

MACHINE VISION – A DRIVER OF DIGITAL AGRICULTURE

WHITE PAPER

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Machine vision – a driver of digital agriculture

How machine vision automates and optimizes processes in the agricultural industry

Digitalization is increasingly invading agricultural value-added processes, as in most other industries. From industrial-scale agricultural enterprises to small farms, everyone is relying more and more on digital technologies in line with smart farming. This trend helps to further automate processes and increase their efficiency.

Machine vision is an important component of automation. In this white paper, you will read about how the technology works and the specific ways in which its use supports modern agricultural processes. You will get to know diverse practical application scenarios and learn how advanced agricultural enterprises benefit from the many advantages.

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The agricultural sector in transition

The agricultural sector is facing growing challenges. Labor shortages, ever stricter legal standards and regulations, rising costs, higher price pressure, and limited farmland are forcing the industry to optimize its processes. As a result, more and more farmers rely on digital technologies to remain viable in the future and use modern information and communication systems based on the principle of smart farming. These systems can be combined with innovative technologies, such as the Internet of Things (IoT), sensors and actuators, geo-positioning systems, big data, unmanned aerial vehicles (UAV) like drones, and robots.



Smart farming is becoming more and more prevalent in modern agriculture.

Efficient and automated processes with machine vision

Machine vision plays a major role in this context. Increasingly it helps make agriculture-specific processes more efficient and automate them to an enormous extent. The technology originated in industrial applications, where it has been used successfully for decades to detect objects as well as monitor and optimize manufacturing processes.

Machine vision consists of two main components: hardware and software. Hardware refers to what are known as image acquisition devices, such as cameras, scanners, and sensors, which record a large quantity of digital image data from certain scenarios. This information is then processed by machine vision software and made available for appropriate applications. The software generally runs on associated industrial PCs (IPC) and increasingly also on compact embedded devices or even right on the image acquisition unit. The system is then capable of automatically recognizing certain objects and situations based on visual features alone.

Object detection: precise, flexible, and fast

Machine vision offers a number of key advantages over other identification methods: Especially high accuracy and reliable detection rates make the technology attractive. It is also extremely flexible. The image processing algorithms can be optimized to detect a wide variety of objects in all conceivable scenarios, even from different angles. Machine vision furthermore operates at very high speed and is able to identify objects precisely in just milliseconds.

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Technologies for modern agriculture

Since it offers so many benefits, machine vision is predestined for widespread use in modern agriculture. The technology is thus applied for

- automating farm machinery and harvesting processes
- digitalization of greenhouse processes (greenhouse farming)
- targeted and site-specific cultivation of farmland (precision farming)
- automated classification and inspection of seeds and produce
- optimizing animal husbandry (livestock farming)

Modern machine vision solutions come with a great many innovative technologies to increase the efficiency of agricultural value-added processes sustainably. These include:

Embedded vision

Like in the industrial setting, embedded systems are also used in digital agricultural production scenarios. Such devices are compact, often mobile, and electronic. Due to the harsh environmental conditions, they must be particularly robust and resistant to external influences. After all, the systems are often exposed to massive dust accumulation, strong vibrations, and high humidity or even come into direct contact with water. For example, farmers use handheld devices, smart phones, and tablets for mobile data collection. Special image acquisition devices, such as smart cameras and vision sensors, can also be mounted on tractors or other farming machinery. They record digital image information of harvesting processes, for instance, or other scenarios. Embedded devices are especially suitable here, since space is usually at a premium. They are small, with compact dimensions, highly efficient, and generate little waste heat. If the systems have integrated machine vision software, they can be used for a wide range of image processing applications. This is known as embedded vision.



Machine vision is used in a wide variety of agricultural sectors.

