Anomaly Detection algorithms applied to the Quality Control of detector components
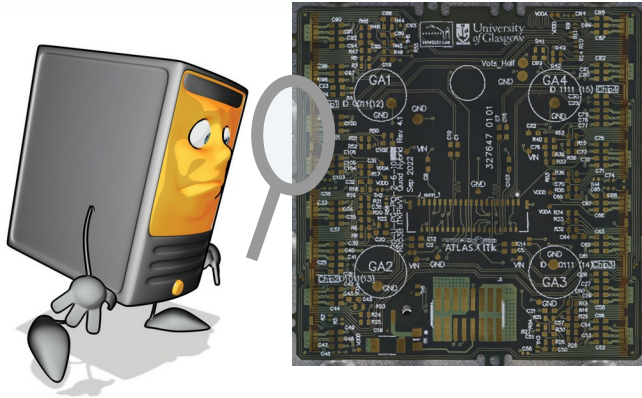
Presenter :

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[1]KEK   [2]QUP   [3]Oxford University

Quality Control in detector production
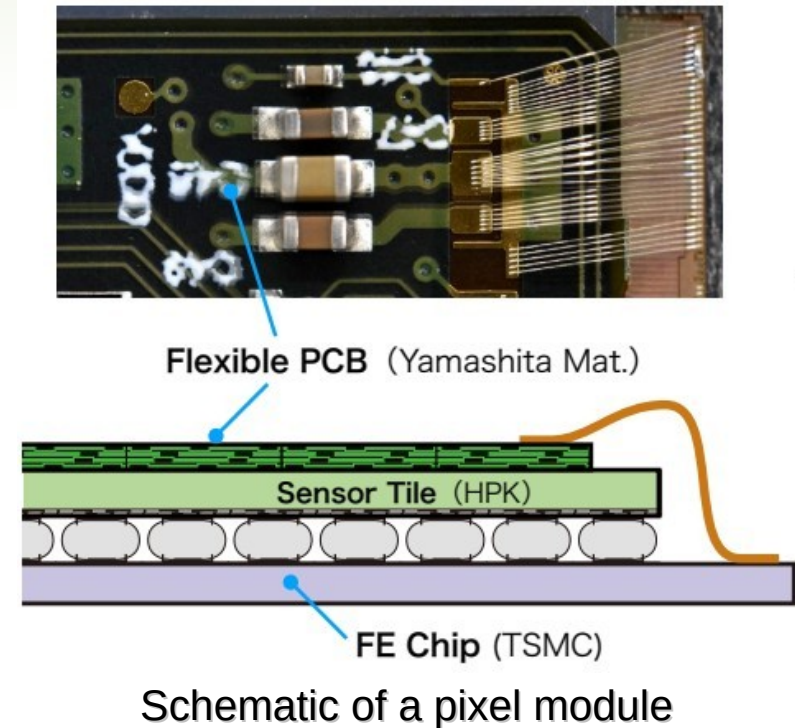
- ## Objective

  Ensure that <u>each component</u> is in **good working condition**

  => *Impact on Physics results*

- ## Application case

  Upgrade of the <u>ATLAS detector</u> for HL-LHC

  Focus on the mass production of <u>pixel modules</u> for the **new Inner Tracker (ITk)**

Flexible PCB (Yamashita Mat.)

Sensor Tile (HPK)

FE Chip (TSMC)

Schematic of a pixel module

Visual Inspection

- Principle

  <u>Inspect module components</u> and look for **visible defects**

  Performed for **every components** at **every stage** of module assembly
  => *At least 5 VI check per modules*

