# Machine Vision

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**Abstract -** *Machine vision is how the machine sees the outside world to interact with it. With use of data collection tools such as photo sensors, IR sensors, UV sensors, and mechanical pressure plates, a machine can gather the information it needs from its surroundings. Using a written program or an AIit can perceive the environment and respond accordingly. The combinations of sensors and software result in specific programmed outputs. The range of sensors and outputs allows this technology to be applied in many real-world situations. New developments and technological advancements could lead to even greater possibilities in the future.*

***Key Words***: Defects, Inspection, Machine Learning, Machine Vision, Sensors

## 1. INTRODUCTION

Machine vision has many uses in manufacturing, in the medical fields, in agriculture, and even in food processing settings. Machine vision includes but is not limited to using sensors such as cameras, scales, temperature transducers, and sensors that recognize infrared and ultraviolet light. These capabilities allow a system to provide the quality engineer and manufacturing engineer with feedback of the part quality data. With this data the engineers can maintain the standards required along with the help of computer algorithms, AI, and deep learning technology. Recent advancements in technology enable machine vision to collect larger sets of data quicker for the user.

## 2. INSPECTION

Sensors are needed to capture information on all aspects of a part. These aspects might include analysis of what the machine is viewing, where the part is in space or where a feature is on a part. Quality check of location, size, and instances may be viewed. An example of a widely used sensor that may intake this type of information is an optical sensor.

A wide array of optical sensors may be implemented into a system such as visible light sensitive cameras, IR or UV sensitive cameras, and simple light sensitive photocells. For example, let us say a factory makes pudding cups. The cups come from the filling station and continue down the convey belt into the packaging station, which puts on the foil covers on. A camera can be used further down the line for process inspection and quality control. If a set of cameras were to be positioned to see both pudding level and the foil covers, a system could effectively flag any cups that have not been covered or filled to the proper amount. This camera input would be then sent into a computer system which would act accordingly. Let us imagine if a cup was only half filled. The system would flag that cup for not meeting the specified amount of pudding. Then, in response, an automated arm may be actuated, removing the defective cup from the line. This is just one potential use in an automated line. Another way the cup could be checked to ensure the correct amount of pudding has been dispensed is by weight. If the cup traveled over a weight sensitive conveyor scale, then a system could compare the weight of a full cup to the cup in queue and determine if it has met the weight requirement to pass.

The details of the camera used in the above example can vary. For the camera to see the cup in question it needs to be properly illuminated. One simple way is to illuminate the inspected cups passing by is to use a strobe light, timed such that the light goes off just as the cup in question is in view. The camera is also timed with the light, such that a picture is taken when the necessary details of the cup are fully illuminated. Using a strobe light allows for quick pictures and fast inspection. Since the cameras used are not like a camera you might find on a smart phone, they need the extra light, for proper illumination at the focal point. The cameras used typically have a very small range and depth of view, to keep the information sent to a minimum and to ensure the focal point is always in the right spot. Due to the speed required during inspection the camera does not auto focus, rather it maintains its one focal point, and the cups are brought into view. Additionally, unless needed for a specific use, the cameras photograph in grayscale. When the camera takes a picture, that picture is made up of many pixels. The smaller the image size, the less pixels and data it contains, resulting in less processing power needed to gather the needed inspection information, such as cup fill height or cover presence. To further decrease computation time, the program could be written to only look at a very specific section of pixels. Let us say that a camera has a field of view that takes a picture of the entire cup. But when checking fill height, the area in question is only at the top quarter of the cup. By selecting to inspect only the top quarter of the picture, the computer can spend less time processing the redundant and not needed information and check only the pixels that contain pertinent information for the fill height. As seen in Figure1, the areas of interest are highlighted in green and red. In these images, the systems are checking for fill height as well as cover presence and flatness. The cup has two inspection points, made to a minimum size for computational efficiency. The top red area is to check for cover presence and flatness. This area is short in size due to a constant cup height and location making the size to be reduced to not much bigger than the cover. It must be just long enough to account for the precision of the conveyor alignment of the product to camera. The lower green area of inspection is set to read product level in the cup. This will detect proper presence of product within the inspection area. In addition to minimizing the inspection area, by utilizing a grayscale camera, each pixel in each image carries fewer information, allowing processing time to be very fast and responsive to a typically high-speed production line for this type of product [1]. The use of a color camera is not needed in this example and would only add to the amount of data being transferred as well as computation time.

