Modulation transfer function of bar code scanning

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Abstract. Bar code scanners are ubiquitous in supermarkets. As a bar code is passed over a scanner, a laser beam scans across the bar code. The scattered light is modulated by the reflectivity of the bars and spaces of the bar code. The bar code scanning process can be described as a 1-D convolution of the scanning laser profile and the bar code reflectivity function. The modulation transfer function (MTF) of bar code scanning is the Fourier transform of the marginal profile of the laser beam. The properties of the MTF of bar code scanning is similar to that of an incoherent imaging system. Measurements of the MTF of bar code scanning at one focal position are presented. The experimental results are then discussed.
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1 Introduction

Bar codes are commonly used in applications that require product, warehouse, or shipping identification. A bar code is a sequence of lines and spaces with alternating reflectivity. Bar codes range in size from 1 cm on a pack of chewing gum to nearly 1 m on railroad cars. In this paper, we analyze the scanning process used to detect the bar code.

Most bar codes are detected with a scanning laser beam. The laser beam is gently focused, and the bar code is detected in a range around the focal point. This range is the depth of focus of the scanner.[1] When a bar code near the end of the depth of focus is scanned, the large laser spot size reduces the detected modulation of the bar code signal. To ensure enough optical modulation is recovered from the optical bar code signal, the modulation transfer function (MTF) is optimized over the depth of focus. The optimization of MTF is an integral part of the system design in a bar code scanner.[2] The MTF also provides important information as to the optimization of subsequent electronic filters. In this paper, we examine the MTF of the scanning process.

In the following sections, we first describe the generation of a bar code signal. We then review the MTF of a 1-D incoherent imaging system to compare it to the bar code scanning process. We then discuss the irradiance distribution of the focused laser beam. Next, the MTF of bar code scanning is derived and its properties are discussed. Our experimental results indicate that the theoretical analysis is a good indicator of system performance.

2 Generation of the Bar Code Signal

A 1-D bar code with the bars and spaces along the y direction is shown in Fig. 1. As a laser beam scans across the bar code, the scattered light is modulated by the reflectivity of the bars and spaces as the laser beam scans in the x direction. The laser beam irradiance distribution at the bar code is described by $i(x,y)$. The reflectivity function of the bar code is described as a 1-D function $s(x)$.

As the laser beam scans across the bar code, a time-varying light signal is received by a detector. The detector is placed in the optical system so as to collect a significant percentage of the light reflected from the bar code. An unfolded configuration is shown in Fig. 2. The elliptical reflector has one focus at the bar code and one at the detector. The detector converts the light signal into an electronic signal.

Assume that the laser scans in the x direction at a speed of v. The electronic signal g at time t can be represented by

$$g(t)=\frac{\mathscr{G}\mathscr{R}\Omega}{\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}i(vt-a,\ y)s(a)\ \mathrm{d}a\ \mathrm{d}y, \tag{1}$$

where Ω is the solid angle of the collection aperture subtend at the bar code, $\mathscr{R}$ is the responsivity of the detector, $\mathscr{G}$ is the gain of the amplifier, $i(x,y)$ is the laser beam irradiance distribution function, $s(x)$ is the bar code reflectivity function, and the integration in y direction is done by the detection process.

It is convenient to discuss the signal in terms of the independent variable in spatial coordinates. It is also convenient to neglect the constants Ω, $\mathscr{R}$, and $\mathscr{G}$ in Eq. (1) because the treatment in subsequent sections is relative to the maximum signal. Substituting vt with variable x, Eq. (1) becomes

$$g(x)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}i(x-a,\ y)s(a)\ \mathrm{d}a\ \mathrm{d}y. \tag{2}$$