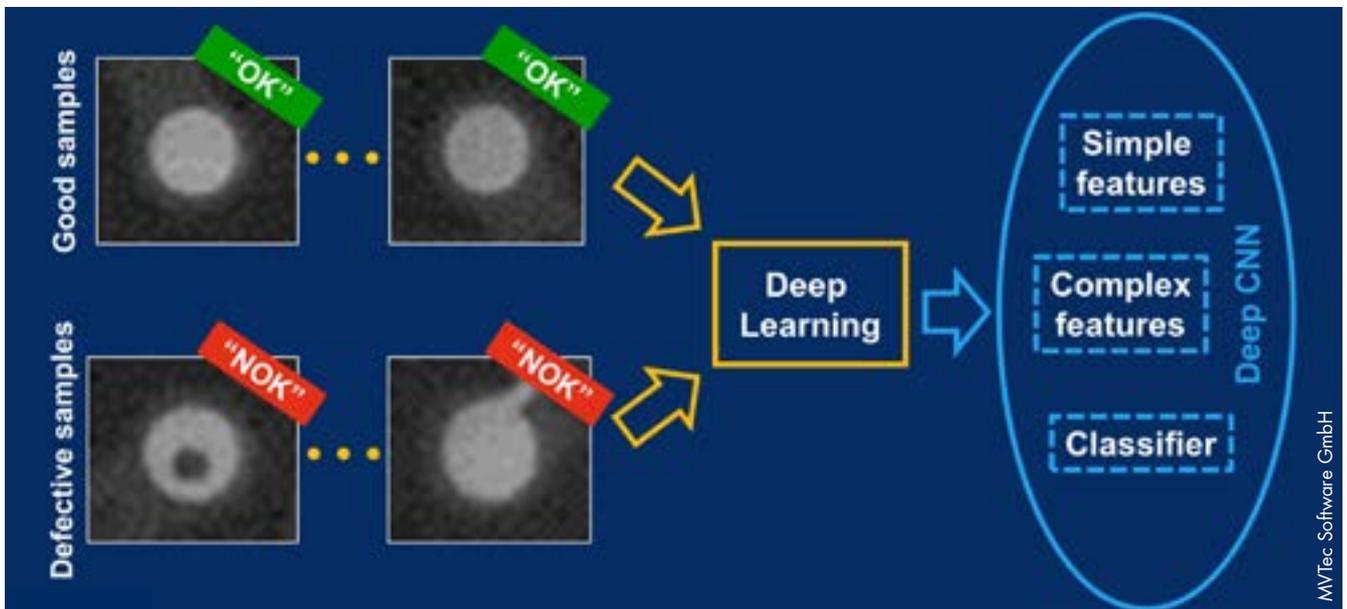


Rule-based machine vision systems

Rule-based machine vision systems have a key role to play in detecting objects or defects in agriculture. Used for decades in the industrial context, the technology is extremely reliable and proven, which makes it highly relevant in the agricultural sector as well. Unlike artificial intelligence (AI), rule-based machine vision requires special programming. Developers define certain rules or features manually to extract the crucial information needed for the detection processes from the image data. The technology requires much less strict system requirements than do AI-based methods, which increases efficiency noticeably in agricultural scenarios. Moreover, the system's decision-making processes are always transparent and can be tracked at any time.

Deep learning

Even though a number of benefits make rule-based systems attractive, as described above, AI technologies may offer even more possibilities with regard to detection accuracy under certain circumstances. These include mainly machine learning, here especially deep learning processes, based on a convolutional neural network (CNN) architecture. What's special about these methods is that they learn new things on their own, based on comprehensive training, in which the machine vision software analyzes in detail the image data generated by the image acquisition devices.



Deep learning uses images of both defect-free and defect objects for defect detection.

Before the training, the images are marked with a digital label to assign them, for example, to a specific object or error class. However, this labeling is extremely labor-intensive, as is the management of the large volumes of image data associated with this. A suitable label tool is therefore necessary, which maps these processes and allows them to be controlled. During the course of the training, the deep learning algorithms then learn typical features that allow them to assign the objects to be detected to certain classes, for example features for "apple" or "pear." Deep learning is also suitable for identifying and localizing all kinds of defects precisely. This technology is used primarily when the objects to be inspected are very dissimilar and the task cannot be performed by rule-based approaches for this reason, or only with great difficulty.

Combination of rule-based and AI systems

Rule-based and AI systems, such as deep learning, can be combined sensibly into a single solution to always achieve optimum results for the particular application. In this way, the particular strengths of the two technology worlds can be made apparent. By interacting with each other, they can achieve even better results than the individual technologies on their own. Agricultural users thus benefit from a consistent end-to-end solution, much higher detection rates, and faster machine vision processes. All decision-making criteria that were crucial to the object classification can be tracked transparently.



