White paper

Artificial intelligence in industrial testing technology

GÖPEL electronic
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Contents

Introduction

Artificial intelligence (AI) is given tremendous importance when it comes to fundamentally changing processes and products. In the private sector, for example, the extraordinary performance of AI applications is taken for granted when using intelligent assistants. In the industrial sector in particular, however, the development of domain-specific AI applications is becoming a key issue for future innovation steps: "AI will contribute 15.7 trillion dollars to the economy in 2030"[1]. In the field of industrial production, networked production grouped under the keyword "Industry 4.0“ is unimaginable without big data and artificial intelligence. The use of AI technologie in this area is also about equipping the individual production systems with artificial intelligence and thus paving the way for semi-autonomous and later fully autonomous production. Although there are already promising AI applications and products in the field of fully autonomous production, there are of course, still many development steps to be taken.

Fundamentals of artificial intelligence

Artificial intelligence is a key technology that will profoundly change all sectors of the economy and society. Again and again, previously inconceivable performance can be seen which machines achieve thanks to this technology. In particular, advances in machine learning and automation, in which the same or even better performance compared to humans is achieved, arouse great interest these days. The basic idea behind all these approaches is not new.

History of development

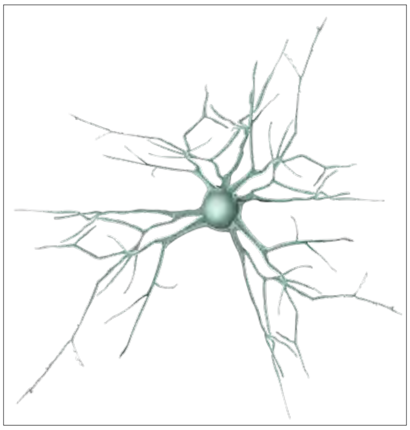
The starting point of artificial intelligence is the not entirely new desire to mechanise human or general thought processes. Knowledge is expressed by information. Machines that can process information automatically and quickly have been familiar to us for a long time. So it is not surprising that IT became the core area of artificial intelligence. Yet Gottfried Wilhelm Leibniz, one of the most important polymaths of his time, had already considered the basics of this science much earlier, at the close of the 17th century, to be precise. Later, machine evidence, i.e. the succession of new statements from a large number of given statements, played a major role in artificial intelligence. For the first time, it was therefore possible to process an unclear amount of logical statements in a structured, comprehensible manner and at superhuman speed and to verify them automatically. Such approaches can be used for ***expert systems*** that are used to help the user handle complex tasks.

Gottfried Wilhelm Leibniz (born 1 July 1646 in Leipzig; died 14 November 1716 in Hannover)

[1] *PricewaterhouseCoopers: „Künstliche Intelligenz in Unternehmen“, Studie 2019.*

Artificial intelligence in testing technology

This was followed by artificial neuronal networks: A greatly simplified simulation of biological neurons, such as those found in the brains of mammals. In the simplest case, each neuron is defined by a weight matrix and a non-linear function. The weight matrix determines how much the neuron responds to its individual inputs. The non-linear function controls neuron output.

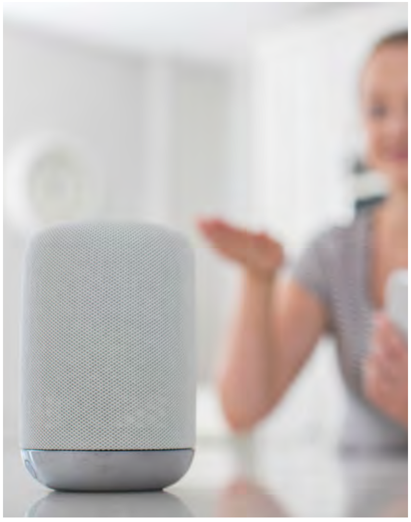


Representation of a natural neuron

Learning methods adapt the matrix's weightings over many training steps. A large number of neurons are combined into a single layer. Each neuron is linked to other neurons in the previous layer by its weight matrix. Several layers are combined to form a network. Regardless of the artificial intelligence approach chosen, the benefit of intelligent systems and intelligent automation for industry can not be dismissed.

