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How to specify a web inspection system?

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How to specify a web inspection system?

Read how leading manufacturers in web and sheet operations specify their inspection solutions. Each section will focus you on the key issues that will help reduce cost of purchase while optimizing performance.

- 3 key figures that will decide the cost of your inspection system.
- 5 steps to categorizing defects.
- The whole is greater than the sum of its parts.
- 4 results gained from specifying your system correctly.

If you are part of a team that uses, purchases or plans capital expenditure for inspection systems, this framework will add value.

Thank you,

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Maxcess Vision Systems

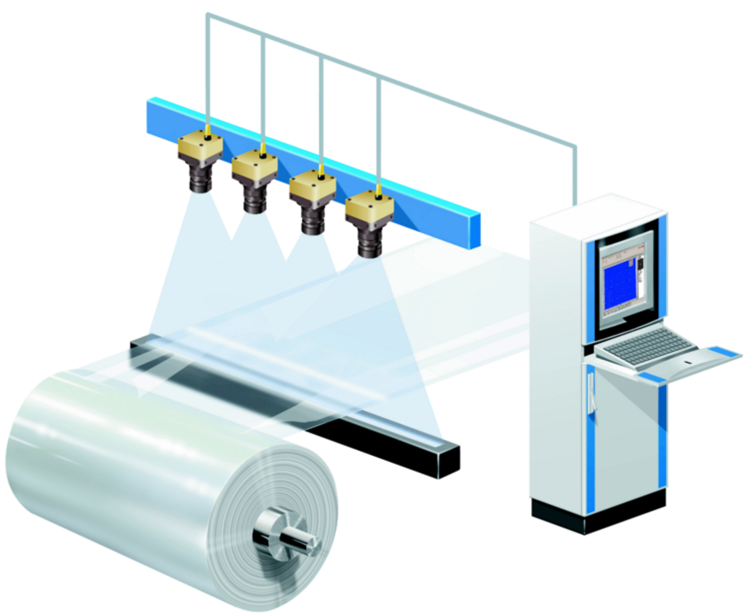
3 Key figures that will decide the cost of your inspection system.

When specifying a web inspection system, there are so many different technologies and issues to consider. Let's understand some of the critical criteria.

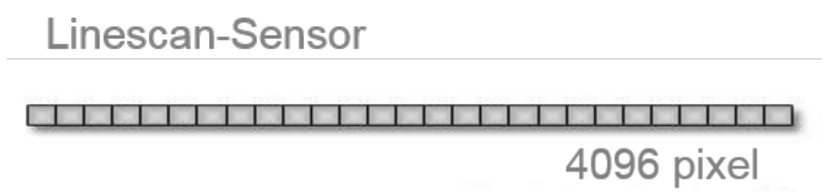
The three key factors are:

1. *Line speed* – does your line run at 100mpm or 10mpm?
2. *Product widths* – what is the maximum width of product to run on that line?
3. *Minimum defect size* – what is the smallest defect that must be detected?

Let's create an outline and explain how each element affects the cost and the best practice for specifying a surface inspection system. The system below illustrates a typical line scan application. Assume the web width is 2m and the line speed is 400 mpm.



I first started designing such systems in Japan in 1988. I had only known standard cameras, such as we see in our smart phones. These we refer to as matrix cameras. The vast majority of machine vision applications use matrix cameras, but the vast majority of print inspection systems and surface inspection systems use line scan sensors. I was fascinated by this technology and now have spent close to three decades working with the technology and its variants. The rest of this article will take you through the necessary steps that will make you an expert in vision system design.



It's important to understand the technology if purchasing a system. Line scan cameras use a sensor that have a single dimension. The motion of the web or sheet then supplies the second dimension. The sensor is synchronized to that motion using an encoder, so for each tick that the encoder provides while its disk rotates, the sensor also delivers one scan.

The first step to solving any problem is to define the question and to make sure each element of that question is well understood. For a web inspection system, we need to define what we are inspecting. Let's ask the following questions.

1. *What are the defects that need to be detected? A clear list should be defined.*
   This list should be split according to a Pareto chart. There will be some key defects that represent the majority of the complaints and then a number of outliers. An outlier could be defined as a defect that would be nice to detect but not absolutely necessary.
2. *What are the characteristics and tolerances for each defect class? This includes width, height and contrast.*

3. *What are the typical run time speeds for manufacturing? But also record the minimum and maximum speeds?*
4. *What are the typical product widths? Also specify the minimum and maximum widths.*
5. *What substrates are used? Match the defect list to the substrate. Note the percentage of each substrate used.*
6. *Clearly define the installation envelope and the environment.*

The goal should be to specify a system for the maximum width, speed and all substrates. Doing so can increase cost of the project considerably. It is important to investigate the cost of a system that will address the key products, defects and requirements and to determine what the delta in cost to address the remainder is. Many projects never get off the ground as a result of over specifying.