Cloud technologies

Innovative agricultural enterprises frequently rely on the cloud for using digital applications. Modern machine vision providers now also make certain services available in the cloud. These services have a number of advantages over on-premise solutions. The necessary resources can be scaled flexibly and, if necessary, additional capacities can be added at any time. The cloud purchasing model is also extremely cost-efficient because only the services actually used, such as server services, have to be paid for, depending on the contract model. Farmers can outsource the system hosting to experienced cloud service providers, who generally operate highly available and reliable infrastructures. Finally, using the cloud can also save money, since users do not have to procure their own system landscape.

Multispectral imaging

When it comes to crops, in particular, it is helpful to consider not only the visible spectral range but also other color spectra that cannot be perceived by the human eye. Suitable hardware can detect these spectra and evaluate them with special machine vision methods, which are able to detect these types of multispectral color channels. For example, crop diseases or a lack of nutrients can be identified early on before the consequences can be perceived in the visible range. Farmers can thus react at an early point and take targeted countermeasures. This reduces harmful substances and leads to better harvest results.



3D vision technologies enhance robot-assisted harvesting processes.

3D vision

3D-based machine vision technologies (3D vision) are also extremely important in high-tech agriculture. Detecting, evaluating, and processing sensor-supported 3D information allows for better control of mechanical systems or processes. This makes it possible to implement agricultural applications that are beyond the capabilities of 2D approaches. Not only does this permit the exact localization of stationary objects, but objects moving in three-dimensional space can also be tracked precisely and gripped, for example. To do this, multiple cameras record image information from different angles. The reliable and precise, 3D-supported position determination is indispensable in special agricultural application scenarios, for example in robot-supported harvesting.



Modern smart farming concepts

Precision farming: targeted cultivation of farmland

Machine vision facilitates targeted monitoring, fertilization, and irrigation of farmland and allows the land to be cultivated more efficiently and sustainably. In addition, valuable resources can be used as needed, including pesticides, water, and fertilizer. This helps farmers save money, reduce effort, and meet legal requirements in the use of fertilizers and pesticides more easily. The following examples illustrate how it all works in practice:

Precise pest control

A drone with a high-resolution camera flies over a field. The integrated machine vision software evaluates the recorded images and automatically detects certain features from the air. For example, abnormal chlorophyll content in the plants indicates a stress situation, such as a fungal disease or pest infestation. Based on these findings, farmers can take highly targeted measures. For example, they can precisely spray only the affected areas with pesticides or fungicides. The multispectral processes described above, which are integrated into the machine vision systems, help determine the condition of the plants. Special multispectral cameras are used to detect and process additional color channels that are invisible to the naked eye. This allows abnormalities in the vegetation to be detected automatically, reliably, and at an early stage.

Drones with integrated machine vision software detect a wide range of properties on plants.





Machine vision software assists in targeted weed control.

Efficient fertilization and irrigation

Another application scenario is targeted fertilization. The machine vision software precisely measures the crop height based on the digital image data, making it possible to fertilize only low-growth areas as needed. According to the same principle, fields can also be irrigated on a site-specific basis. In this case, for example, infrared cameras measure the temperature and prepare a heat map of the relevant area. Based on the measured evaporation chill, the actual, precise moisture level in the individual regions is then made visible so that irrigation can be deliberately adapted to requirements. The image data does not necessarily have to be recorded by drones but can also be captured by satellites from a great height in some applications.

Efficient plant protection

Plant protection is an important topic in modern agriculture. Growing objections and increasingly strict regulations of traditional protection methods are challenges that have to be faced. Machine vision makes it possible to distinguish between crops and weeds in real time and to apply herbicides particularly efficiently. To distinguish between the plants, an industrial camera (multispectral image data) is mounted on a sprayer to take pictures of the planting. The camera sends the data to an embedded device, which runs the integrated machine vision software and controls the application. The software uses deep-learning-based object detection to spot the weeds between the crops and then signals the system to spray an herbicide precisely onto the identified weeds. The targeted application reduces the environmental impact, the herbicides are used cost-efficiently, and this ensures high yield of optimum quality in keeping with nature conservation regulations and consumer wishes.