Overview

Our lives are determined by electronics and it is impossible to imagine our lives without it. From electric toothbrushes to powerful household appliances, cars as de facto (self-) operating computers, consumer electronics in every corner of smart homes – we are accompanied electronically on almost every step of our lives. But even away from consumer goods and entertainment, industrial plants, transport systems and medical technology in particular rely on perfectly functioning electronics. In many areas of everyday life, a failure of our now familiar technologies leads to trouble or a change of manufacturer – much higher risks are associated with critical areas such as car control systems or surgical medical technology. No manufacturer can afford functional failures or defects due to faulty electronics and for this reason, automated testing of electronic assemblies has become one of the most important process steps in production. Meanwhile, the following has been shown: The assembly test determines the quality of the delivered product and represents the image and reputation of the company. Production processes are individual and differ according to industry and application. However, regardless of whether large electronics manufacturers for



Example of known AI-based applications.

the mass market (high volume) or small manufacturers for particularly complex assemblies (low volume): Industrial production processes are usually structured according to a similar scheme. Accordingly, testing and inspection solutions have found their places. Printing solder paste onto the unpopulated printed circuit board and then loading the individual components before soldering on the assembly is often the first step.

Expert systems

Knowledge-based systems that perform mental activities such as diagnosis or classification comparable to the performance of human experts. Expert systems work with a knowledge base. From this foundation, problem solving is generated for the problem characteristics entered by the user.

Numerous errors can occur during these steps. ***Optical test methods*** are used at the earliest stage of production in order to be able to intervene in good time and adapt processes where necessary. Once the assembly is finally manufactured, there are numerous ***electrical test*** procedures to check the actual functionality of all installed components and connections. Finally, the assemblies are installed in systems or modules or delivered to the end customer, who then inserts them into the respective environment. Examples include control units or electric motors in car seats or electric drives for window lifters, tailgates, etc. Such systems are usually tested at the end of the production line – ***"end-of-line"***.

AI automates test program creation

Optical inspection systems are based on ***inspection programs***. In AOI systems (automatic optical inspection), they store the structure of the circuit board (e.g. based on CAD/assembly data) and the type of test by the system (test or component library). Each product and assembly requires its own test program in production, which is usually created by the operator or AOI programmer. Depending on the size and complexity of the assembly, this is a time-consuming and costly process. Programming consists on the one hand of program creation and on the other of program optimisation. The latter is always used to prevent pseudo defects caused by fluctuations in the production process or due to component variances (good solder joints are assessed as bad) or defect frequency (bad solder joints are assessed as good). Optimising test programs adjusts the threshold values between "good" and "bad", i.e. when an image is evaluated and how. This process is also sometimes time-consuming and can take a long time with a large product spectrum. The PILOT AOI Version 6 system software from the GÖPEL electronic AOI system uses artificial intelligence for automatic test program creation. After importing Gerber and assembly data as well as an automatic layout analysis, the "MagicClick" function creates the required library entries and assigns them to the respective article numbers. Inspection parameters are then automatically adjusted based on a sample assembly and predefined tolerances. With a single mouse click, the AOI test program including component library is created fully automatically and optimised using the sample assembly.

The test program creation and optimisation process, which used to take a long time and often several hours, is now typically completed in less than half an hour, even for complex assemblies. Compared to the conventional approach, MagicClick thus offers significant cost savings and allows AOI to be used even with the smallest quantities.

Optical test methods

Optical test procedures are used to check the visible quality characteristics of an assembly. They only state that an assembly should work.

Electrical test

These give certainty about the function of an assembly. However, no statement can be made as to whether, for example, a soldered joint will last a few minutes or even years.

End-of-Line (EoL)

End-of-line (EoL) testers are responsible for testing the overall functionality of the end product during the manufacturing process, including the installed electronics.

Inspection program

A structured sequence of individual test steps. Each step checks one or more characteristics for deviation from a target value. Optical inspection usually comprises complex image processing steps and heuristics. In the electrical test, test steps can verify individual electrical measured values or longer signal sequences.