How do vendors determine the number of cameras?

Let's do the calculations. The web width is 2m and speed 400 mpm. The defect catalogue has been calculated and our minimum defect size is 250um.

The Nyquist principle applies to image processing, so *a simple rule of thumb is that the resolution must be at least twice that of the smallest defect*. This is not always true as certain lighting techniques can magnify defects. The contrast of a defect to the background also plays a role. However it is a starting point. Please note that detection is not the same as classification. To classify an item, *four to five times* the resolution is often required.

So for detection, we will need a resolution of 125um in both machine and cross directions as the smallest defect can be a spot so with an equal aspect ratio in both directions.

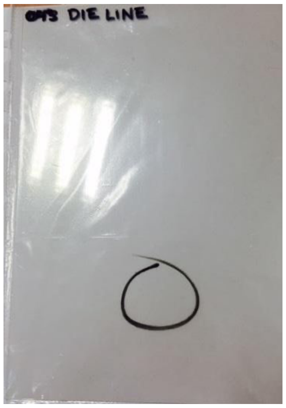
- So we need 2000mm/0.125mm = 16000 pixels across the web.
- The speed of the web is 400 mpm or 6660mm per second so we need cameras that can scan at 6660/0.125 = 54kHz.

- A good fit will then be four 4k cameras running at 70 kHz. Each camera will have a field of view of 500mm.
- Now we have a camera, let's choose a lens. The length of this sensor is just over 40mm. Each pixel is 10um wide. If we then look at the desired resolution 125 um divided by the size of sensor we can calculated the desired magnification125/10 = 12.5.
- If we were to use a 50mm lens, the approximate working distance would be 50*12.5 = 625 to the camera sensor. So allow 625mm + 200mm as a vertical envelope.
- The length of light should be 2.2m allowing an overshoot of 100mm on either side of the web or sheet. The basic specification for this application will then be four 4K line scan cameras running at 70 KHz with a 50mm lens, and a 2.2 m back light.
- Let's also consider the same defect specification, but we decided that 90% of the product was not 2m but 1.5m in width and the typical line speed never exceeded 250mpm. The same application could be completed using two 6k cameras running at 40 KHz. This could reduce the cost of such a system by as much as 30%.
- If width remained at 2m and speed at 400mpm but the minimum defect doubled to 500um, it would also have the same effect. It's key to understand the effect of these three key criteria.

5 steps to categorizing defects.

We looked at the effect of the minimum defect size, width and line speed on the complexity and cost of an inspection system in above. The next step is to analyse the defect suite and to understand how best to catalogue and specify for detection.

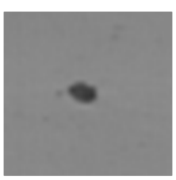
1. Identify all the defects that are present where the machine vision system will be installed. Also include defects that are caused upstream such as substrate issues.
2. Identify the source of each defect.
3. Identify the defects that are causing customer complaints, and if possible use a Pareto chart. These are the key targets.
4. Identify any measurements such as print to edge, or sheet width that if out of specification would result in defective product downstream.
5. Categorize according to color and substrate type.



The result should be a table with a list of defects. It's then important to start a collection process so that there is a set of samples that vendors can test. A good practice is to collect A4 or letter size samples of defects. Insert these into plastic covers to protect. Label the plastic cover and clearly identify the defect. It's crucial you communicate all such information to a vendor.

Classification is important.

Which one is the Insect?



Now you have your defects list. The next step is for the defect to be categorized according to class and action. The following is an example of how to classify.

- **Class 1** - Critical defects that must be alarmed immediately and the operator must take action. This may require an alarm to be reset, the machine to stop until the reset is complete. It may also mean placing a physical mark put on the product such as a tag, so that it can be removed downstream prior to shipping.

- **Class 2** – Defects that if identified are not an issue unless there is a density of such defects within a time frame or a defined product area. Until then the defect is displayed as a warning, and when the density of that type exceeds a threshold, it is elevated to a class 1 type.
- **Class 3** - Small defects that need to be tracked for statistical issues but no action to be taken.

Each defect on the list should be classified. The next step is to assign priority according to returns. There may be a class 1 issue, but if it does occur on all substrates, and what percentage of returns are attributed to this problem. This is a key exercise.
You may ask why?

