Breakthrough in Detection and classification of Surface Inspection Systems (SIAS®) via deep learning

Surface inspection has been part of the high technology landscape of the steel industry for three decades. Over this period of time, real time defect detection, with its need for massive data processing, has required significant research. Proven technologies have now reached a high level of maturity and operational experience, such that they are part of the basic package for high-end production control. These technologies include facilities serving the automotive industry, especially for the external panels of cars, where surface quality is the key driver. It must be acknowledged that a ceiling is observed in terms of detection, or classification performance. Although many add-ons, or tricks have been created to improve results in specific cases, an updated consistent and comprehensive approach is missing.

Clecim SAS has been a well-known manufacturer of equipment for the metals industry for more than a century. It provides automatic inspection solutions under the worldwide registered brand SIAS®. With more than 150 references, SIAS® has been installed on all types of flat carbon and stainless steel production lines, from hot rolling mills, to pickling lines, galvanizing and continuous annealing lines. The systems are based on a linear camera technology. Steel strip runs in front of the cameras and is scanned on both sides, with selected angles of lighting and vision, to obtain the most relevant image to detect defects on the sheet.

A recent technological breakthrough has been achieved by Clecim, by reshaping its overall solution with deep learning technology, which will pave the ground for the next remarkable chapters within the inspection technology field. Starting with a general description of deep learning technology, this article explains the development path to a new industrial solution, along with the expected operational benefits gained from this new technology.

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DEEP LEARNING AND ARTIFICIAL NEURAL NETWORKS

Rebirth of deep learning

In the field of image analysis, with topics such as classification and segmentation, recent years have seen the rebirth of artificial intelligence in the form of the Artificial Neural Networks (ANNs). This rebirth of ANN, which is called deep learning, started in 2009 when the technique won its first official contest. Since then, most classification and detection challenges have been won by deep learning (*Table 1*) **[1]**. Examples of the utilization of deep learning are shown in *Figure 1*.

What is deep learning?

Deep learning does not require the traditional and sophisticated computer vision techniques developed over recent decades. Rather, it relies on artificial neural networks that take their inspiration from the human brain and learn to recognize objects through supervised learning, during which many examples are presented to the neural network. The architecture of deep learning may vary but it is mainly composed of several layers of artificial neurons (*Figure 2*).

Today, deep learning has clearly shown its effectiveness in the field of computer vision for detection, classification and segmentation. These three topics are at the heart of automatic surface inspection for the metal industry.

HISTORY OF THE PROJECT AT CLECIM

Based on observations in respect of the above-mentioned inspection fields, Clecim's R&D team launched a research program in 2016 to create a proof of concept that would evaluate the feasibility and potential performance of a next generation inspection system, SIAS® product. By thorough benchmarking and evaluating what was originally developed and made available by private and public organizations, in both academic or industrial fields, the development team elaborated the preliminary

Competition	Date	Image size	Improvement/ %	Winner
ICDAR 2011 Chinese handwriting	15 May 2011	variable	28.9	IDSIA
IJCNN 2011 traffic signs	2 Aug 2011	variable	68.0	IDSIA
ISBI 2012 brain segmentation	1 Mar 2012	512x512	26.1	IDSIA
ICPR 2012 cancer detection	10 Sep 2012	2048x2048x3	8.9	IDSIA
ImageNet 2012	30 Sep 2012	256x256x3	41.4	Univ. Toronto
MICCAI 2013 Grand Challenge	8 Sep 2013	2048x2048x3	26.5	IDSIA

Table 1 Challenges won by deep learning

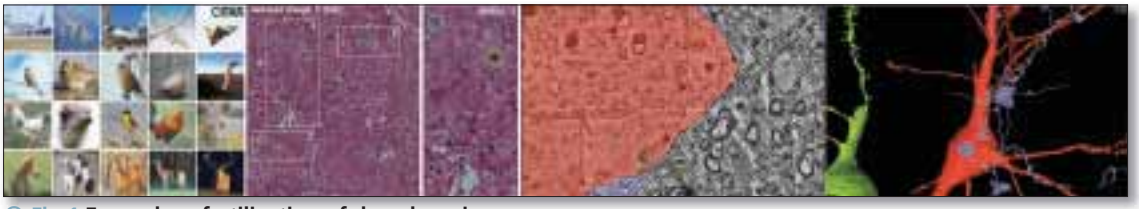

Fig 1 Examples of utilization of deep learning.
L to R: CIFAR image classification, detection of cancerous breast cells, 3d brain reconstitution from scan

concept, to leverage this technological baseline and confirm its feasibility.

