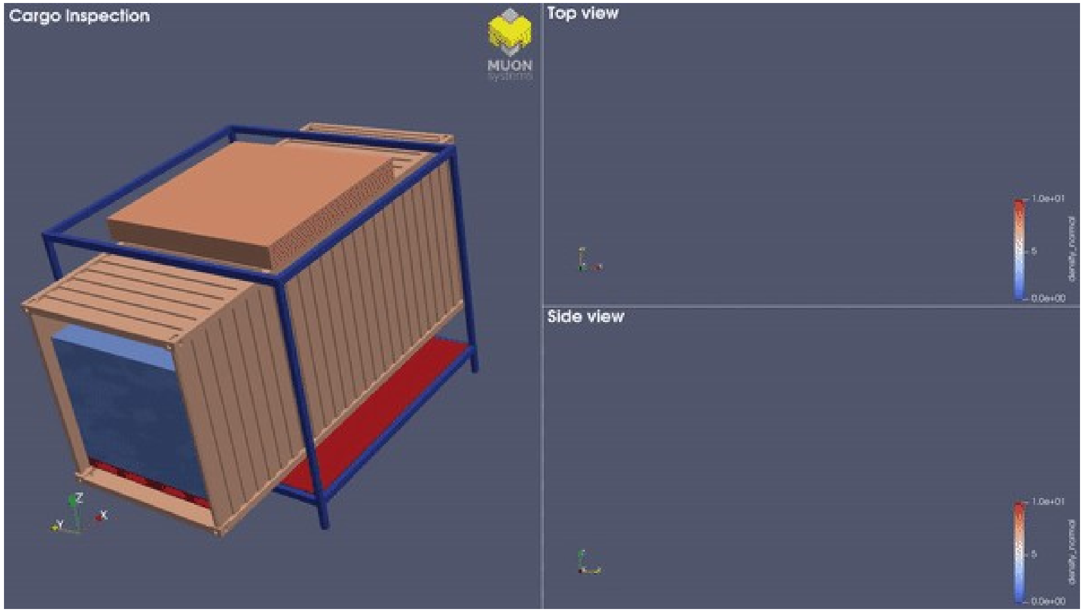




Next steps

- Consolidate results with more real images in order to see different casuistic of corrosion
- Implement a measurement of the thickness of the walls to automate the alarm procedure
- Apply the technique to other non-industrial applications such as port security
- Extend the segmentation to 3-dimensions





PROYECTO FINANCIADO POR
EL FONDO PORTS 4.0
Puertos del Estado
PORTS 4.0

Conclusions

- Industry is a great consumer of NDT techniques where Muography could have a significant place
  - It allows to perform inspection of large and dense structures
  - It allows to perform the inspection while the facility is in production (online monitoring as well)
- The nature of industrial problems differs from other Muography applications
  - Geometries are almost known → large reduction of parameters
  - Modern Deep Learning techniques can be exploited in this context
- Segmentation techniques can also be used to identify objects in classic muon images (POCA-like)
  - Two systems have been tested using a UNET and Yolo v8
  - Very promising results observed so more research will be done in this direction

Thanks