AI-based classification for inspection of assembly processes

Despite the rapidly increasing automation in industrial production, there will still be many assembly processes to be carried out manually in the foreseeable future. Due to the complex structure of the products and/or a high degree of individuality of the product variants, complete automation of assembly in such cases is not economically viable. In addition, with product cycles getting shorter, manual assembly is often the only way to add value efficiently. Examples of such assembly processes can be found in a wide range of industries. In the field of electronics production, the assembly of THT components (through-hole technology) belongs to this category. In the age of Industry 4.0, manual assembly sites are increasingly demanding the direct integration of optical inspection systems and automated reporting.

However, the direct integration of optical inspection into the assembly process requires completely new and innovative equipment concepts compared to traditional AOI systems. The cameras for inspection must be arranged in such a way that they do not affect the assembly process of the people working there. Lighting cannot be optimised for the requirements of image processing, but must meet the legal requirements of a workstation for assembly processes. Furthermore, it is not possible to have a light-shielding cover as this would restrict the manual assembly process. With the "MultiEyeS plus", GÖPEL electronic offers an optimally suited inspection module for the described application for a large image area of approx. 550 mm x 450 mm. The system is based on a multi-camera image capture unit consisting of up to 12 cameras with integrated lighting. The individual images of the cameras are combined into a common image, as is familiar from panoramic photography. All tests are carried out on the overall image. It is not necessary to assign inspection areas to individual cameras. The "MultiEyeS plus" module is designed to be mounted directly above the assembly table without the need for additional measures for light shielding. From the point of view of classic image processing, such an open system is not optimal and reproducible inspection would not be possible with the classic approaches or would only be possible with very complex debugging of the test programs. This is precisely where an AI-based solution comes in.

Due to the relative immunity of ***folding neural nets*** to fluctuations in brightness and position, they are the ideal way to reliably detect manually installed objects.

CAD/assembly data

Electronic design data used to produce the electrical flat assemblies. Depending on the type and scope, the data includes the positions, extensions and designations of conducting tracks, pads, components and position marks. This data provides valuable information for automated optical inspection.

Test/component library

The library links test steps with a specific component. As components usually exist several times on a test object, the library not only facilitates test program creation, but also debugging. The test program is quickly generated by means of ready-made modules and changes can be made to all specimens at the same time thanks to the logical linking of the components.

MultiEyeS plus: an example of an open system for the inspection of assembly processes.

Approaches based on neural networks, however, require a large number of examples in order to be able to handle complex problems. Such sample data is usually very complicated and costly to obtain. This hurdle to obtaining high-quality data has so far dampened the widespread use of deep learning in inspection areas. After the data has been compiled, it must be cleaned and pre-processed. For monitored training procedures, it is still necessary to determine the corresponding labels. This is a labour-intensive process and requires the same level of domain knowledge that AI later requires. Once the data record is complete, the model can be trained and tested for real data.

GÖPEL electronic takes a different approach here. A system of mathematical-statistic procedures and methods of machine learning complement each other. Mathematical functions describe at an early stage the observed distribution of data and confirm or correct the untrained neural network in the first "assumptions“. This achieves a condition that does not yet promise a reliable test, but can independently label a large part of further training data. This removes the time-consuming labelling task from the user. If the system is not "certain", i.e. the mathematical and neuronal models drastically contra- dict each other, additional training content can be requested using an active method. To this end, a training example of the system is presented to a human expert at any point in the process and he is asked to give his opinion. The interaction of human expertise, mathematical models and the adaptability of neuronal networks results in a trained model in a very short time with little human effort, which enables reproducible inspection even under unfavourable image capture and illumination conditions. Together with a sophisticated camera system for optical inspection directly at assembly stations, there is great potential for further optimising of assembly processes and, in particular, the assembly of THT components.

