Rapid pattern inspection of shadow masks by machine vision integrated with Fourier optics

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Abstract. We present a machine vision inspection method that is specially devised to detect defects on shadow masks. This method incorporates Fourier optics to capture only irregular defects in real time by blocking out the periodically repetitive pattern of normal mask holes using a pinhole type spatial filter under coherent illumination. In addition, a fast defect-detection image processing algorithm efficiently suppresses undesirable background noisy images. Experimental results prove that this method provides a detection capability of 500 nm for the least defect size. © 1997 Society of Photo-Optical Instrumentation Engineers.

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1 Introduction
Shadow masks for the cathode ray tube are made up of a thin Inbar metal plate on which a 2-D array of fine holes of rectangular or circular shape is chemically etched. For manufacturing quality assurance of the shadow masks, a suitable inspection method is needed to detect abnormal holes whose size or shape is not within allowable tolerance limits. This inspection has long been performed visually by the naked eye of skilled labor, but it should be automated by adopting a more consistent, productive means. Machine vision technology can be adopted for the inspection. One simple way is to examine all the holes one by one, but this plain method consumes too long an inspection time to be tolerated for production use. Instead, a drastic improvement in throughput can be made by incorporating Fourier optics in which only defective holes can be extracted in a fast manner without relying on time-consuming software image processing. This is possible because the pattern of normal holes has a periodic appearance, so any defect violating the periodicity can be singled out by blocking the normal pattern.

2 Inspection by Fourier Optics
It has long been known that optical Fourier transformation coupled with subsequent spatial filtering provides a fast means of parallel processing in inspecting a large target area of periodic pattern. This inspection method is currently gaining attention because its industrial demand is growing together with widely available machine vision technology. Several attempts have been made in such areas...
as integrated-circuit patterns, lithography photomasks, and textured materials. Along with the practical applications of Fourier optics, increasing efforts are being made to develop effective spatial filters such as photographic plates, emulsion mask, holography plates, gelatin pin holes, and photorefractive filters.

### 3 Inspection System Design

Figure 1 shows the optical configuration setup used in this investigation. The shadow mask under inspection is illuminated by the collimated coherent beam of a HeNe laser expanded to 50-mm-diam size. A Fourier-transforming lens is placed in front of the shadow mask. In addition, a circular pinhole-type spatial filter made of aluminum foil is located at the back focal plane of the lens, where the Fourier-transformed image of the shadow mask appears. The cutoff frequency of the spatial filter is adjusted to block off the high-frequency terms dominated by the pitch of the holes so that only low-frequency terms passes through. The transmitted beam is then inverse Fourier transformed by an imaging lens to cast the shadow mask image with apparent defects on a CCD camera.

The intensity levels of defects on the captured image deviate from the mean background intensity; if a hole is smaller than the nominal size it appears darker and vice versa. For rapid inspection, it becomes essential to derive the quantitative relationship between the defect size and measured intensity level. An experimental result is shown in Fig. 2, which was performed on a 14-in. size shadow mask with about 80,000 200-mm-diam holes. The defect size is measured as the area deviation of a hole from its nominal value, while the intensity deviation is scaled by the absolute difference from the mean background level, which is normalized by the signal-to-noise ratio (SNR) of the electronics used for image frame grabbing. The experimental result shows that the measured intensity deviation is in good proportion to the defect size, whose proportional constant is computed as $1/500 \text{ mm}^2$. The test results also demonstrates that the minimum detectable defect size is

![Fig. 1 Optical configuration of the defect inspection system.](image)
The coherent laser beam used for illumination gives rise to a significant level of background disturbance in captured images due to stray reflections between optical components. Fortunately, the background disturbances can be effectively removed by simple software image processing since they remain stationary and are not affected by the presence of defects. Figure 3–a! shows a raw image of the shadow mask seen with two defects, one smaller hole on the left and one larger hole on the right. When a pinhole spatial filter is inserted to block off the normal pattern, the resulting image is captured, as in Fig. 3–b!. Not surprisingly, a high level of background disturbance appears to be mixed with the defects image. However, if the shadow mask is taken away, then only the background disturbances are observed, as in Fig. 3–c!. Thus, a clear defects image can be extracted simply by subtracting the image of Fig. 3–c! from the mixed image of Fig. 3–b!, as demonstrated in the final image of Fig. 3–d!.

5 Conclusion
We have investigated a machine vision inspection method for rapid detection of defects on shadow masks. This method incorporates Fourier optics to effectively block off the regular pattern of fine holes using a pinhole-type spatial filter so that only defects can be extracted with minimum inspection area, whose corresponding intensity level reaches the SNR, i.e., unity intensity deviation, which is not detectably bothered by electric noise.

![Graph](image_url)

**Fig. 2** Intensity variation with defect size.
Fig. 3 Software image processing procedure: (a) raw image of a shadow mask, (b) spatially filtered image (with defects), (c) background image without shadow mask, and (d) extracted defects.
software image processing. Experimental results prove that this method is useful with a detection capability of

\[ 500 \mu m^2 \]

for the least defect size, which is sufficiently more than the industrial requirement of \[ 1,000 \mu m^2 \] least defect size.

References

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