- Sometimes one defect class that seems easy for a human to see can define the scale of an automated optical inspection system. Simple examples are very subtle streaks. Large defects that are low contrast can be easily recognized by humans as we can integrate over large areas and can segment these problems. This is not the same for a vision system and may require special processing techniques.
- Maybe one defect out of a list of ten, may require an extra optical setup such as another bank of cameras and lights.

So the final column needs to be added to the list. This column defines if this defect is detected by system specification A, or A+B, or A+B+C, or by C alone. This will then allow you to allocate your capital where you can best get a return. So to recap, the steps to complete are:

1. List of all defects
2. List of all measurements
3. List sources of defects
4. List substrates and colors
5. List minimum acceptable sizes
6. Classify according to action
7. Determine minimum equipment requirements for each defect
8. Understand which optical setup is required for each defect

A little extra on classification

Classification is always the most complex part of a vision system. The ability to classify is often dependent on the number of camera angles, the lighting used and also the ability of the imaging algorithm to extract the appropriate information. To classify defects, they must be first segmented from the background. This is done using a variety of image processing techniques.

Print inspection systems use a golden template comparison while surface inspection systems normally use adaptive thresholding. The image is normally passed through some enhancement filters, then a threshold is applied, and the resultant image with segmented areas of interest are fed to a feature extraction tool. Key features include location, width, height, intensity, perimeter analysis, and elongation factor and often many more are calculated. This data is then fed to a classification algorithm either a rule based system or a self-learning statistical solution such as K-Means. Deep learning or neural techniques are also used but can be slow to setup and complex to run in real time as they require large amounts of CPU/GPUs.

The whole is greater than the sum of its parts.

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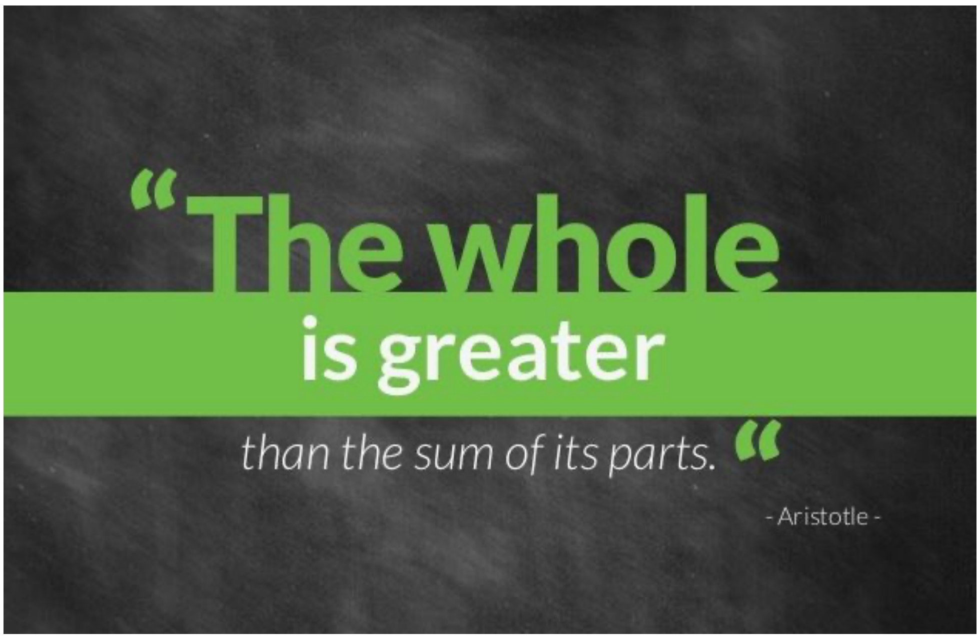


Aristotle put on his engineering hat and was looking at designing vision systems when he said the above. Let's look at the key elements of the line scan inspection system.

We will break the inspection system down into functional elements. A solution can be split into the following elements.

- **The imaging system** - This includes cameras, optics, illumination and of course sometimes the product itself.
- **The processing system** - This is the PC or embedded hardware along with the software to analyze the images.
- **The output system** - This includes the display for the operator, alarms to be initiated, the parent machine interface, and the data to be output.

The imaging system

Typically the imaging system represents 50% to 60% of the cost of an inspection system and is often the least understood by the buyer. When an application is analyzed, a particular camera is selected usually according to the methods explained in the earlier chapters. The key item now when choosing the brand is its capability and if it conforms to standards.