- Methodology

  Manual Visual Inspection **'*by eye*'**

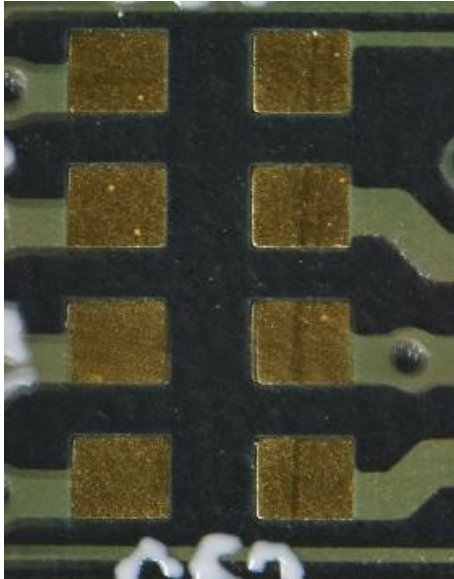 **Slow process** (*~10min FLEX PCB*)

  Error prone

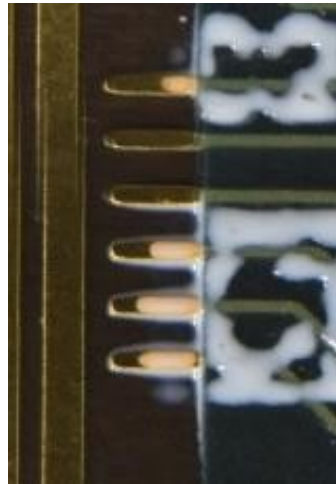 *Can we use **Machine Learning** to <u>improve the process</u> ?*

Example of defects

- ## Image from FLEX PCB

Sub-millimeter scale defects in a 40x40mm PCB

Scratches

Silk ink leakage

damage on wirebonding pad

And others …

Machine Learning assisted Visual Inspection

- Objectives

  Create a Visual Inspection helper

  Improve **efficiency** and **reliability**

  Easy to integrate and usable on *any computer*

- Strategy combining 2 different approaches

  – Unsupervised algorithm

  Use **Anomaly Detection** to highlight rare/unknown defects

  – Supervised algorithm

  Use **supervised classifier** to label common defects

Unsupervised algorithm

- Overview

  Deep Auto-Encoder-like CNN

  - Trained on high resolution images of <u>ITk module components</u>
  - Learn to <u>reconstruct main features</u> of input **and** to <u>remove defect-like patterns</u>
      => Denoising Auto-Encoder
  - Identify <u>anomalous pixel areas</u> in the image

  Filtering based on DBSCAN clustering

  - <u>Cluster anomalous pixel</u> and extract **major anomalies**
  - Provide list of most **relevant defect candidates** and <u>reduce false positive rate</u>