[Watch the video for more details about Farming Machinery](#)



Farming machinery: Automating harvesting processes

Machine vision methods are also being used increasingly in modern farm machinery. For example, tractors, combines, and robotic harvesters are equipped with embedded devices such as smart cameras. These devices generate large amounts of digital image data, which is evaluated in detail with integrated machine vision software. The results can then be utilized for a wide range of applications.

Detecting ripe apples of sufficient size

The apple harvester of the Belgian ACRO Institute (Automation Center for Research and Education) demonstrates how to automate the harvesting of fruit, such as ripe apples, with the aid of machine vision. The robotic harvester is first positioned in front of the tree. 3D sensors then scan the front area from 40 positions and divide the tree view into the same number of sectors. The apples in each sector are sensed so that they can be harvested with a gripper one by one. The integrated machine vision software determines an apple's position in the image precisely and selects only ripe fruit of sufficient size. While the robot arm approaches the apple, the software processes multiple images at the same time in order to determine the remaining distance to the target object. Air is simultaneously blown through the gripper to clear away the leaves. The gripper then carefully approaches the fruit, surrounds it, and sucks it in. The apple is picked by rotating and tilting it, after which it is gently placed in a container.

Benefits of automated harvesting

The use of a robot gives farmers significant benefits. They can automate the entire harvesting process, thereby increasing both economic feasibility and profitability. One robot can perform the work of six orchard workers and also maintain very high standards in terms of harvest quality. In addition, agricultural enterprises can compensate for the increasing difficulty of finding seasonal pickers for the harvest.



Ruud Morijn / stock.adobe.com

Automated processes mean economic profitability.



Seeds & produce: Automating the inspection of seedlings and grain



Machine vision systems can also be used to automate the inspection of seedlings, seeds, and harvested crops.

Machine vision algorithms analyze wheat precisely

The Technical University of Ilmenau, Germany, has developed a system for the precise determination of wheat quality. To analyze wheat samples quickly, the kernels are first placed in a hopper. From there they fall onto a conveyor belt and pass through a separation unit, which separates the kernels from each other. They are then moved past the camera one by one and scanned. Machine vision algorithms analyze the recorded images based on different color, texture, and shape criteria. By using special cameras and imaging the wheat against a bright background, major differences in kernel patterns in terms of size, shape, and color become visible.

After scanning and classifying the objects according to "OK/NOK (not okay) criteria," such as

- flawless grain
- damaged or dried-out grain
- pest-infested wheat
- foreign seeds and straw

they are divided into specific classes for weighing and storage, using a pneumatic sorting unit. In doing so, each individual object is handled and separated automatically.

The classification system has a very high throughput rate. Growers receive detailed information on the grain quality in a very short period of time, thanks to the automatic analysis. The composition of the analyzed grain can also be displayed graphically, and the total sample weight, the weight of the proportion of flawless grain, as well as numeric and graphical statistics of the analyzed sample can be calculated and stored in a database.



Automating the inspection of rice grains

The quality of rice grains can also be inspected with similar speed and performance. The Japanese company Kett Electric Laboratory developed an automated inspection system for this purpose in collaboration with the LINX Corporation, Japan. The machine vision software in this system has to perform complex image processing tasks and handle them very quickly. The software runs directly on a powerful embedded platform. Numerous operators optimize the process of calibrating the cameras, segmenting the grains of rice, extracting features, and measuring size for the purpose of quality classification. The overall solution makes it possible to automate and speed up the entire inspection process. The improved results also maximize the quality of the rice grains and help save costs.



Kett Electric Laboratory/LINX Corporation

The inspection of rice grains can be completely automated.

Classifying tomato seedlings

In another application scenario, a machine vision system sorts tomato seedlings automatically. Produce growers must ensure that the seeds they receive from their suppliers will germinate reliably. The Dutch company Westland Plantenkwerkerij (WPK) joined forces with the Dutch Wageningen UR-FBR (University & Research Center – Food & Bio-Based Research) to develop a system that classifies and sorts 18,000 seedlings per hour.