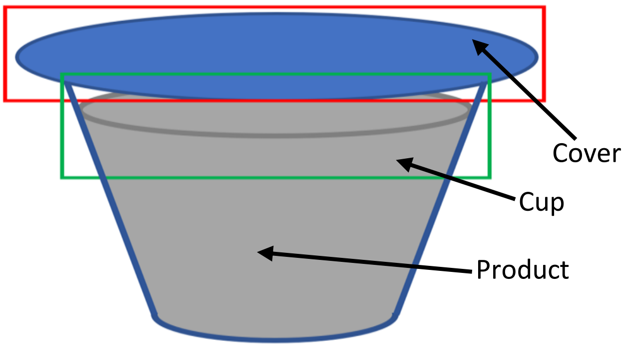


**Fig. 1:** Pudding Cup with Image Inspection Points

By using grayscale, the computer can give the pixels a value between 0 (black) and 255 (white) [2]. This contrast between pixels gives the computer the ability to distinguish edges of parts, steps in a part, locations of features such as holes, and even fluid levels (if there is a transparent element). With a high pixel count, high resolution can be attained, allowing for quality control checks of parts quickly and effectively. As the parts move past the inspection camera, they can either be back lit or illuminated from the above, ensuring good photo contrast. When a part is back lit, the light is on the opposite side of the part as the camera. This set up is good for detecting edges, or through holes on a part, or where part reflectivity would interfere with image capture. Back lighting is also great for checking fluid level in transparent containers due to a high contrast and diffractive difference between the fluid and the container. When a part is illuminated from above it is done so in axis with the camera. This allows the camera to image inside of blind holes, see facial steps on a part or even detail engravings on one side. Contrast is key when detailed and accurate pictures are desired. The camera can quickly take a photo and ensure proper placement of feature, proper number of features, such as too many or too little holes in a part, presence of part on an assembly, and correct orientation. Each pixel on an imaged object has grayscale values that represent the intensity of the pixel. At the edges, a part image will yield lighter pixels, as the image "fills" only part of these pixels. With algorithms and AI, the computer can effectively locate the edges of the part or locations of other features based on the intensity of pixels. Based on this data, the part can be inspected for geometric dimensions. The resolution of the camera, which is based on the size of the pixels, will determine the accuracy of the visual inspection. For high accuracy needs a lens can be used to focus on a smaller portion of the part, increasing pixel density and edge clarity. Depending on part size and camera field, multiple images may be needed to contain a whole part or assembly [3].

## 3. PATTERN DETECTION

When checking parts, the computer program is looking at the picture taken as a whole. Operators and programmers can focus the program to look a just a certain set of pixels to reduce computation time, however, sometimes the entire picture may need to be processed. This may not just be in a manufacturing and part checking environment either, with uses found in AI image recognition as well as programs which take information such as handwriting from photos. Image recognition depends entirely on how well a computer can detect different patterns. There are general tools and programs that can be coded to detect very basic patterns. The line tool is one of these. Lines can be programmed to be found in any number of ways, including horizontal, vertical, or oblique. A line typically consists of a set of pixels holding the same or similar values that are all connected in a linear orientation. Typical applications of a line tool may be part edge detection. The blob tool covers all other non-pattern shapes, meaning anything that is not a line or specific shape. Shapes to be looked for are pre-determined by the programmer as to their size, shape, and sensitivity to detection. The histogram tool takes the average, the threshold, and the contrast of an area. Typically, this tool is used for part or accessory presence applications and color checking. Lastly, the pattern tool covers shapes that fall into normal patterns such as numbers, letters, and geometric shapes. This tool is very useful for quality control. Inbound parts with lot numbers can be rapidly scanned in and logged with this pattern tool. Checking of part and lot number engravings is also a very important use for quality reassurance. Possible checks include readability and clarity, correct location, and margins on the part, as well as the proper markings. The pattern tool also has many useful applications outside of a manufacturing environment. Handwriting to text converters rely on accurate depictions of handwritten text. The amount of variability with peoples handwriting make programming these algorithms and AI very difficult, but with enough training they can be very accurate. Pattern detection capabilities are growing rapidly with the use of AI. The use of collected data and feedback from users assists in training the AI to properly pick up patterns that can be almost impossible to code traditionally.

