CRT Display Inspection Simplified Using Optical Pre-Processing™

Mike Muehlemann, Illumination Technologies, Inc.

Vision Systems Design, May 2000

Aperture Masks

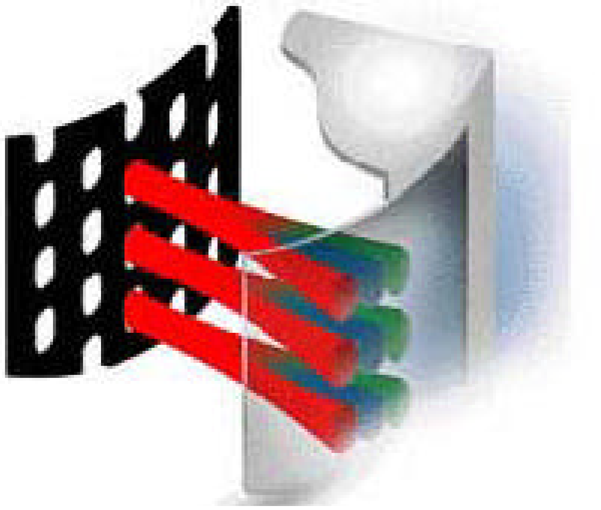

Fig 1: An aperture mask creates the individual pixels on a CRT type display. Slight changes in the color gun angles causes the electrons to strike the different R,G and B phosphors on the back side of the screen. The size, form, position, quality and orientation of the precision etched holes within the aperture mask are all critical in determining the final performance of the finished CRT monitor.

The quality of the final image that you see on your television set or computer monitor is based in large part on the quality of a critical element which sits invisibly behind the front glass face plate. Televisions and computer monitors, and almost all other displays based on cathode ray tubes (CRT), rely on a critical component called an aperture mask to control the intensity and color of the small dots (pixels) which combine to make up the screen images. Concealed behind the phosphor coatings on the inside of the glass face plate, these complex masks, sometimes called “shadow masks”, are produced from steel or nickel alloy sheets with a typical thickness of around .007” (0.18mm). Small holes or slots are formed by precisely etching the material to form what resembles a finely meshed screen (see Fig 1). The size, form, position, quality and orientation of these etched holes are all critical in determining the final performance of the finished computer monitor, television set or display terminal. On first examination, the function of the aperture mask is straightforward and the manufacture and implementation would seem rather simple. As with many things that appear simple on the surface, the devil is in the details.

The size and geometry of the precision etched holes depend mainly on the type of CRT display being manufactured, and can also have subtle differences and variations depending on the manufacturer and material type. There are also geometry changes that occur within a given mask depending on its actual location. Holes in the center of the mask tend to be very symmetrical, while holes near the edge of the screen tend to be asymmetrical due to increasing angles subtended from the center position of the electron guns. In the case of television masks, the etched holes resemble rectangular slots, with typical dimension on the order of 150 by 450 microns. Close examination of your home

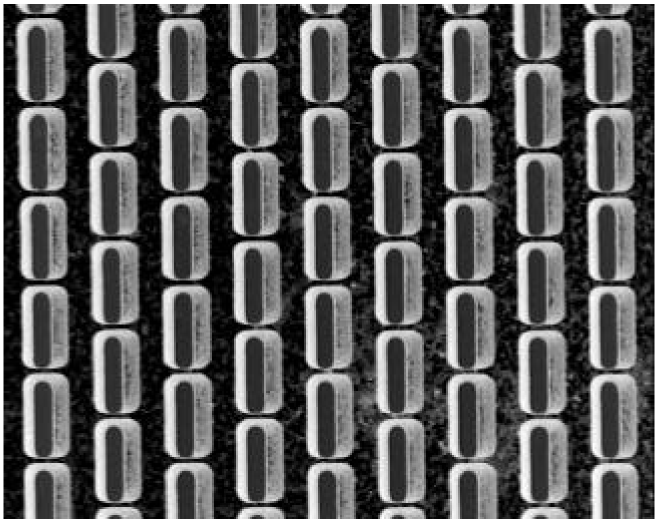

Fig 2: High magnification image of a typical TV mask shows the typical asymmetry present between the front and back side of the etched holes. These concentric variations shift depending on their location on the masks, and are created by parallax issues from the centrally located electron guns.