AI monitors human decisions

Most of the industrial production processes described above are characterised by a high degree of automation. On the one hand, this is a consequence of high cost pressure and on the other hand, of the demand for consistently high product quality. It can be seen here that both the actual production and assembly steps of an assembly or product as well as the subsequent mechanical, electrical, acoustic, optical or whatever type of tests take place automatically and without direct human influence. Because wherever people carry out monotonous activities, there is a risk that fatigue can cause defects.

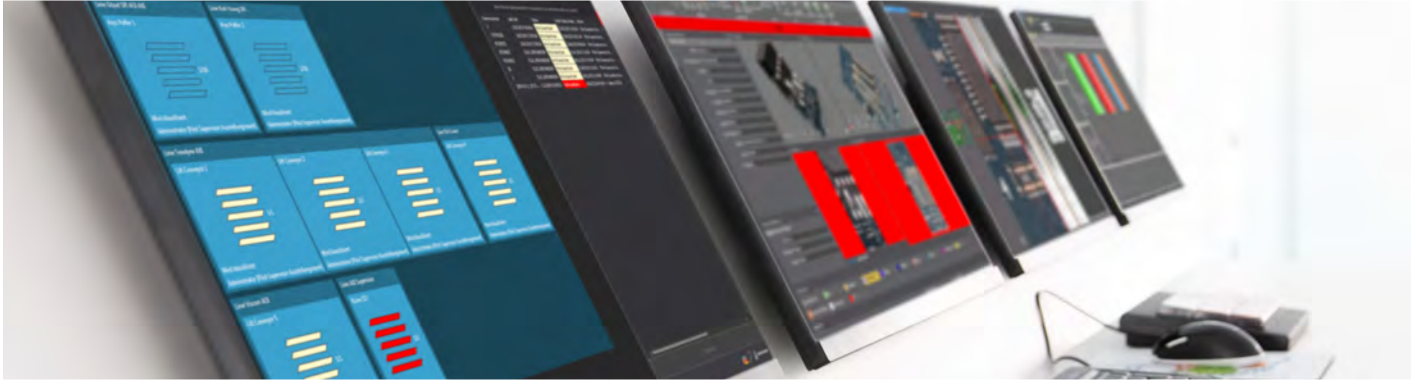
Typical examples of high levels of automation are found in many production lines for electronic SMD assemblies (surface mounted devices): assemblies whose miniaturised components are applied to the circuit board instead of wired through holes (THT - through hole technology), where the production steps of printing, assembly, soldering, etc. usually take place fully automatically. Automated optical inspection or automated X-ray in-

Folding neural nets

Folding neural nets refers to a subtype of artificial neural networks that demonstrate high performance, especially in image processing and image recognition tasks. Each neuron in a layer here only responds to a local accumulation of neurons in the previous layer. It can therefore only be activated locally. So-called filters are used for activation, which determine the properties from this detailled map of the previous layer. These filters are shared for all neurons in a layer, making it the same as a mathematical fold. This structure roughly reflects our understanding of how the visual cortex works in mammals.

DeepLearning

DeepLearning describes the latest trends in machine learning. Significantly increased computational power has made deeper, i.e. morecomplex, artificial neural nets workable in an acceptable time. This development has given the entire field of artificial intelligence research a new boost.

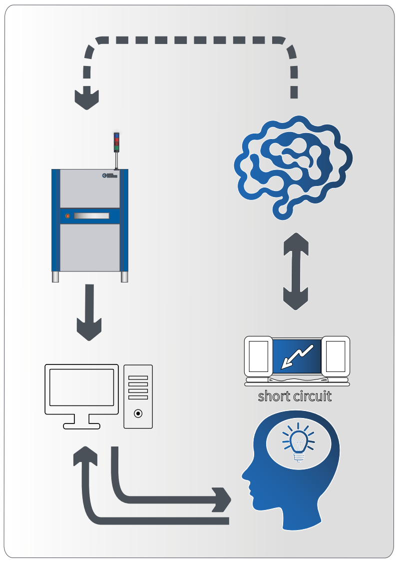


Production line with manual loading and final optical inspection.