Unsupervised algorithm

- Model implementation

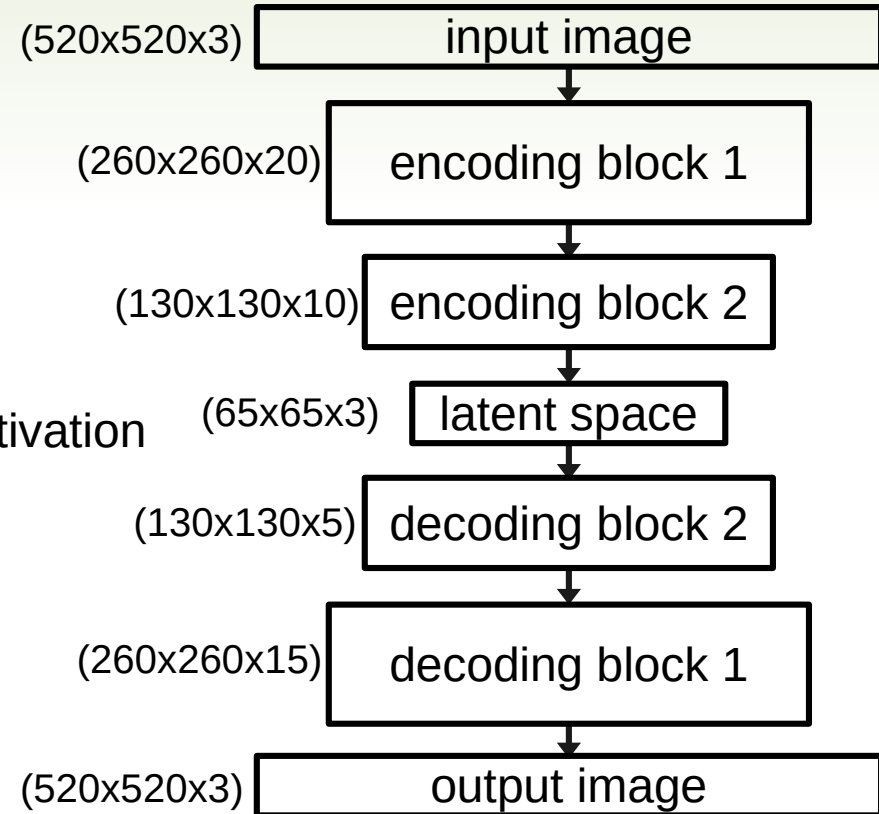 Denoising convolution AE

  Asymmetric architecture

  Encoding block

  2 convolution layer with LeakyReLU activation
  10% dropout on second layer

  Loss

  Use MSE between output and original
  input (without soise)

(520x520x3) | input image

↓

(260x260x20) | encoding block 1

↓

(130x130x10) | encoding block 2

↓

(65x65x3) | latent space

↓

(130x130x5) | decoding block 2

↓

(260x260x15) | decoding block 1

↓

(520x520x3) | output image

Supervised algorithm

- Overview

    Computer vision algorithm inspired by Detectron2 ([GitHub](#))

    Object segmentation/classification inside a image

    Custom implementation

    Lighter and easier to setup

    Focus on common defects

    Higher statistic required for supervised learning

    Multi-class classification with arbitrary number of output labels
    => There might be more than 1 defect in the same image

Supervised algorithm

- Model implementation

  Combines **2 components**

  Feature Pyramid Network (FPN)
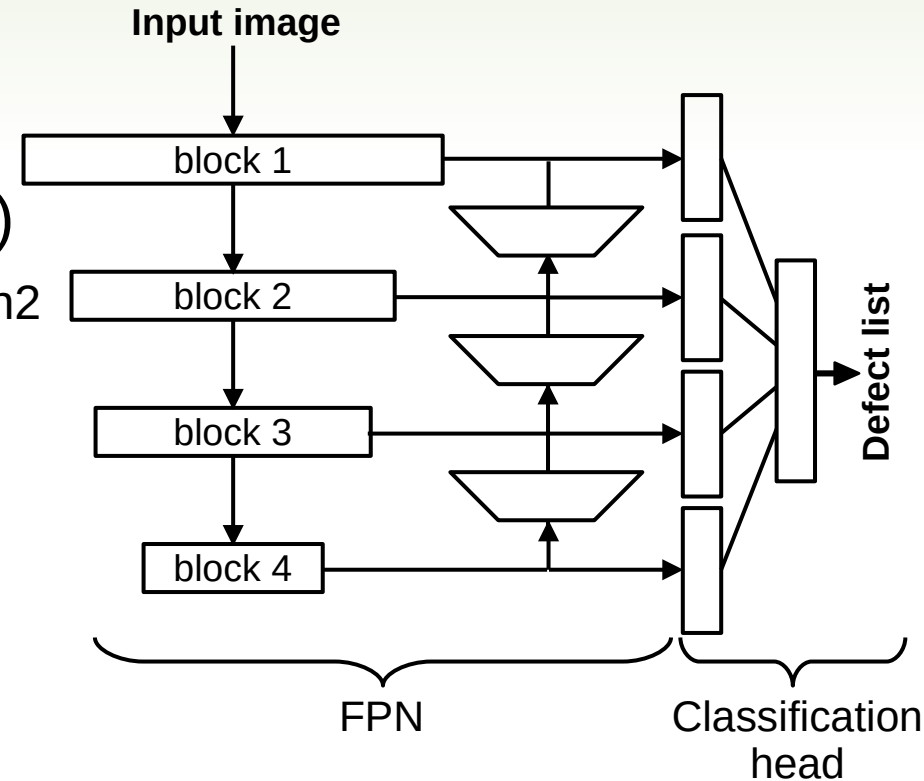
  Use as <u>backbone network</u> in Detectron2