television set (non-HDTV) will reveal that the individual pixels are actually a series of small dashes similar to those shown in Figure 2. From this high magnification image, it becomes apparent that these precision etched holes have more structure than would have been imagined at first glance. Not only are the holes elongated, but this image shows they also have well defined sidewalls (called cones) that are not perpendicular to the surface. This particular image, taken near the top edge of a television monitor, also shows the asymmetry present between the front side of the hole (larger rectangular dimensions) and the through part of the hole (small slots). The slots are clearly not centered within the larger rectangular dimensions. For proper operation of the picture tube, the quality and orientation of these precision etched holes are all critical.

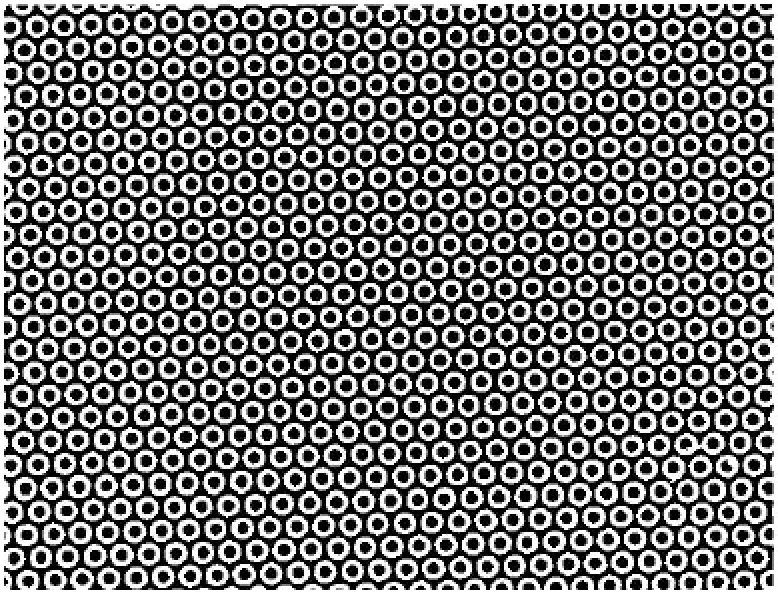

Fig 3: The high magnification of a computer monitor mask reveals distinctive circular or slightly elliptical holes arranged in a honeycomb pattern. Typical hole sizes are on the order of 100 microns with center to center distances of 280 microns – hence the standard .28mm commercial monitor resolution specification.

For comparison, high-resolution monitors such as those used in the majority of computer applications use a series of finely pitched circular or elliptical holes in a honeycomb pattern (see Figure 3). Typical hole sizes are on the order of 100 microns with center to center distances of

280 microns, which is the standard .28mm commercial monitor resolution specification. Here the cones resemble small countersunk holes, and similar to the television masks, the concentricity of the upper and lower edges varies as a function of their position on the mask, especially as the monitor sizes continue to increase.

Independent of mask type, both configurations rely on a complex photo-etching processes that strive to control the ultimate hole size, location and a host of parameters that ensure a precision etched cone rather than a straight-sided hole. Even though the manufacturing of these devices has been well defined for decades, the yields and quality control methods have been significantly below other industry thresholds. As can be imagined, there are a wide variety of defects that render poor performance in the finished CRT display device, in many cases making the entire assembly useless. These defects range from incorrect hole size, missing holes, improper cone angles, and a phenomenon called etched surface area. Since a single improperly etched hole results in a bad pixel which is easily seen in the finished CRT, it is imperative that these aperture masks be 100% inspected. In many cases there are more than 1 million precision holes within a single mask, making 100% inspection very difficult.