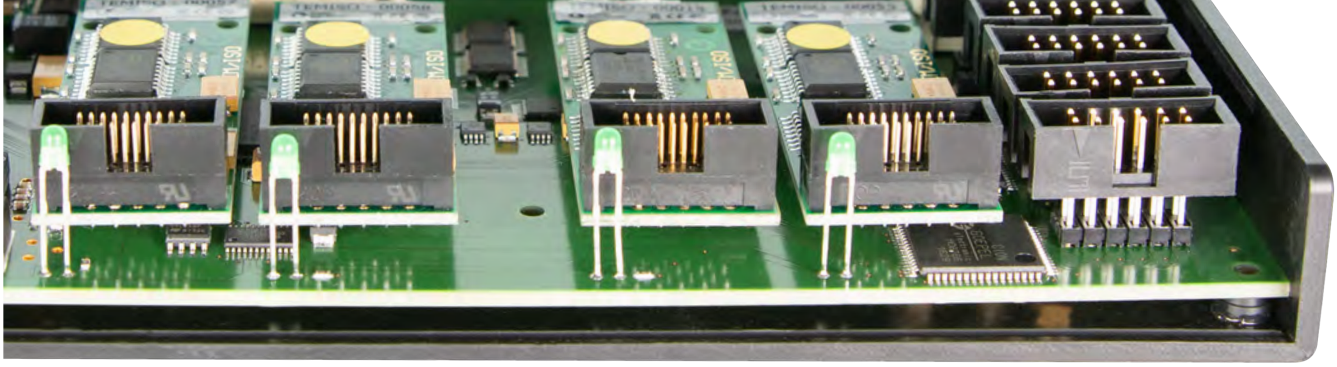
spection tests the assemblies 100% for correct assembly and soldering of the components and rejects faulty assemblies. In the case of rejected assemblies, it is typical for the defects detected bythe inspection system to be finally evaluated and classified with the human eye at the verification station. The PILOT Verify software module from GÖPEL electronic has been expanded with a functionality in which the AI makes its own decision for every defect that requires an operator decision. If artificial intelligence comes to a different result than the operator, a message is displayed and the user is prompted to review their decision. If necessary, the decision of another operator or supervisor can also be requested for this purpose. The purpose of this mechanism is to prevent an assembly with an actual defect detected by AOI from subsequently being declared as a good/pass assembly. If artificial intelligence is then trained to the point where all possible defect situations are reliably detected, verification is then automated in a further step. Artificial intelligence then makes the basic decision and only requests the decision of an operator or supervisor in situations where a safe classification cannot be made.

Optimised test coverage with AI

Electronic testing is an essential part of today's manufacturing process. Not only are all connections of the assembly tested for flawless operation, but also modules such as microprocessors and FPGAs are programmed and their function tested. SYSTEM CASCON™ is a software platform that combines various technologies and makes them usable in both production and development. Similar to the inspection test program, test programs first need to be developed. This requires very detailed information about the test object and its individual elements. Based on CAD data, items must be classified and functional models assigned from the library. The problem with this is that the elements (modules, pins and connections/networks) from the CAD data, apart from the name that can be freely assigned by the hardware designer, have neither information about which



Example of a cooperative classification of component defects by man and AI. AI classifies the same inspection data as humans. If there is a dissent, the classification result must be checked.



class they belong to, nor a model describing their internal functioning. This is where artificial intelligence is used: Modules (e.g. resistors, capacitors, RAM and FLASH components) as well as networks (power, ground, JTAG) are classified and suggested to the user by a learned model, which analyses the structure of the elements and their connections to each other.

The search for a suitable library entry is also improved by neural networks. Instead of searching for any identifier, the structure of the module is compared with the entries in the library. This filters out the potential models. Only the completeness of the board information will allow automatic test generators, analysis and diagnostic algorithms to fully perform and support the user in their goal of 100% test coverage. By using artificial intelligence in the software platform SYSTEM CASCON™, the user is taking a significant step closer to this goal.