Let's understand the standards used for camera communications:

1. **CamLink**, a high-speed serial digital bus designed specifically for machine vision cameras,
2. **The USB 3.0 standard**, also known as SuperSpeed USB, is the second major revision of the USB standard for computer connectivity.
3. **Gigabit Ethernet** is a new camera bus technology for machine vision systems. With relatively high bandwidth, long cable lengths, and wide usage in the consumer and industrial applications, Gigabit Ethernet shows promise for security and long-distance vision applications.
4. **CoaXPress**, higher speed serialization version of CamLink.

Gigabit Ethernet can be cost effective but faster more complex applications tend to be CamLink. All of these standards are acceptable and widespread. What is key is that you understand the interface that is used and that there is no additional proprietary hardware in use that will lock you into a cycle of obsolete systems.

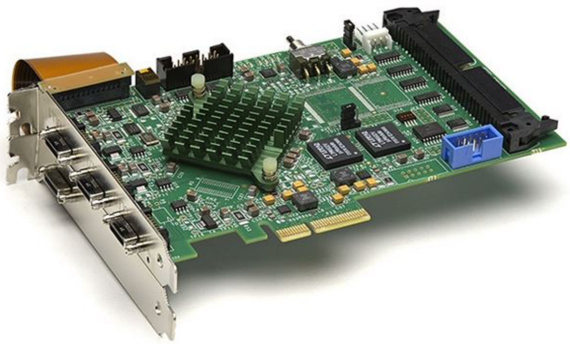
The lens choice will determine the working distance. If there is a small envelope to install a system an integrator may choose a wide angle lens. The tradeoff is that there will be imaging problems on the edge of the field of view. This can mean that defects such as holes cannot be classified. Understand which lens is used, the tradeoffs and why it was chosen.

Lighting usually is often the most expensive element of a web or sheet inspection solution. Depending on the substrate and defects, there may be a requirement to use multiple lights to image a product. Understand the cost of replacement, if the light has enough power for the variety of substrates you use and what if any maintenance does it require. Some high powered solutions use water cooling.

The processing system

The processing system for a web inspection solution normally includes a high end workstation, frame grabbers if it is a CamLink camera, some input output (I/O) card and the software application to process the images and display the results.

The crucial element is the application software. The processing hardware may represent 15% of the hardware cost, but the software is the magic sauce. Inspection companies are really software companies and as a purchaser you must understand the key features and advantages.



The key facts to be determined when choosing the processing system:

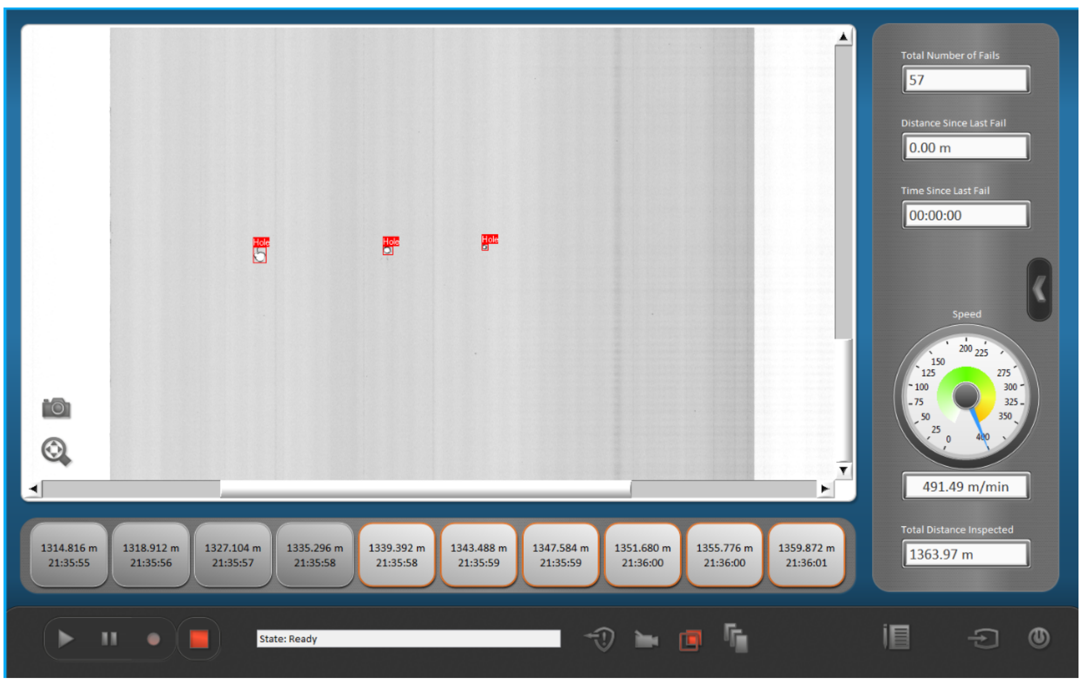
1. The specification of the PC
2. Make and type of frame grabber
3. I/O Module manufacturer
4. Operating system and if the application software can be upgraded

The output system

An output system is defined as those elements that provide an interface with the operators the machine or the downstream, process.