Quality and Yield

From strictly a quality control standpoint, it is critical to remove any defective mask from the end of the manufacturing stream before shipping it to the tube manufacturer. For example, an aperture mask worth an average of $5 is eventually encased within a finished CRT which may be worth almost $200. The CRT manufacturing process is irreversible, and the final quality of the aperture mask cannot be fully determined until the CRT is operated. A defective mask renders the entire CRT of sub-par quality, or in many cases useless. In many cases the final cost of the *finished scrap unit* is applied as credits to the payables account within the terms of the production contracts. These quality issues have measurable direct costs associated with them which can be many multiples of the actual associated part costs. In an industry where 8000 ppm is considered exceptional, there is plenty of room for additional improvement. Automated inspection techniques have the potential to deliver higher product quality, while at the same time lowering labor costs. The combination of simultaneously improving both customer satisfaction and bottom line profitability is currently driving the pursuit for automated solutions to these inspection challenges.

Additional (and even more significant) financial incentives exist on the yield side of the equation. Current production facilities throughout the world operate with yields ranging between 60% and 80%, and may dip as low as 45% for extended periods of time. With the comparatively high cost of a production hour within the facilities, and the associated cost of producing scrap material, these manufacturers stand to gain a great deal if new automated inspection technologies can eventually provide real-time process control information. This information can then be fed back upstream so that process changes can be rapidly made. The possibility for the development of process information that will improve overall yield and plant efficiency is the *holy grail* that will become the real long term equipment driver once the core technologies prove themselves in the quality control arena.

Typical Defects

While there are upwards of 30 different industry standard defect types, the majority of critical defects that occur regularly can be summarized as defects for which the etching boundaries have not been properly controlled. Either the through hole is under or over etched, the cone walls are under or over-etched, and/or the land area has been improperly etched.   There are many potential process reasons that any one of these conditions might exist, but from a strictly quality control standpoint, these are the basic and logical breakdowns for the process related defects that occur in a normal production environment.

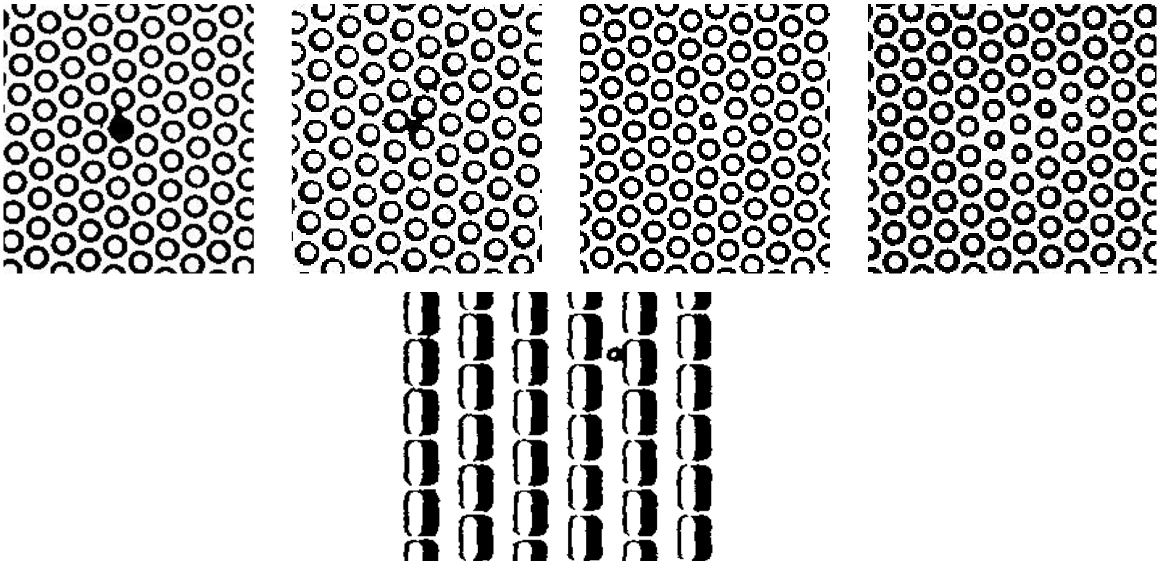

Fig 4: Typical Defects (clockwise from upper left) range from un-etched hole, etched land area, under-etched hole, bubble (under-etched group of holes) and photo etched land area (TV Mask).