The first paragraph under each heading or subheading should be flush left, and subsequent paragraphs should have a five-space indentation. A colon is inserted before an equation is presented, but there is no punctuation following the equation. All equations are numbered and referred to in the text solely by a number enclosed in a round bracket (i.e., (3) reads as "equation 3"). Ensure that any miscellaneous numbering system you use in your paper cannot be confused with a reference [4] or an equation (3) designation. (10)

## 4. ASSEMBLY

Machine vision can be used for more than just quality control too. Let us say a factory makes assemblies. They take part A, a shaft with a blind cross drilled hole in it, and orientates it such that the top, defined by the hole, if facing upward. This orientated part is then put into the matching bore, part B, a square block with a bore and set screw hole in it, matching part A. Let us assume part B is always in a fixed location and part A can be given in any direction. This is a suitable job for a robotic arm. Automating this process would eliminate potential errors such as misalignment or, in more complex assemblies, missing parts, common issues prone to normal laborers. The trouble comes in when you now must program the arm to grab the parts, orientate them, and fit them into part B. A manufacturing engineer may have the decision to spend the time and money on the programming and cost of a robotic arm or deal with the potential incurred costs of human errors, but such decisions are outside the scope of this paper. When implementing a machine vision system, it is important to have the entire variable. Machine vision becomes the eyes for the computer, allowing the arm to know where to pick up, and how to orient it before insertion into the assembly. One way to simplify the amount of information to gather, is to pre-orient the parts coming into the robotic arm. When the arm is at the picking point, proximity sensors and cameras will let the computer know where it is in relation to the part. Additionally, the computer knows where the arm is in space, and the picking point will be relatively close each time. The cameras allow for adjustment of the robotic claw into final position to pick up the part for assembly. Once the arm has part A gripped, additional cameras can ensure that orientation is correct and that the position in the claw is also correct, to allow for ease as of installation into the mating part B.

## 5. MAINTENANCE

In addition to cameras using the visible spectrum of light, others may use no visible and thermal optical sensor for data. By using a non-contact thermal vision sensor, a computer system can check, for instance, the temperature of a bearing on a shaft. By comparing the normal operating temperature of the shaft to the current level, the computer may warn an operator of potential bearing failure. Additionally, shaft temperature may be recorded over time and records kept for maintenance purposes and possible statistical service life calculations. Vibration sensors can be coupled with these thermal sensors to give additional information of bearing conditional, without the need to disassemble and inspect. Other preventative maintenance systems may be in place, with the use of automated controller to warn of either sudden changed from the norm, or a slowly creeping value reaching a tolerance limit. By using a computer system, feedback based off the behavior of the mechanical system can point to issues and potential failures, resulting in a preventive maintenance schedule saving money. Compared to following a typical calendar or working hour-based schedule where parts are changed when needed, a feedback based preventive maintenance schedule can save on unexpected breakdowns and unnecessary part changes. If a part is starting to fail before its regularly scheduled maintenance, it could cost even more in repairs from a catastrophic failure. With a sensor system in place the likely hood of catching the issue rises dramatically. Likewise, in the opposite scenario, if a part has substantial life left in it, and it shows no sign of wear, the system may not flag that part, saving money on unneeded parts changes. This, however, is not always the case. It may be better suited to change parts on a schedule, and as needed if flagged by the system.

## 6. COMPUTER SYSTEMS

Every one of the sensors used in machine vision send their signals to a computer or central processing unit (CPU). The computer is the piece of the system which holds the program written by the user. This program is a list of commands based off logic gates. Going back to the pudding example, let us say a passing cup is scanned. The image showing the full cup is sent to the computer. The computer takes each pixel and assigns a grayscale value. The programmer has previously told the computer to recognize the location of the pixels, and if a certain set of pixels shows, in this case black, due to the light being blocked by the presence of pudding, then that cup must be full, and it can pass down the line, with no action taken by the program. Now, if a cup is empty or half full, the certain set of pixels that the computer needs to confirm to pass the cup will be white. If that is the case, the program would then move onto its execution of that scenario. This would mean that the cup must be rejected, so the computer sends out a signal to a mechanism or operator to remove the cup from the line. This will also need to have a timer or other process to assure that the rejected cup is logged as such, and that the cup is removed without interruption or effect on remaining processes down the line (i.e., empty slot on conveyor, carton counts).