  Extract **image features** at <u>different scales</u>

  Classification head

  <u>Custom</u> classification network

  Use FPN feature space to <u>identify defects of arbitrary size</u>

Input image

block 1

block 2

block 3

block 4

FPN

Classification head

Defect list

Data

- ## Acquisition and preprocessing

  Image taken with microscope
  Cropping, resizing and splitting
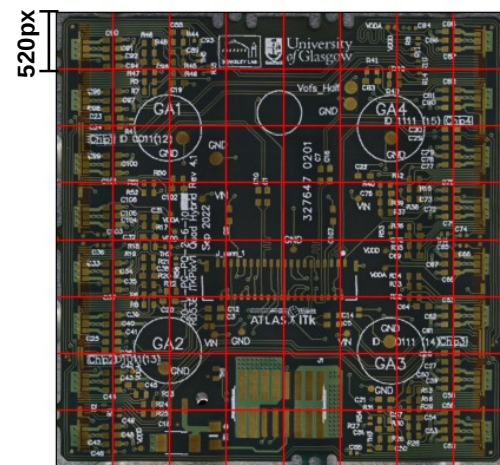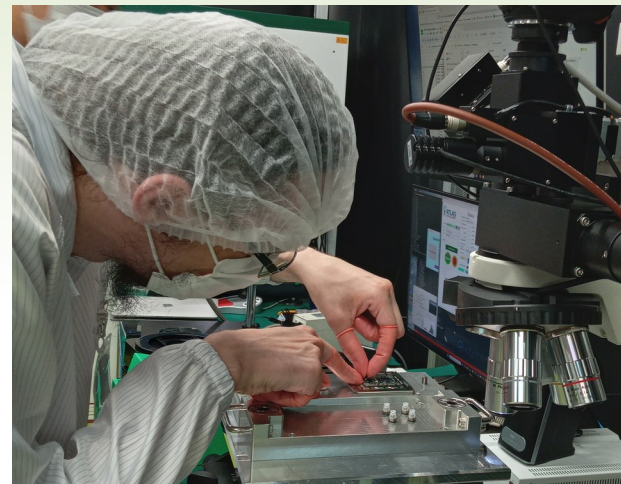 ~150 images available before splitting

- ## Data augmentation

  Duplicate images with <u>small variations</u>
  Luminosity, contrast, scale, position …

- ## Noise pattern

  Add random rectangle patches

Demonstration

- Test anomalies
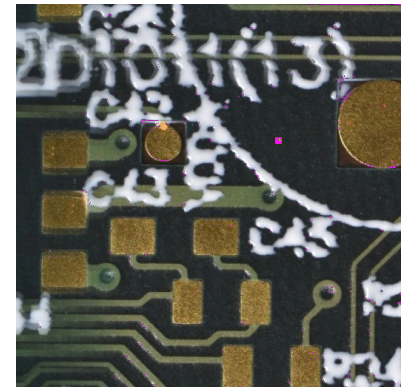
    Use <u>artificial defects</u>
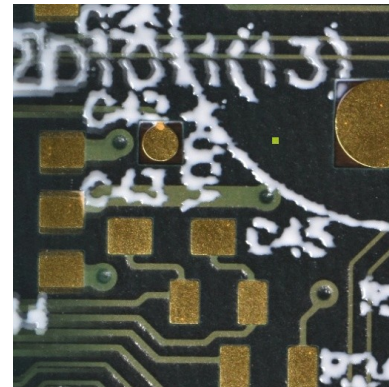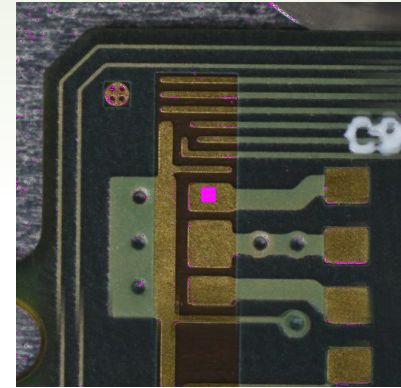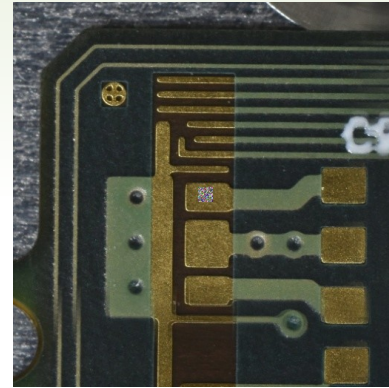
    Similar to noise patterns

