Applying Automated Optical Inspection

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Introduction

Automated Optical Inspection (AOI) uses lighting, cameras, and vision computers to make precise, repeatable, high-speed evaluations of a wide range of products. Human vision has limited accuracy and is slow, but is very flexible and easy to train. Mechanical gauging is accurate and precise but slow, and cannot be used to evaluate changes in visual appearance – burn marks, for example.

A machine vision or AOI system can take millions of data points (pixels) in a fraction of a second. These data points are used for visual inspection and for precision measurement. With modest effort and cost, an AOI system can resolve about 25 microns. With increasing effort and cost, measurement resolution can approach a micron.

Typical applications for AOI include:

- Gauging the diameters and concentricity of holes in automotive parts.
- Insuring that lids and labels are properly applied to food and pharmaceutical products.
- Evaluating molded parts against 3D CAD data.
- Insuring that all parts are present in a product assembly
- Checking for cracks, flaws, contamination, scratches and other defects
- Reading barcodes or text ("Optical Character Recognition")
- Grading agricultural products such as seed corn or fruit

From these applications you see that AOI systems are used for inspecting parts that have limited and known variations. For defect or flaw detection the AOI system "looks" for differences from a perfect part. Agricultural inspections might look for variations in "part" color, perhaps to find ripe fruit. To successfully apply AOI, you must set up the AOI system for specific types of parts and limit the visual appearance of those parts.

An AOI system must also be set up or trained to inspect specific structures (visual "features") of the parts. For example, you must tell the AOI system what features to measure on an automotive part or teach it the color of ripe fruit for sorting agricultural products. We are working on making set up and training easier, but current technology is no where near a human's ability to understand and quickly learn what parts and features to inspect.

What is in an AOI System?

Figure 1 is a schematic diagram of a typical AOI system. This system is used to inspect automotive bearings for cracks and flaws, but the components used and methods are similar for other AOI applications.