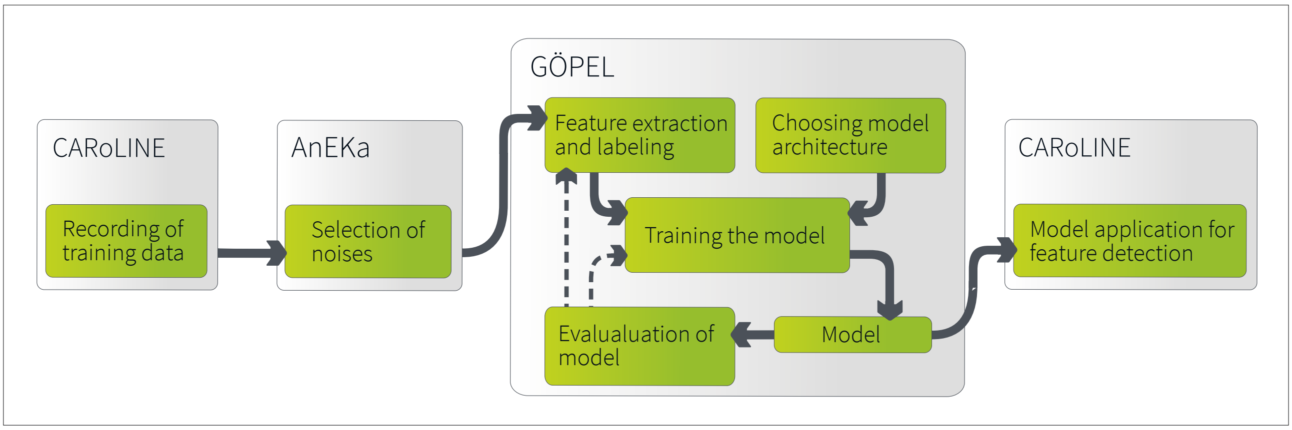
Airborne and structure-borne noise analysis with AI in production

Mechatronic components such as electric motors and lumbar pumps for car seats or motors for adjustable side mirrors are also subject to strict quality requirements in the production process. Optical tests and function tests are common. Noise analysis also plays a major role in quality assurance as it allows completely this basis, the manufacturer can primarily use acoustic analysis to optimise its own production process. An assessment of the sound quality, i.e. whether a sound is perceived as pleasant and typical or as unusual and disruptive, can only be determined by means of airborne noise. Particularly in automotive construction, acoustics that are perceived as pleasant are of great importance. Noise greatly impairs the passengers' driving experience. For the end customer, acoustic analysis can be used to ensure comfort. Structure-borne noise based test systems are already in use in production. In order to also detect noise patterns in airborne noise, it is necessary to establishnew processes in the production process.

The CARoLINE test system is an acoustic system that analyses production based on airborne noise in addition to structure-borne noise. The objective analysis of the products has been extended with predefined mathematical algorithms. This enables subjective evaluation using psychoacoustic measurement methods and artificial intelligence. The particular advantage: Noise (unavoidable in the production hall) has no significant influence on noise-sensitive acoustic analysis through the use of AI. Previous solutions consisted of acoustic shielding. Test objects had to be removed from the production line and subjected to acoustic testing in a noise-dampened, insulated area.

The CARoLINE test system offers a different approachdirectly in line operation. Machine learning combines previous mathematical calculation functions with the collection of data sets for classifying specific characteristics and noise patterns. During the production cycles, the determined acoustic records now form the basis for determining the characteristics. Existing noise is also recorded. These records are a prerequisite for accurate prediction of subjectively determined classifiers. Clear and distinct noises are no longer dependent on the frequency response or fluctuations in speed, but only on the assignment (annotation) of the interference that has occurred in the product. Detailed mathematical knowledge of the determination of the false noises