Inspection Techniques

The sheer number of holes within a typical aperture mask, combined with their minute size, presents a real inspection challenge. In the past human inspectors have been trained to spot a variety of gross level defects with marginal success. Using the naked eye, teams of human inspectors bend and flex thin screens in front of light tables as they strain to detect singular pixel defects in masks that now regularly have in excess of 1 million precision holes. Typical of the comparison between human inspectors and machine vision solutions, the aperture mask inspection task is much more suited for the tireless and quantitative excellence that only automated inspection techniques can provide.

Over the years, a variety of laser and white light techniques have been developed and adopted to provide some form of densitometry measurement with varying levels of success. While these techniques have been helpful in eliminating many of the gross defects from making it to the end-of-the-line inspection stations, in general, they lack the specificity to detect and classify the defects shown in Figure 4.

The problem with most current off-the-shelf (COTS) machine vision systems is that they are not adequately equipped to handle patterned inspection tasks. The simple fact that you have relatively small defect areas within a great deal of regularly spaced features provides sufficient computational overload to render the general purpose vision machines, and COTS software and hardware useless. As a quick demonstration, in order to get the kind of resolution shown above under normal production conditions, we need to use a 4k linescan camera running at 8kHz. If we are using 8 bit we must process 262 Kbytes of patterned grayscale information per second. In order to process an average web of 36" width requires 18 of these cameras making our total processing load approaching 5 Mbytes per second, well outside the range of any existing COTS system.

The problems are ones of raw data speed and sufficient processing algorithms. Typically golden template based algorithms require expensive high-speed subtraction routines and have significant problems with acceptable real world process variations. If subsequent scaling is required in an attempt to reduce the associated noise, the processing time and related costs put this approach out of reach.

Optical Pre-Processing™

The speed at which optical information is transformed, under any typical and routine interaction, is rivaled by no other technology. The solution that we have been developing centers around the fact that optical processing of information takes place at times which are for all practical purposes instantaneous, and at costs which are significantly less than any computing hardware or software solution. In the machine vision world, we summarize this simple fact in the phrase "Optical Pre-Processing™", which describes a host of potential solutions that allow us to solve potential applications by using the power of light ***before*** we apply any additional hardware or soft ware solutions.

In the case of the aperture masks, many attempts have failed to solve the inspection problem primarily because of the problems listed above. Previous attempts tried unsuccessfully to apply standardized grayscale imaging techniques to the problem. The majority of these fatal problems are eliminated once you realize that this application, and many others like it, can be optically pre-processed to a completely binary system.

