Mastering Automated Visual Inspection

**Future Trends in Automated Inspection**

- What is deep Learning?
- How deep Learning will transform VI?
- Key Milestones last decade
- 1st proof of concept with cracks and particles
Objective: Presentation of current trends in AVI and computer vision

1. Main function blocks of AVI
2. What can « see » a machine?
3. Historic milestones
4. Comparaison Man/machine
5. How is working « deep learning » ?
6. Some practical demos
The content, material, perspectives and opinions expressed in this presentation are solely those of the presenter, and do not reflect the views or opinions of the presenters employers or PDA. Conflict of interest: Romain Veillon is an employee of the GSK group of companies. This work was sponsored by GlaxoSmithKline Biologicals SA.
• MVI is a Baseline

• Pharmacopeia test

Standard work defined
- Illumination intensity lower limit 2000-3750Lux
- Black & White Background contrast
- 5 sec per each background for each container
- Maximum inspection time must be defined
- Break time must be defined
- Standard work defined
- Certification of operators

Key Take Away:
• MVI method is described in Pharmacopeias
• It remains the Baseline
Key Take Away:
- MVI operator can detect + classify defects
- MVI operators are subject to psychophysical interactions, leading to variability in performance
• Example of psychophysical impact

**Key Take Away:**
• Example of chromatic continuity shows how our brain influence decision making

Chromatic continuity:
We see snow even when color changes drastically (RGB)
• What are MVI Baseline Performance?

✓ Average Probability Of Detection (PoD): [70-99%] on true defects

✓ Inter operator Variability: * Less variability in true defect Zone: **

✓ False reject rate in MVI: 1 to 2%

✓ Throughput +/- 1800 units / shift / operator including breaks

Key Take Away:
• MVI slow speed
• MVI variability
• Low False rejects
• Classification

*Romain veillon PDA Bethesda 2011 / ** Romain Veillon PDA Bethesda 2013
Comparison MVI to AVI

Manual Visual Inspection (MVI)
- Adaptation
- Brain
- Flexible
- Decision capable
- Classification of defects
- Inconsistent (fatigue effect, emotional)
- Not highly reproducible
- Susceptible to influence
- Slow
- Monotonous repeated work

Automated Visual Inspection (AVI)
- High speed and high capability
- Highly reproducible
- Consistent (no fatigue effect)
- Defects presentation
- High initial investment
- Works within strict condition (validated upstream process)
- Indiscriminative (i.e.: fiber and cracks are seen the same way)
- Some uncovered area
- Higher false reject rate

Key Take Away: AVI and MVI are complementary
• What are main function of AVI equipment?

Key Take Away:
• AVI machines very complex equipment to combine
• Fast accurate mechanical handling (swiss watch like)
• Light illumination fast synchro / optical path with fast moving mirrors / vision processors to compute images in less than 15ms.
• Complex Automation to synchronize and store with data integrity
Image Acquisition principle will remain the same

- Field depth
- Working distance
- Depth of view
- Focal Objectif
- resolution Sensor size
- Image Acquisition principle will remain the same
Grey level 8 bits
255 = white
0 = black

If 255 = white contour
If 10 = dark black
What is a digital image?

In computer vision language (python/C++), it is a matrix object:
```
np.zeros(img.shape, dtype=img.dtype)
```

**Key Take Away:**
- Computer vision see only a matrix
- That represent spatial distribution of grey levels
- Neural Network will work with image matrix

Digital Image = matrix grid of figures in X and Y
AVI: From image acquisition to feature extraction and decision

1. 3D Object presented
2. 2D image
3. Area Of Interest (=AOI)
4. Binarization
5. Object detection
6. Image feature rules
7. Pass / Fail

Key take away:
- this engineering step of vision recipe development is done to reduce information of images and to enhance specificity of decision....in less than 10ms
- It remains low level vision
AVI is a fast evolving technology with LED / Digitalization / Deep Learning

Key Take Away:
- AVI is a young, maturing technology
- Many changes over the last 30 years, next one is deep learning
• What is benefit of digitalization?

Key Take Away:
• AVI machines with Digital Cameras pave the way to very high resolutions, higher Detection and lower False rejects
• Higher resolutions will pave the road for deep learning model fine tuning
Machine Learning versus Deep Learning?

**Key Take Away:** Machine Learning (SVM) never achieved promising results with parenteral.

Machine Learning

Can work with strong image signals (Faces / Road Sign)

Deep Learning

% error

• Learning from past pitfalls
• Why Machine learning did not delivered for parenteral defects

In 2008, first PDA presentation with Neural Network for Lyo cakes (R. Veillon)

Key Take Away:
• Machine Learning (SVM) never achieved promising results with parenteral
• Neural network with vectorization gave limited results
• Basic concept of neural network

**Key take away:** Neural Network can be compared to multiple layers of wired nodes with adjustable weight (potentiometers) in order to link an input signal (image) to an output response (classification).
Comparison MVI and Convolutional Neural Network

- 1 real object that was trained to the operator = supervised learning
- Observation; concentration/ light/ fatigue....
- Cones in retina activated
- Image projected in V1 area of brain for detection angles/ edges/ contours
- Area V2 of brain to detect gross forms/shapes
- Area V4-V5 for forms more abstract
- Activation memory area

**Object Identification + classification**

- 1 real object that was trained to the machine = supervised learning
- Image camera capture
- Presentation of image in 1st layer of neuron = number of pixels
- Each part of image is sent to other layers of neuron that are interconnected, adjustment of coefficients to match elements as best (weight+bias)
- Last neuron layer to classify object

**Object Identification + classification**

Key Take Away:
- CNN deep learning mimic human brain with better performance on repetitive task
- But it is Not Artificial ‘Intelligence’
What is a Convolution Neural Network (CNN)?