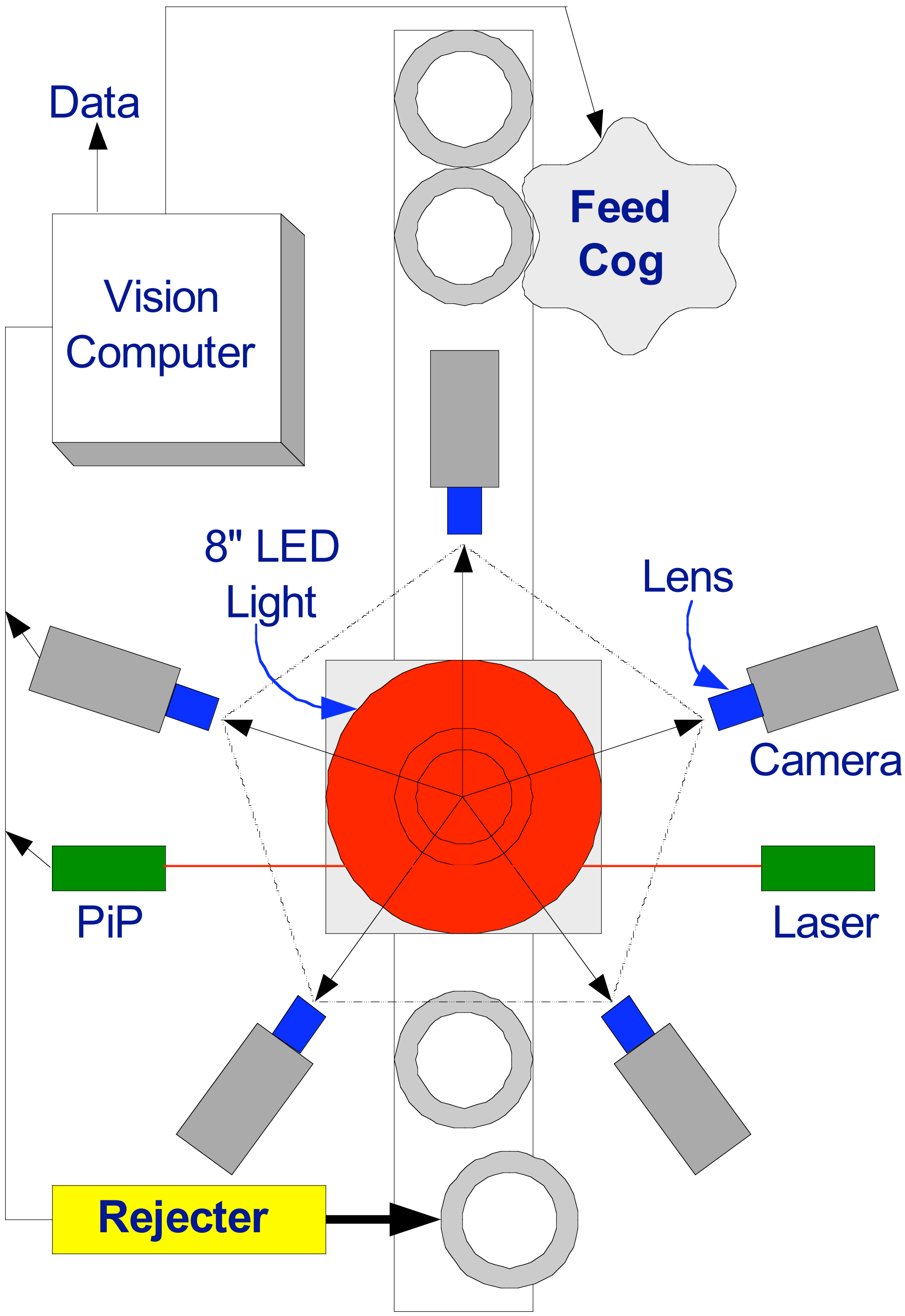

Figure 1. Schematic diagram of an AOI system, viewed from above. A feed cog (at top) releases a bearing. When the bearing interrupts the PiP beam, 5 cameras image the part. The vision computer signals a compressed air rejecter to remove defective parts.

In this example, bearings are released by a feed cog wheel and slide down an inclined track. The track has rails that limit the part's side-to-side movement. This kind of mechanical restraints is known as "staging" or "fixturing". Staging positions the part in a known location and thereby reduces variability in where the parts are and how they look. This reduces the computation required from the vision computer, so that parts are quickly inspected.

As the bearing slides down the track, it interrupts a laser beam. A Part-in-Place (PiP) sensor detects this interruption and signals the vision computer that the part is in a known location. The vision computer then triggers the five cameras to simultaneously acquire images of the bearing. When a PiP sensor cannot be used to trigger image acquisitions, the vision computer must detect when a part is present by analyzing the images, and this slows the system down.

Lighting the part is critical for AOI. Obviously the AOI system has to be able to see the parts and features to do the inspection. Beyond this, lighting is used to amplify features (part structure) of interest and suppress visual features that are "noise". For example, many products reflect the light sources, causing bright highlights in the image. Highlights can obscure features in the image that we want to inspect. In this example, we use a large, diffuse red LED light directly above the part. The cameras are set at an angle such that they can see both the top and sides of the part, but there is no highlight. This allows the visualization and detection of fine cracks in the part as well as "chip outs" along the top edge.

Staging and lighting are critical for an AOI system because they reduce variability in part images and act as pre-processors to select image data for the vision computer. Without this pre-processing, the vision computer would be too slow or unable to do the inspection. You may be able to use an AOI system that has built-in staging and lighting, but often these have to be designed for your AOI task. A variety of standard lights and mechanical components help with this task.

The camera's lens forms an image of the bottle on the camera's sensor, typically a CCD or CMOS image array sensor. Inexpensive "machine vision" quality lenses are used in this inspection, but inspecting small parts or high precision and accuracy measurements requires more expensive lenses. Again, the optics may be included in the AOI system or chosen for your specific task.

The camera translates the pattern of light from the part into an electronic image. Cameras designed for AOI systems have square (1:1 aspect ratio) pixels to simplify measurements, progressive scanning rather than interlaced scanning, a fast shutter and an asynchronous trigger for acquiring images. The progressive scanning and fast shutter reduce blurring of the part's image due to movement of the part. The trigger is necessary to synchronize the image acquisition with the presence of the part.