Clecim noticed that research in the field of imaging and even in the field of metallurgy, was limited to using images of defects generated by legacy systems. It was limited to proving that the deep learning system could do better in terms of detection and classification of the images previously extracted from these same legacy systems. This is an approach uniquely and wholly based on post processing. Clecim, on the other hand, wanted to implement this technology on 100% of the surface of an inspected sheet, starting from the camera image and without pre-selecting the most relevant images.

Clecim has set up working groups with metallurgists that have facilitated the implementation of prototypes, for example on galvanizing lines, that have led to a new generation of a SIAS® deep learning surface inspection system, which has been named 'SIAS® DeepLearning'. The results have surpassed all expectations, by improving the detection of very low contrast defects, such as those of roll marks and skin pass folds.

This technology is radically different from previous SIAS® related software. The deep learning based breakthrough necessitated a complete overhaul of the software. In parallel to the SIAS® DeepLearning systems, Clecim has also developed a software suite, making this fully fledged product directly exploitable by our customers. To illustrate the computing power implemented here, the SIAS® DeepLearning inspection system achieves more than 150,000 operations per mm^2, or a thousand billion operations per second. This is a typical requirement for a galvanizing line.

OPERATIONAL GAINS FOR FLAT PRODUCT PRODUCERS

Gains in intrinsic performance

It is possible to better detect defects, especially those that are difficult to see in images commonly measured by surface inspection. This is the case for galvanizing lines processing exposed automotive products. The example in *Figure 3* shows a piece of sheet metal, where a foreign object has been caught in the process and sandwiched between the strip and a roller driving the strip. Such a defect is known as 'rolled in foreign material'. The object has marked both the strip and the roller, such that the damage to the roller has caused repetitive defects on the strip, which fade as the strip runs through.

The substrate is shown in dark gray and the areas marked by the roll are in white. The image on the right shows marks detected by a conventional system and on the left detection is by a SIAS® DeepLearning system. Many more defects are detected by using the SIAS® DeepLearning related system of inspection.

Clecim experts and customers engaging in a pilot scheme, expect to increase detection performance in highly textured sheets, where a traditional algorithm cannot distinguish between a defect and the background texture of the sheet surface. Such an example could be the latest generation of high yield strength products on a hot mill where the product looks dirty and only the expert eye can distinguish the defects. It is also the case for galvanized products with spangles, where we find similar problems. Pattern products, for example floor plate, are also very promising products. In the ▷