Operator Display

It's important to specify how defects are shown. It is no good if you are displaying a postal stamp image of a defect on a tiny LCD display. Monitors should be wide screen, high resolution, with graphical overlays to highlight the position of defects.



Alarms, marking systems and taggers

Tree lights are useful if used sparingly. Buzzers can be annoying if there are lots of defects. These are useful to alert the operator when problems start, but should time out soon after. There is nothing worse that alarms when trying to solve a production issue. Make sure that the software can be configured to output and drive outputs depending on class and number of defects. For roll to roll operations, marking systems and tag inserters are common.


The key requirements are :

Specify the equipment to visualize the defects for operators.

Determine if there is to be a parent machine interface such as stopping a line.

Look at the effectiveness of alarm lights and buzzers and how they can be used.

Consider tagging systems and marking solutions to enable waste identification but these must be considered according to the classification system.

4 results that of specifying your system correctly

Before purchasing a system, think hard on how you will use a system. What are the primary goals?

1. Stop embarrassing defects getting to your customer.
2. Increase productivity.
3. Reduction in substrate waste.
4. Fault identification so as to enable process improvements.

The overall specification must be reviewed according to these criteria. Make that the output, the hardware and each feature specified brings you closer to meeting these business objectives. Let's look at the examples above in more detail.

Stop embarrassing defects getting to your customer.

We already discussed the output element of an inspection system. Alarms and display systems work well to alert operators to problems. Early intervention will reduce waste. However, it can be difficult to remove waste and that is what is required if you are to stop embarrassing defects getting to your customer.

Marking a defect is not always an option. If defects are frequent, or go on for a long distance defect marking systems can cause a lot of problems. It may be that the end result will be what we call a hedgehog roll. This is a roll with hundreds of tags sticking out on one side and can cause rewind issues. Marking systems tend to solve this but are more expensive and often require an edge guide.

What is required is a smart way to use the data generated by the system while synchronizing the data to an event on the web. Your inspection solution should be capable of outputting a results that can be synchronized so that a downstream process can remove the defect. Typically it can be possible to use a splice or a large defect, or a small number of tags as zero events to allow water removal.

So investigate what data is stored, the data format, and if it is possible to reverse the data to match the next process and to use zero out events for synchronization.

Increase productivity

What is the goal here? To run faster while using less resources. Inspection by humans can be a slow and repetitive process. Inspection systems allow operators increase line speeds, as the inspection system will not care what speed you operate at if specified properly. An inspection system with the proper data collection capability can allow you to run at top speed and the information is stored to allow the next converting process to also run faster.

What is required is to understand what tools are available to allow quality departments check production runs to see if there is any requirement for rework prior to converting, or in some cases when automated waste control systems are used, prepare an automated converting strategy for the next process. This is often referred to as *"Smart convertin*g". Ask your supplier if this is part of their offering.

Reduction in substrate waste

The key to reducing waste is to identify problems quickly and make corrections or even to forecast issues prior to converting. If an inspection system is installed on a process upstream, then that data can be used to reduce waste at the subsequent process as well as increase productivity.

Examples of this is to inspect plastic film and foil before used in the production of flexible packaging. By analyzing the quality of the film delivered to a printing line from the extrusion department, it may be possible to use the poorer grades during the make ready. The net result is that you will be using waste from the prior process during the high risk start up time of the second process. Rather than adding to waste you are optimizing your chance to produce higher yields during the second process, as the defects of the first will not be present to cause problems also on the second process.

What is required is the ability of your roll quality system to use data from a variety of inspection solutions to optimize process decision and enable smart converting.

Fault identification so as to enable process improvements.

Inspection systems produce a large amount of data. This data can be used in feed forward operations. By integrating the output of the inspection system with a historian, the data can also be used for regression analysis and fault identification. It's also important to specify the capability of video streaming to disk so that what happened prior to defects can be checked.

Conclusion

This whitepaper's goal is to outline the information that as a purchaser you should have when evaluating equipment.

It is important to understand:

1. The key factors that determine the cost of the equipment.
2. To clearly define what defects and measurements are required, the priority and cost of implementation for each.
3. Have a clear classification of each issue and an action plan for each issue.
4. To understand the technology used for key components as it will affect total cost of ownership and obsolescence.
5. How to use the results and to identify which features will support that effort.

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