The “brains” of an AOI system is a vision computer and its software. This computer analyzes the images to extract measurements, counts, colors, and other visual features needed to do the inspection. The results of the inspection are used to reject defective parts. In this example, a compressed air “kicker” is activated to remove defective bearings from the line. The vision computer also sends statistics and process data to a database.

Another Example – Grading Corn

The AOI task in Figure 2, is to find the ratio of bad (dark) corn kernels to the total of good (yellow and orange) and bad kernels. This ratio is used to grade seed corn lots – lots with fewer bad kernels sell for more.

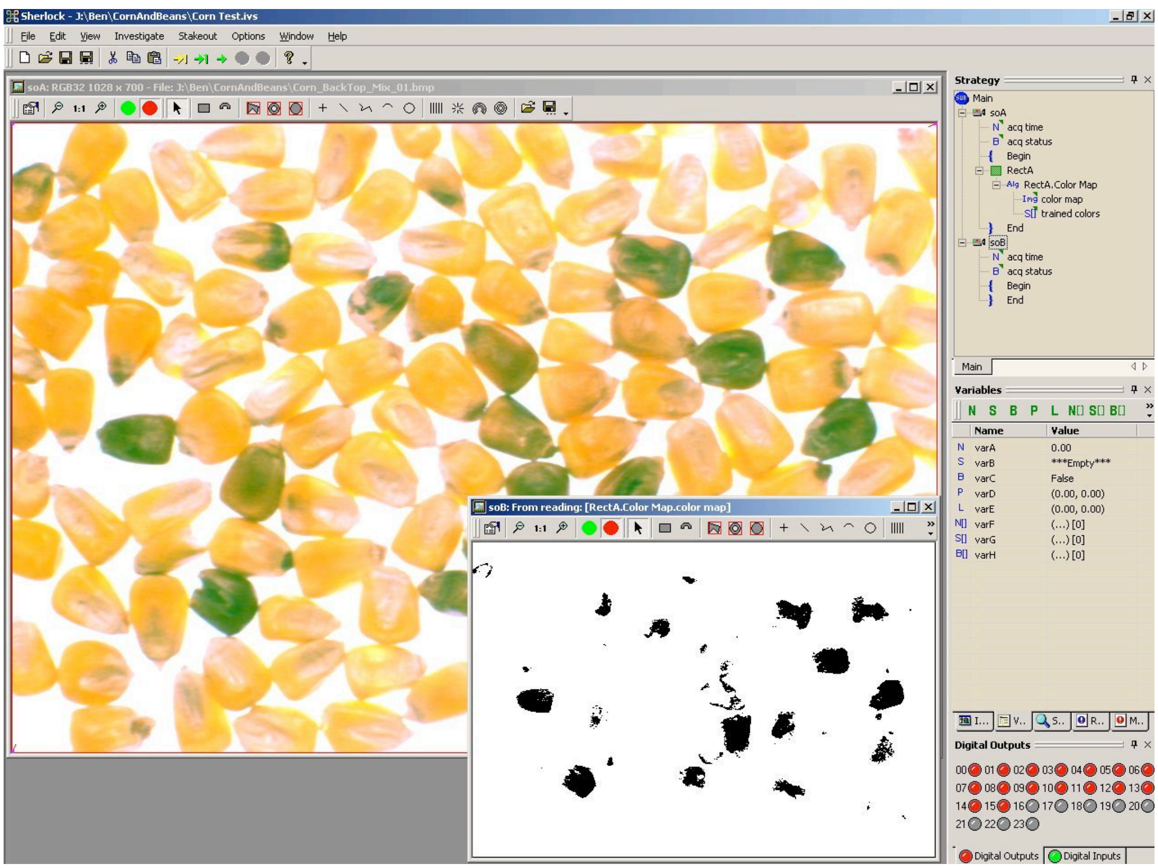

Figure 2. Using the color of the corn kernels as the visual inspection feature, we can estimate the proportion of bad (dark) corn kernels. The inset image shows image areas that have colors corresponding to bad corn kernels.

A typical AOI measurement task assumes ridged, well defined parts, and that any variation beyond some tolerance is a defect. Here, the parts are not well defined in size and shape, so trying to use a caliper tool to measure kernel size would be useless and frustrating. Instead, we use the known colors of good and bad kernels to approximate the desired ratio.