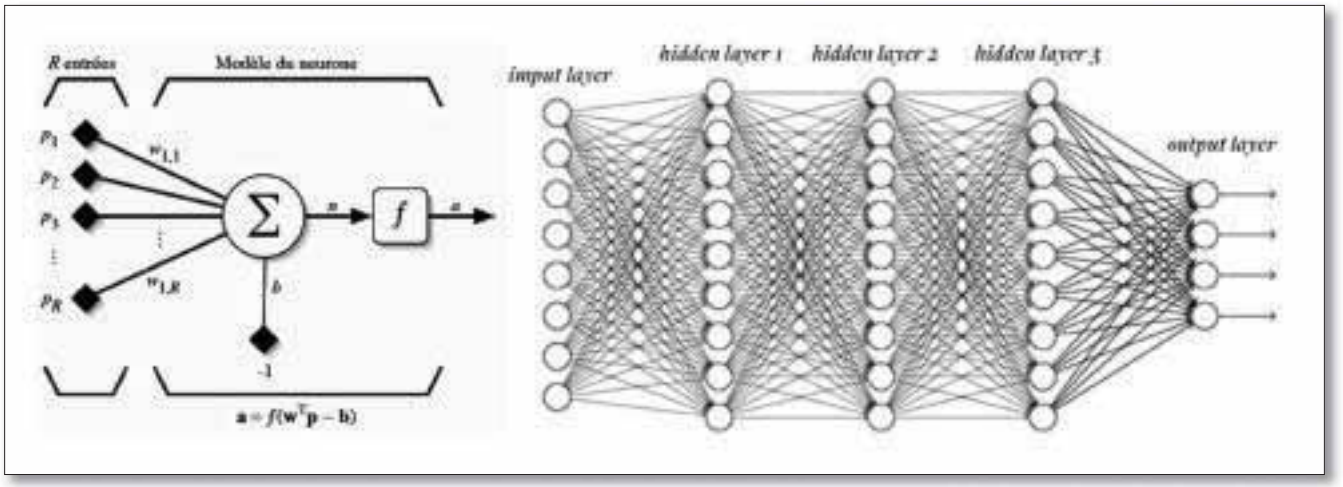

Fig 2 **Artificial neuron (L) and the artificial neural network (R)**

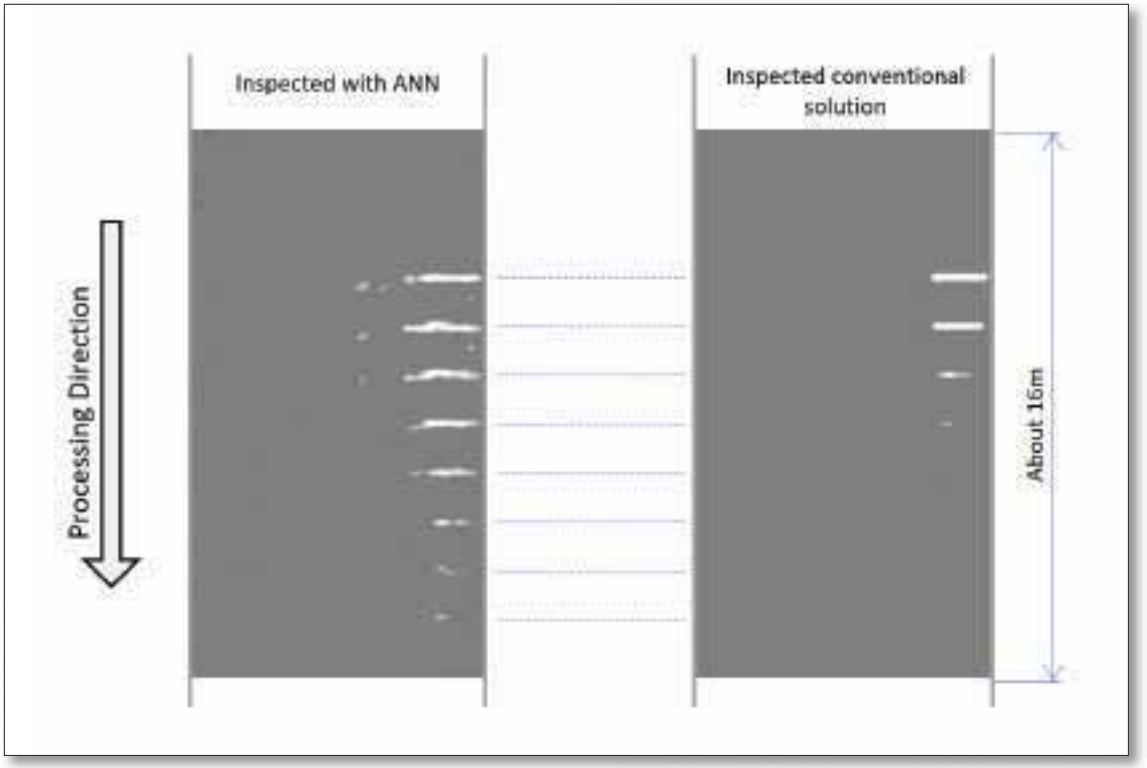

Fig 3 **System comparison at the macro level by inspecting the same strip with different methods**

absence of the new generation of SIAS® DeepLearning inspection systems, it is impossible to distinguish the defects on the sheet. Clecim laboratory tests show a very good isolation of defects such as scratches, roll marks and damage of the teardrop shapes. Improved date classification has also been observed, especially using multi-fields, as deep learning grabs all fields together to process the data.

Time saving

Learning requires a lot of examples of defect images, but the tools Clecim is putting in place facilitate this collection. The knowledge base that has already been implemented shows that we have reduced the learning time by two-thirds, as compared with legacy systems. In addition, the latest technologies allow a shift from one product family to another much more quickly, whereas until now

a new type of product required starting from scratch for image collection.

Gains in standardization

Advantage has been taken of this breakthrough to standardize the inspection product and in so doing make it more easily integrated into our customers' production lines. Transfer of the knowledge base of defects from one line to another, is feasible due to the capacity of the new algorithm to adapt and generalize behavior. For metallurgists, this will ensure that both systems on both lines have the same sensitivity to the same defects.

Wider products available

The automatic surface inspection product branded under SIAS®, including the new generation SIAS® DeepLearning technology, is a core product of Clecim SAS. This sits alongside other Clecim products, such as welders (including full laser-based cutting and welding technology), the Dynawipe air knife, dross removal robots, side trimmers, skin-pass mills, scale breakers, tension levelers, plate levelers and X-HI® mill stands. Processing lines are also provided for galvanizing, annealing and pickling.

REFERENCE

[1] Schmidhuber J: 'History of computer vision contests won by deep CNNs on GPU', *IDSIA*, March 2017.

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