**Key Take Away:**
- It is a NN dedicated to image treatment using convolution kernel filters.
- Pitfall with Neural Network is risk of overfitting on training images.
How Convolution Neural Network (CNN) work?

Key Take Away: Goal: To learn a classification model from the data that can be used to predict the classes of new (future, or test) cases/instances.
Risk of overfitting with training data

Key Take Away: to avoid overfitting there must be cross validation strategies and use of independent prediction set.
• **Validation strategy to avoid overfitting**

- **Supervised learning**: classification is seen as supervised learning.
- **Supervision**: The data (images) are labeled with pre-defined classes (defect categories). Supervised because it is like a teacher.

**Key Take Away:**
- Supervised learning is a frozen model that stops learning and never evolves
- With multiple independent image sets and use of cross validation => avoid overfitting
Supervised learning WOW

Key Take Away:
- Library preparation is key
- Need to concentrate effort on image library selection and review

1 images library 3 class: 600 images of syringes on 1 Camera (200 Conform / 200 Crack / 200 Particle)
+ all images checked visually
+ corresponding labels

1 training set 400 images random selection (Conform / Crack / Particle)
+ corresponding labels

1 Set validation random and never shown to the CNN. 100 images Without labels

1 Set prediction random all 600 images Without labels
- Problem statement for Deep Learning Proof of Concept
- Detect and classify crack and particle defects

- Detect real Defect / conform units with artifacts very borderline
- Classify units in 3 class: Conform / Crack / Particle
- Do it in less than 15ms

**Key Take Away:**
- Choice of most difficult images very borderline to this first Proof of Concept
- Conform have many artifacts / Defect are very small and similar to conform

Wide Design space

Choice of most boarder line conforms

Choice of most difficult defects

Wide Design space
• First Proof of Concept
• with real AVI Defects images

1 New images library 3 class:
1224 images of syringes on 1 Camera
(645Conform / 234Crack / 345Particle) + corresponding labels

1 New Set validation never shown to the CNN. 122 images Without labels

1 training set 400 images (Conform / Crack / Particle) + corresponding labels

pre-trained CNN on 1000 image class (ImageNet.org)

>99% defect detection
<1% False reject
95.1% of labels found
4.9% wrong classification
Cross entropy very low <0.05

Key Take Away:
• With Pre trained CNN on large number of image class, it is possible to re-train on new images.
• Performance is very high >99% and units are classified in 3 class.
Investigation for miss classification errors

**Key Take Away:** Quality of training set is key, avoid any misleading images. For example when some angle of view can show only one part of crack => considered as particle.

- 100% defect detection
- 0% False Reject
- 95.1% of labels found accurately
- 6 defect images seen as defect but with wrong classification
- Crack $\leftrightarrow$ Particle
- Retrained without 6 images = 97.9% accuracy

- Crack 5 classified as particle
- Crack 26 classified as particle
- Crack 31 classified as particle
- Particle 12 classified as crack
- Particle 363 classified as crack
- Particle 367 classified as crack

8 images per syringes, min 2 images well classified can balance this.
• Challenge deep learning model
• with stress test

Key Take Away:
• Stress test are key to evaluate if model can be robust on industrial machines
• As initial source image were taken on industrial AVI machine at fast speed, vision parameters can be controlled
• Parameters of model design are critical and must be defined in project definition
• Coming back to J. Knapp
• Training test with only true defects zone (MVI PoD > 70%)

Key Take Away:
• If training is done only on true defect, deep learning model will detect all true defects with perfect accuracy
• However, if we submit all defect to this model = poor ability (40%) to detect gray zone defect (PoD < 70%)
• This shows that Human and Neural Network will have to share same training practices
• How Deep Learning will transform AVI?

**Current Industrial vision**

- Adjustment light + optic + image
- Image Capture
  - Images conforming units (kits)
  - + defect images (kits)
  - + identification defects (logbooks)
- Preparation of image treatment for each camera
  - click and drag software
  - Optimization processing time 1 to 3 weeks
- Adjustment on images / auto adjust.
- Evaluation on machine
- Validation (PQ)
- Go Live to production

**Deep Learning Proof of Concept**

- Need AVI Machine
- Adjustment light + optic + image
- Image Capture
  - Images conforming units (kits)
  - + defect images (kits)
  - + identification defects (logbooks)
- Construction of 2 data bases of image: 1 week
- Learning (training_set) 20 min
- Evaluation (Prediction_set) 5 min
- Programming neural network 1 hour
- Evaluation & adjustments 1 day
- Optimization processing time
- Validation (PQ)
- Go live to production

**Key Take Away:**

- Deep learning will benefit to AVI
- Need to develop image libraries, opportunities for PDA to launch initiatives

More effort in computer vision tools

More effort in image library
Conclusion:
• Accurate parenteral defect deep learning is possible.
• Future AVI equipment will encompass digitalization combined with Deep Learning and virtual machines.
• Need for high quality images on robust AVI equipment.
• For Validation purpose need to restrict to supervised learning concept.
• Will human reference remain?
• Need to work on image libraries for parenteral, PDA could lead this initiative.
• Thank you for your attention
• Contact: romain.veillon@gsk.com

• Many thanks to Fernand Koert for providing image library
• ….is there any artificial „intelligence“ behind this?
• “…and we call invisible, either what is absolutely – as we consider impossible in other cases –,
  Or what is visible by its inherent nature, but in fact it may only be hardly visible or invisible »
  Aristotle, De Anima, Book 2, 10
What do you need?

- 1 PC Linux
- Python + OpenCV
- Scikit-learn
- TensorFlow + Keras
- Some tagged images (many!!)