The staging and lighting consists of the operator taking a scoop of corn from a lot and spreading the kernels on a light table, such that kernels are not overlapping. As this is done on sample evaluation basis, automating the staging is not worth the cost and effort. What is critical is that the ratio measurement be consistent over time and across operators. So the evaluation task must apply objective standards to classifying bad and good corn kernel, perhaps so customers can't argue about the grading!

We teach the AOI system the color and color variation of know good and bad corn kernels and the color (white) of the background. The ratio we want is approximated well enough by taking the ratio of pixels with bad colors to the pixels with bad or good colors, ignoring the background colors. While not as exact as if we had counted each kernel, it is a lot faster and removes the operator's subjective judgment from the evaluation.

Advances in Applying AOI

Many of the problems in applying AOI arise from the limited intelligence and flexibility of an AOI system. We can pick up a part, examine it with various views and lighting, do an amazing amount of neural processing, and draw conclusions based on our extensive knowledge about objects and the materials they are made from. An AOI system has to rely on staging to present the part and has a limited time to examine the part. An AOI system doesn't understand objects and materials and has very limited processing capabilities.

Improvements in lighting, computing capability, and vision software have made AOI systems smarter and more flexible, though still far from human visual intelligence.

I mentioned that lighting pre-processes the image to amplify features you want to inspect and suppress "noise". Advances in lighting have therefore improved the capabilities of vision systems, in part by reducing the computation required by the vision computer. The adoption of standard, LED-based lighting has improved AOI systems because LED lighting is very stable and easily controlled, compared to the older incandescent and fluorescent lighting solutions. For example, we can strobe an LED light source to give a brief and intense flash of light that "stops" part motion. This is difficult to do with older lighting technology.

Another lighting method is to project a pattern of light on an object, often by using a laser with a holographic lens. The distortions of this "structured light" pattern can be measured and processed to recover the object's three-dimensional structure, at least what we can see of it. AOI systems using structured light can, for example, compare complex objects such as engine blocks to the designed shape in CAD files.

Another major boost to AOI systems' intelligence comes from the rapid improvement in personal computers. AOI tasks that previously required special computing hardware are now done with generic PC hardware along with hardware for image acquisition, communications, and synchronization. This is approach is used in ipd's VA-40 Vision Appliance. Demanding inspection tasks, such as inspecting LCD flat panel screens, still require the "horsepower" of a dedicated vision processor, such as the DALSA Coreco "Anaconda" board.

The biggest advance in applying AOI is the improvement in the vision computer's software. In the not-so-good old days, you could expect to spend many months laboriously programming the vision computer for your task. The thrust of recent software development is to make this task much easier by providing interfaces to hide the nasty hardware details and to incorporate the specialized knowledge needed to do AOI tasks.

The mantras AOI vision computer vendors are currently "ease of set-up" and "ease of use." With a specialized AOI system, perhaps for three-dimensional measurement using structured light, the set up and operator interfaces can be very easy to use because the task domain is very limited and well specified.

If you need a custom AOI system, then you, an integrator, or a vision component vendor have to write the AOI software. Rapid application development (RAD) packages, such as ipd's Sherlock™, make this relatively easy. These packages typically have an easy-to-use interface with features such as drag and drop selection of tools and operations and extensive, on-line help. If you need extra computing power or find the RAD package limiting, there are many "mature" software libraries. Just be prepared for a long learning curve.

Many AOI tasks can be solved with a good set of general vision tools. These tools include visual search (find the part in the image or finding a reference point on a part), measurement tools (calipers, concentricity, distance, etc.), defect detection, and barcode and OCR reading. Vision computer vendors have developed packages that bundle these tools inside a graphical user interface. There is no programming required and most of the specialized knowledge needed to solve an AOI task is incorporated in the software.

Figure 3 is screen shot from one of ipd's Vision Appliances™ showing the simple interface. The same interface can be used for set-up and for the operator – with optional restrictions so that the operator doesn't tamper with the data. When this kind of product fits your needs, you can be up and running AOI in a matter of days and for comparatively little cost.