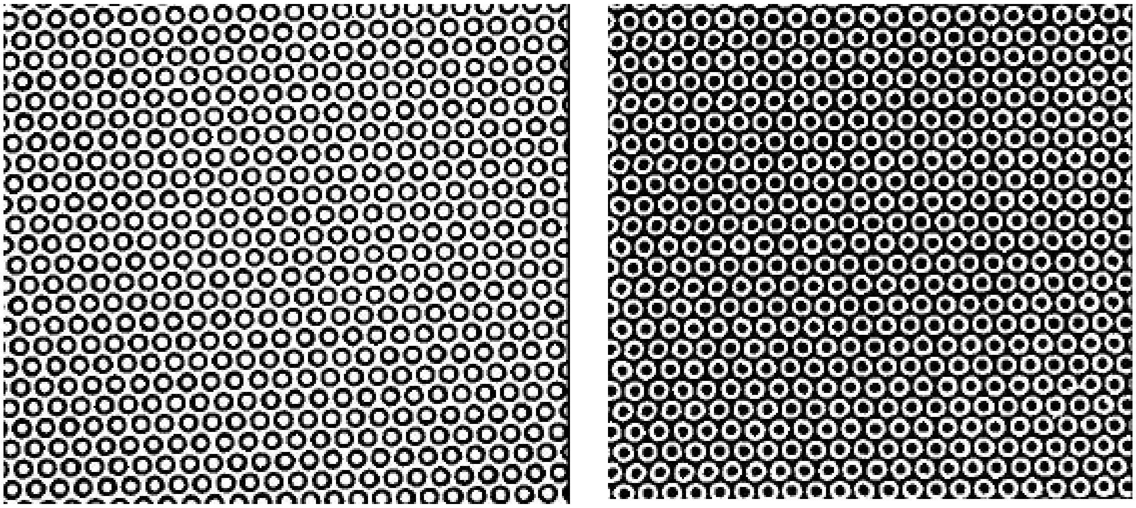

Fig 5: Optically Pre-Processed CRT images. These monitor masks demonstrate the two distinct binary solutions available for the solution to this application. While these images are identical with respect to any subsequent digital signal processing hardware or software, they represent entirely different lighting patent pending lighting schemes.

Since the major problems associated with this application, and many patterned applications like it, will always be that of data compression, it is important to use these types of optical compression techniques first followed by available hardware and software solutions. The benefits can be tremendous.

COTS Development Platforms

Once the lighting techniques were developed for the proper binarization of the entire range of aperture masks, the task of developing a fast, robust algorithm which could be implemented on a standard PC platform was initiated. Over the past 5 years the PC has become the *de facto standard* for machine vision applications. We felt compelled to drive any serious attempts at the overall solutions to these types of patterned application towards this industry standard and cost-effective platform.

```
Blob Analysis                       Level 1 ▲
4 - Select blob type #4
5 - Select blob type #5
6 - Select blob type #6
7 - Select blob type #7
L - Learn current Blob type
n - Null select Blob
S - Search image for 'Bad Blob(s)'
~ - Radial signature difference
& - Radial signature match
@ - Max - min Radial signature
O - Max Radial signature
o - Min Radial signature
* - Set Blob center to bounding box
                                           ▼

   Blob Demo for IT Aperture Mask Inspection Rev 1a

Camera #:      0
Video Mux:    10
Strobe #:      0
Thresh T1:    64
Slice  T2:    64
Gradi  T3:    16                                   BLOB:       1
Pan     X:   224                                   BLOB:       0
Scroll  Y:     0                                   BLOB:       1
Cursor  X:   160
        Y:   114
```

Fig 6: Proprietary algorithm finds minute defects extremely fast using PC based processing techniques. Training of the system can be automated and classifications made based on a number of robust & field proven parameters.

The advantage to the Optical Pre-Processing™ approach is that it expands the available solutions to ones that are very easy to implement, and in fact have been around for over 20 years. Blob analysis tools have more than sufficient power for automatically defining all the key parameters for detecting the defects that we defined earlier, and are extremely well developed, incredibly fast and very robust.

Similar *Optical Pre-Processing*™ techniques may be applied to a wide variety of machine vision inspection tasks, including both patterned and un-patterned applications. While the advantages to patterned applications can be phenomenal, un-patterned applications can also gain a great deal from optical simplification. Such pre-processing not only simplifies the algorithm and hardware costs, it dramatically improves the reliability and robustness of the machine vision inspection system.

In the patterned world, these techniques offer new promise for cost-effective inspection of newly emerging display technologies, including flat panel displays. Since it is becoming clear that the *up-and-coming* flat panel display manufacturing sector will use as much of CRT and semiconductor production equipment and inspection technologies as is possible. Future efforts are currently focusing on third party development support for the necessary PC interface and algorithm hardware.