DOI 10.5162/SMSI2020/D2.1

Artificial Intelligence with Neural Networks in Optical Measurement and Inspection Systems – Opportunities and Challenges

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Summary:

Optical measuring and inspection systems play an important role in automation as they allow a comprehensive and non-contact quality assessment of products and processes. In this field, too, systems are increasingly used that apply artificial intelligence and machine learning, especially by means of artificial neural networks. Results achieved with this approach are often very promising and require less development effort. However, the supplementation and replacement of classical image processing methods by machine learning methods is not unproblematic, especially in applications with high safety or quality requirements, since the latter have characteristics that differ considerably from classical image processing methods. In this contribution, essential aspects and trends of machine learning and artificial intelligence for the application in optical measurement and inspection systems are presented and discussed.

Keywords: Artificial Intelligence, Machine Learning, Neural Networks, Optical Measurement and Inspection Systems, Machine Vision

Introduction

Machine vision plays nowadays an important role within measurement technology. Since the amount of image data generated by such systems is rapidly increasing there is a growing need for automated evaluation of the image data.

If the inspection task can be formulated as a "rule", this rule can be implemented in a "classical" image processing algorithm. For many tasks, however, this classical approach cannot be followed. There can be different reasons for this. The limit between "good" and "bad" may be difficult to define. This limit may even not be defined explicitly, but only implicitly given by numerous examples. For these tasks, artificial intelligence (AI) and machine learning (ML) based on artificial neural networks come into play. On the one hand, such systems try to approximate the human ability to recognize patterns, which make them suitable to deal with fuzzy limits. On the other hand, ML based systems are configured by means of training, making them especially adequate when the inspection task is given by examples.

In recent years, artificial neural networks have demonstrated their capability to an ever increasing extent. By now, systems based on AI and ML made solutions available for a large variety of inspection tasks.

Potential of Machine Learning for Machine Vision, Measurement and Automation

Currently, the main technology drivers for ML in machine vision are the automotive industry, communications and consumer electronics, medical imaging and public safety. In machine vision, ML approaches in general and CNNs (convolutional neural networks) in particular are mainly used for classification, detection, and segmentation. Figure 1 shows an application where pill bags are checked for their correct content by detecting different types of pills.

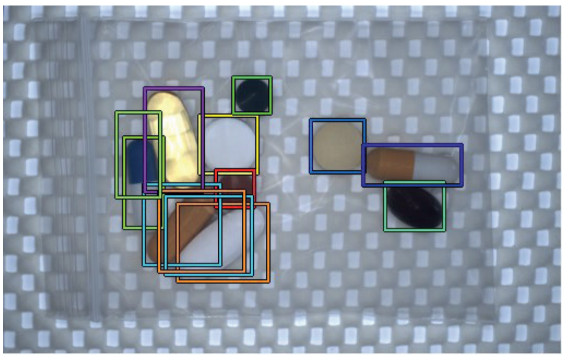

Fig. 1: Example for a detection task: a CNN detects different pills to check the correct content of a pill bag [1].

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Machine Learning can be applied in different fields within measurement and automation: First, it can be used within components for measurement and automation with built-in or subsequent data processing based on ML. Second, machine learning can be applied in the production of devices for measuring and automation; and third, it serves in the overall lifecycle of such devices (from installation over operation to decommissioning).

Challenges for Machine Learning in Machine Vision

However, the benefits of machine learning do not come for free. Above all, the application of ML methods and in particular CNNs requires a sufficient amount of representative training data. The effort required to provide this training data can be immense very great in practice. The data must be meaningful and sufficient for the task at hand. Figure 2 shows an example of grapes that are to be sorted. In the annotated training images, all relevant events (perfect berries, rotten berries etc.) must be present and the events must be contained in all relevant characteristics (e. g. light and dark grapes).

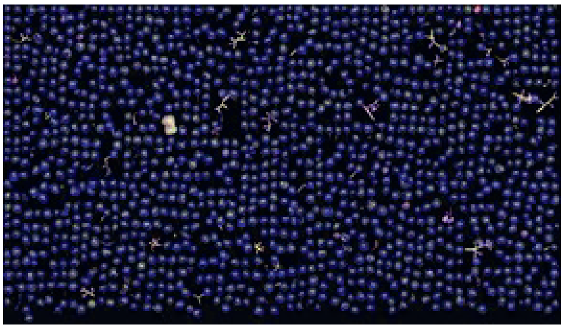

Fig. 2: Data used for learning – here grape berries during sorting – must be representative and robust (image source: Fraunhofer IOSB, Karlsruhe)

Since training data are in principle quality-relevant and therefore sensitive, they are valuable resources that must be treated and protected as such. In case that meaningful data is not available in sufficient quantities for the training of machine learning, concepts must be developed to reduce the need for real, annotated learning data.

In practical use, there are even more challenges. In addition to technical aspects, it is important to take into account the economic aspects. For example, many machine learning processes still require immense computing power. The use of machine learning is often difficult when high demands are made on freedom from defects, since machine learning methods are currently often not able to secure the required low error rates. While there are recognized methods for determining the measurement uncertainty for classical measurement systems (also in machine vision) [2], such a method is still missing for machine learning based measuring systems. Finally, systems using ML often do not have a continuous behavior, which means that small changes in the input to the systems (the images) might lead to large changes in their output (the classification).

Current fields of action

ML is currently one of the dominant research areas in MV. Active research deals with developing methods to make ML based decisions comprehensible and explainable. Another field of activity in MV is to provide a meaningful measure of reliability or confidence of the results of machine learning approaches. With the standards VDI/VDE/VDMA 2632-3 [3] and VDI/VDE/VDMA 2632-3.1 [4], general guidelines for the evaluation of classifying MV systems already exist and will be extended to ML based approaches.

Anomaly detection, active learning, the avoidance of catastrophic forgetting, the use of simulated data, tools for supporting the compilation of training data, learning with few, but representative examples (few-shot learning) are – amongst others – further research topics that are followed at present.

In addition to these scientific and technical challenges, suitable framework conditions must be created. Among others, important aspects are the protection of data used for learning and the necessity for a legal framework for the use of data.

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