    Results <u>without filtering</u>

    Artificial defect **properly highlighted**

    Other *minor defects* <u>also found</u>

    Not so much noise

Demonstration

- ## Real defects

  ### **Full** Anomaly Detection algorithm
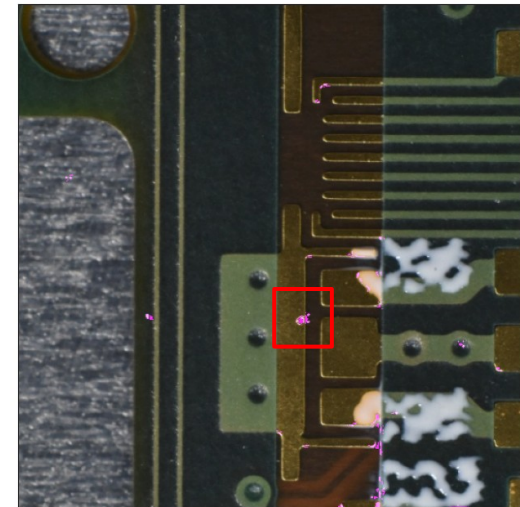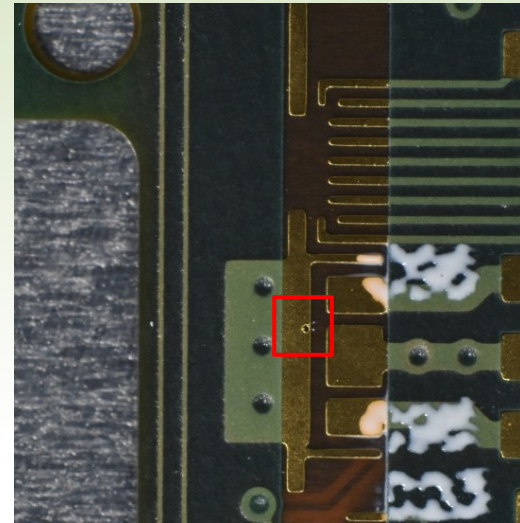
  deep AE **+** clustering

  ### Test on an image where a **real defect** was found

  <u>Single occurrence</u> **=>** <u>cannot train supervised model</u>

  ### The defect turns *pink*

  It as been detected :-)

Summary and plans

- Machine Learning assisted Visual Inspection

    Propose a tool for **defect detection** in <u>detector components</u>

    Combines both <u>unsupervised</u> **and** <u>supervised</u> algorithms

- Application to the production of ATLAS pixel module

    <u>Unsupervised algorithm</u> is **fully operational**

    <u>Optimized supervised algorithm</u> is **under training**

- Future extension of the tool

    In ATLAS and in other experiments/fields

THANK YOU !
ありがとうございます！

BACKUP

About me

- Previously

  PhD in **Clermont-Ferrand** (*I'm back !*)

  Work on <u>Anomaly Detection</u> for New Physics search

- Current position

  Post-Doc at **QUP** (Japan) link

  Work on <u>Anomaly Detection</u> for detector Quality control

International Center for
Quantum-field Measurement
System for Studies of the
Universe and Particles