As seen in Figure 2, a simplified diagram of a typical machine vision system is shown. A camera is shown, pointing downward and imaging passing parts on a conveyor belt. The parts are lit using overhead lighting, ensuring adequate contrast for the cameras, allowing important details to be distinguished. The signal is sent from the cameras, to a computer, which then processes the image using software and an image data library. The CPU, after processing the image, sends out corresponding commands and potentially and optionally logs the data. Data can additionally be sent to a network to alert personnel of issues, record defective parts for statistical records, or to show a live feed of the process. The I/O interface is the connection between any sensor inputs, the CPU, and any outputs such as an actuating arm.

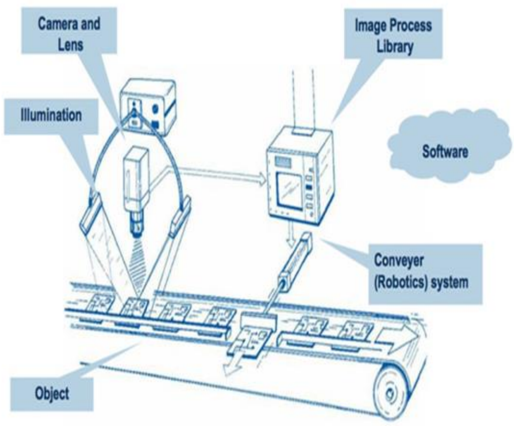


**Fig. 2:** Machine Vision System
[Source: European Editors, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons]

## 7. ARTIFICIAL INTELLIGENCE

In addition to a program written by a programmer, an AI could be implemented into the system. The use of AI can make it so that every possible way a passing or failing cup may be photographed does not need to be programmed. A set of know images may be shown to the AI to allow it to learn and look for patterns. This takes out potentially complex programming with potential errors and replaces it with a system that can update itself mid process.

The use of AI has vastly increased efficiency in machine control. Using algorithms, a technician can train an AI to perceive patterns, check for inaccuracies and out of normal data effectively and efficiently. With machine learning techniques, a complex operation can become hands off, only inspected for assurance. A system using deep learning techniques can effectively calculate and compute a large set of data such as thousands of pudding cups or water bottles, with minimal programming compared to a standard written program.

## 8. Additional Uses beyond Manufacturing

### 8.1 Confocal Microscopy

Newer developments in technology have broadened the use of machine vision beyond general quality checks. Up to recently, machine vision systems used grayscale with two dimensional images. It is now possible to create high detail, colored, three-dimensional images for data acquisition. Confocal microscopy allows for much faster data acquisition, $10^5$ pixels per second, an order of magnitude faster when compared to SEM (Scanning Electron Microscopy) [5]. As technological advancements increase, so will the speed of acquisition as well as the amount of data that can be transferred. Full color, high detail images in three dimensions will soon more accessible for a more generalized use.

### 8.2 Construction and Agriculture

The construction trade has been utilizing machine vision technology for years to assist in more accurate grading work. If you have ever driven by a construction site, you may have seen a bulldozer with antenna sticking up from the blade. These antennae are used for grade control. Grade control automatically positions the blade in all three dimensions to maintain proper grade in all areas of the worksite. The desired grade is set by the operator and the machine automatically adjusts the blade to match. Additionally, this automatic control of grading is much more accurate when compared to an experienced dozer operator. This allows for less experienced operators to do a good job with grades, and potentially eliminate the need for additional finishing operations. Typically, when grading flat surfaces or swales, it takes years of experience to get an acceptable finish that is on grade, but this takes out the need for highly skilled operators. Grade control is also applicable for flat bottom trenches or trenches with a percentage grade for application such as drainage pipes or communication and electrical trenches. Use on excavators allows for proper digging depths to be achieve without the use of a separate ground crew. Even paving crews can use grade control technology, eliminating the time-consuming process of setting up grade stakes and string lines. Grade control can utilize either GPS control or a direct line of sight using lasers. When using GPS, the machine has the locator attached to the working end, being the blade or bucket. Other sensor such as angle and tilt sensor are also attached to give the computer the location of the machine in space. Using the feedback from these sensors, the computer can either tell the operator where they need to go, or by using electronically controlled hydraulic valves, the computer automatically adjusts where the machine needs to be. Using a laser system is preferred as a less expensive alternative. A laser system can be set up on site to project a level plane. A receiving eye attached to the machine then senses where the machine is relative to the sender and tells the operator how it needs to move to get to the desired grade. More advanced feedback systems may also allow for obstacles to be programmed into the machines memory for avoidance features. One very useful application of obstacle avoidance may be a depth limiter on an excavator bucket to avoid hitting buried utilities or even a height limiter to avoid overhead power and communications cables.