In this system, the seedlings are automatically planted in growing trays and transported to the machine vision system on a conveyor belt after a 12-day germination period. When the plants arrive, ten cameras record an image simultaneously to prepare a three-dimensional model of the seedling. The software used generates a 3D model in just milliseconds and calculates the plant's biomass. The seedling is then classified into one of four categories based on this data: first, second, and third class, as well as NOK (not okay), which means that the plant is too small or failed to germinate. The results are transferred from the PC to a programmable logic controller (PLC), which directs each plant to an appropriate conveyor belt, depending on its classification.



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Benefits of automatic classification

Automating the quality control process makes it possible to significantly increase productivity in agricultural enterprises. The inspection result is completely objective, reproducible, and independent of human-induced fluctuations and errors. Uniform standards can also be defined and applied consistently to all inspection and sorting processes. Moreover, high labor costs may often be reduced.



Greenhouse farming: Automating greenhouse processes



The harvesting robot independently detects ripe peppers.

Machine vision technologies are also employed in greenhouse farming practices. Like in the open field, the processes here can be automated and streamlined.



[Watch the video for more details about Greenhouse Automation](#)

Automating bell pepper harvesting

For example, the harvesting of ripe peppers using the SWEEPER robotic harvester, developed by the Dutch Wageningen University & Research as part of the European research project titled "Clever Robots for Crops" (CROPS), makes this concept clear. The harvester is moved autonomously through the greenhouse with a battery-operated platform. The standard machine vision software integrated into the robot contains a shape- and color-based detection algorithm, which examines each recorded image for regions that match the target color thresholds. To detect ripe peppers reliably, the 3D position of each item must be determined with a high degree of accuracy. Once the 3D camera system has located a ripe pepper, the robot arm positions the harvesting tool on the crop stem. The arm then moves it several centimeters downward with a vibrating knife and cuts the pepper close to the main plant stem.

Benefits of the robotic harvester

Automating the harvesting processes makes it possible to better meet the rising requirements of quality, hygiene, food safety, and produce traceability. Automation also compensates for the lack of qualified workers, who perform extremely monotonous, physically demanding tasks in the greenhouse under the challenging climate conditions necessary for growth. As a result, the use of robotic harvesters promotes efficient and sustainable plant production in greenhouses.

Wageningen University & Research



Livestock farming: Machine vision in animal husbandry

Modern animal husbandry (livestock farming) is another important application of machine vision technologies. Special applications can improve the conditions of livestock management and significantly increase yields.

Determining growth and physical features precisely

Machine vision software can be used, for example, to track the growth of animals such as cows. The cattle are first scanned individually using a 3D sensor. The backs of the animals are measured during feeding with a time-of-flight sensor, combined with 3D image processing. Typical body shape features can be determined precisely in this manner. These include, in particular, the animal's length and width, as well as the size of special body parts including haunches, hips, or shoulders. Farmers can derive valuable findings from this information, such as the potential yield of the cattle. Multiple measurements over time also provide insight into proper feeding and the animal's state of health.

Milking cows with robots

Another application supports automated milking processes. A time-of-flight sensor is also used here to locate the cow's teats precisely. Based on 3D coordinates, the milking machine is guided to the udder in a targeted manner, using a robot. Since the teats are extremely sensitive, the equipment's position and direction must be determined as precisely as possible. The milking machine can thus be attached to the udder easily and gently, avoiding unnecessary pain and stress for the animal.



Automated milking is gentler on the animals' sensitive udders.

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Conclusion

The agricultural sector is facing many challenges all over the world. Innovative agricultural companies will have to rely on smart farming technologies in order to be productive, efficient and sustainable. After all, consistent digitalization and automation of value chains will be necessary to remain competitive on the international market over the long term.

Machine vision plays an important role in this development. In the growth market for digital agriculture, it acts as a key technology and helps optimize process efficiency in many different application scenarios. Farmers are therefore able to not only increase their productivity and reduce costs, they can also cultivate their land more sustainably, conserve valuable resources, and thereby protect the environment.



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