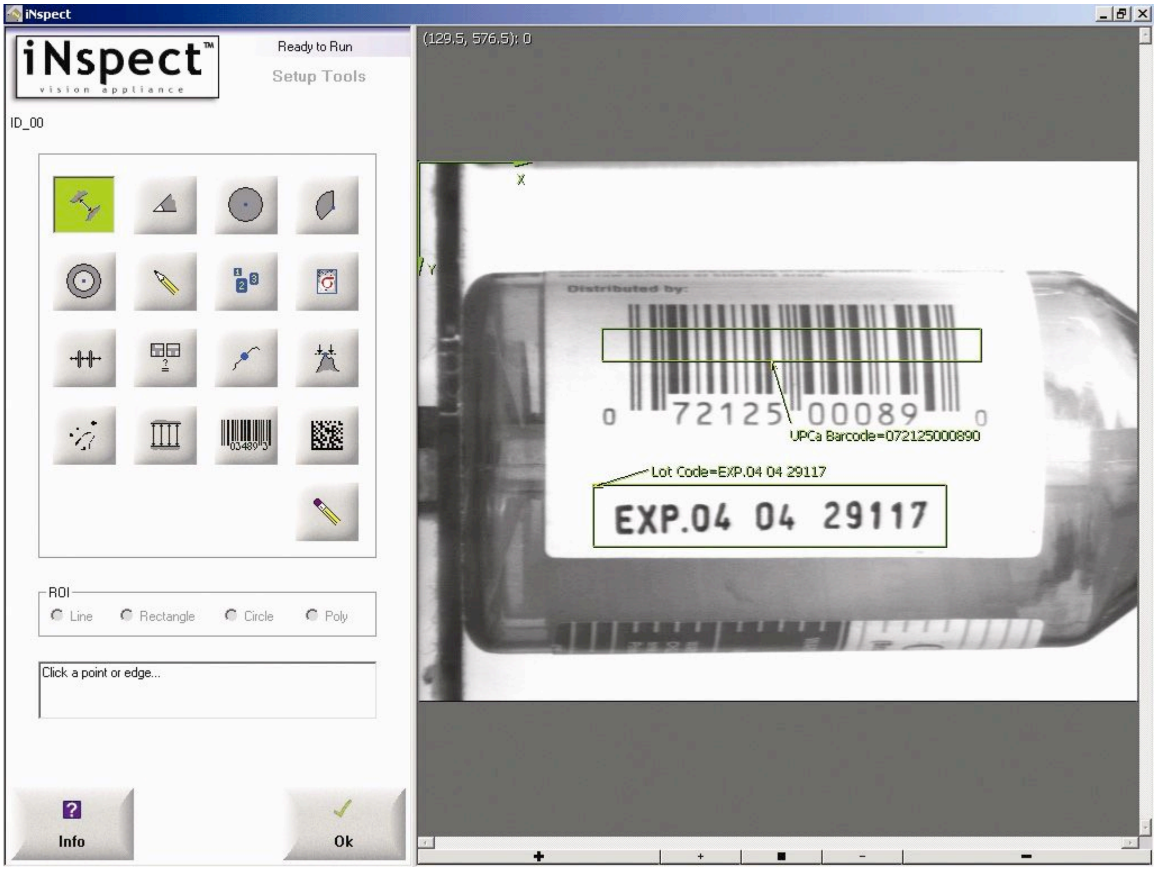

Figure 3. The iNspect graphical interface, set up to read the barcode and lot code on a pharmaceutical vial.

Summary

AOI has many applications, but is limited to well-specified parts in well controlled settings. It would be nice to have an AOI system as flexible and as easy to train as a human, but with the speed, accuracy, and resolution of a computer vision system. Such systems are many years off, but that doesn't discourage us from continually improving existing AOI systems.

The three major efforts in putting together an AOI system are building the part staging, getting the right lighting, and programming the vision computer. Improvements and standardization of lighting and mechanical fixtures have made the first two tasks much easier. The improvement in computing power and vision software, particularly the focus on easy-to-set-up and easy-to-use vision software continues to make it easier and easier to program the vision computer.

Developing a fully custom vision system using traditional software libraries can take many months of work. Using a RAD package reduces the time to weeks of work. For many common AOI applications, new "programming free" software packages can cut development time to a few days. In all cases I advise you to get help with staging, lighting, optics and the camera choice.