Building on the use of computers and GPS on worksites, machine vision has recently been developed to be used for site surveying. Extensive and detailed site plots can be mapped in all three dimensions with the use of computerized surveying equipment. Once the surveying station is set up and calibrated it begins taking in millions of points, recording the angle, coordinate positioning, and distance from the station. These points are then compiled into a three-dimensional map of the area. Additional stations can be set, and the coinciding points matched to make a very large and complete map of the area. Color images can also be overlaid on these point maps to allow for a more realistic view of the worksite. This site data proves very valuable when it comes to engineering of the land. Not only does it reduce the amount of work needed to survey land, it also does it more accurately due to the removal of human error. These surveying tools use a multitude of sensors to enable accurate work. The use of optical sensors such as radio frequency or infra-red senders and receivers to obtain the distance of objects is one. Gyroscopic sensors are used to get the position of the camera at its current angle in all three directions, giving all the data needed to plot a 3D map of the site.

The agricultural field also utilizes machine vision to increase efficiency. With the world population increasing every day, the ability to produce enough corps will soon become extremely strained. A need for more efficient use of airable land became evident and some have turned to machine vision for improvement. Use of cameras and sensors on UAV drones have given land planners and producers valuable information on crop status such as potential diseases, weed infestations, and control of automated harvesting machines [6]. The use of algorithms coupled with soil samples has allowed farmers to cycle their plots more efficiently for crop yield and land stability.

### 8.3 Military Unmanned Aircraft

Building on use in UAVs, machine vision has a vast use in the military market. The use of autonomous and remote-controlled vehicles is growing rapidly. Being able to take out the human life factor is invaluable. Systems such as proximity sensors, gyroscopic and tilt sensors, thermal and infrared imagining systems, are all used on these vehicles. UAV drones may have thermal scanners to detect personnel. Detection of concealed arms factories may be done with thermal imaging also. Use of aerial photography is vital for reconnaissance. As sensors for machine vision grow, as well as capacity of computers to process the data from them, the use in the military field will also grow. The ability to learn the terrain and adapt to conditions based on feedback from onboard sensors is vital to the use of ground vehicles. The sensors used to display terrain to the controller need to be accurate and well placed.

### 8.4 Automated Shopping

A very interesting new development by the retail company, Amazon, was their use for computer vision. They have developed a cashier free retail store. This store called Amazon Go, uses what they call Just Walk Out. This is an AI computer system with programmed algorithms that detect the actions of the customer with use of sensors. These sensors include cameras and weight sensors, which are placed both on shelves and in the ceiling to monitor items [7]. To keep track of a customer's cart, they are required to sign into the store when they first get there. By doing so, the store's system links the customer's Amazon account to their cart and will charge them for the items they leave with. Keeping track of which items the customers grab and leave with or grab and put back required extensive use of cameras and weight sensors on the shelves, as well as a very accurate and well-trained AI system. There are many variables to account for. Such as the potential for many people shopping at once. Keeping track of who grabs what can be very difficult for an AI system to accomplish. Additionally, if a customer garbs an item, however, then decides to put it back, but not it the correct spot, the AI needs to be able to account for this and not incorrectly charge a customer. Amazons use of machine vision and machine learning has grown as they have 29 Amazon Go stores either planned or currently open [8].

## 9. CONCLUSION

Machine vision is a growing field. Previously, a typical system may be used in the manufacturing environment, conducting simple quality checks. The use of a machine took out human errors and enabling both quicker analysis and data recording. Recently the growth in the robotics field has allowed more computationally and cognitively involved processes to be transformed into machine vision accessible systems. The use of AI has drastically helped in this field also. The future is bright for machine vision, and the fields it can cover are expanding. From manufacturing to science to agriculture, machine vision holds a key to the future.

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