CARoLINE: acoustic testing based on airborne and structure-borne sound



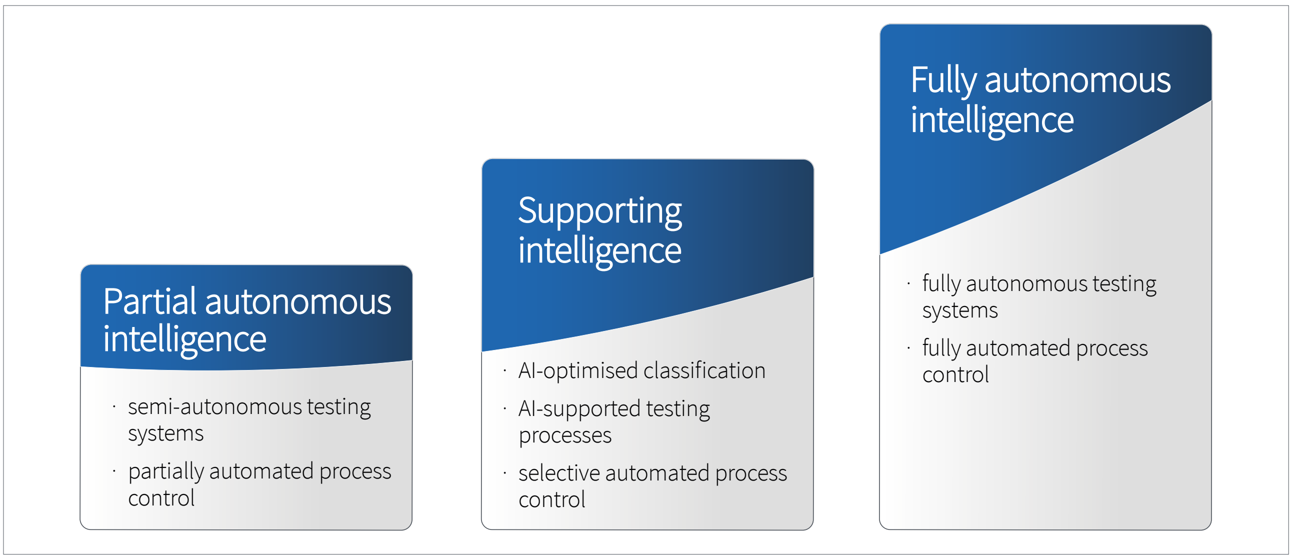
Procedure for creating a classifier for CARoLINE and its application in production.

is therefore no longer necessary. They just have to be perceptible in the recorded audio signal. The schematic diagram shows the process for creating a classifier and its application in production. The fourth generation of CARoLINE thus combines good mathematical practices as well as the application of AI. This enables an effective acoustic inspection of the manufacturing process through structure-borne and airborne noise, even in noisy environments, which meets the requirements of both manufacturers and end customers. Artificial intelligence is intended to improve and simplify our lives.

Summary

AI is also used in industry with clear objectives: higher efficiency, cost savings and increased quality of end products. Using industrial testing technology as an example, the white paper has provided insight into various areas and demonstrated how AI is already changing processes today. There are many advantages for companies, but also for humans. AI-controlled systems take on time-consuming or even annoying tasks. The user can take care of other, more important things. Processes are even easier to automate and reproducible, which also provides long-term benefits. Test and inspection systems for electronic assemblies and mechatronic components are extremely sophisticated in 2020 and are subject to years of optimisation. Artificial intelligence offers enormous potential on the way to a zero defect strategy. As more defects are found, the test coverage is increased. AI sees things that the human eye might misjudge. The interplay between humans and AI means that unsafe situations are handled even better and pseudo defects are reduced. Artificial intelligence enhances testing systems, especially under difficult production conditions (light and noise).

In addition to all these aspects, cost savings are of paramount importance to industrial companies. Faster testing, fewer returns and field failures not only increase reputation with the customer, but also offer financial benefits. "Machine learning in the manufacturing process can make the greatest contribution to value: Production can save up to 61 billion dollars, for example through AI-based quality control"[2], according to a study on the automotive industry in 2025. The path to semi-autonomous and later fully autonomous testing systems using AI is predetermined. In times of global technological change, artificial intelligence in industrial testing technology can provide a crucial competitive advantage.



Stages in the foreseeable development of fully autonomous testing systems.

[2] *McKinsey & Company: Artificial Intelligence – Automotive's New Value-Creating Engine, Studie 2018, p. 7.*

Bild Gerd Altmann

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