Watermark Detection with Digital Capture Systems

Alastair Reed and John Stach, Digimarc (USA)

Introduction

Digital watermarks are used to help protect secure documents such as driver's licenses[1]. The license is validated using an Identity Document Verification System (such as Digimarc IDVS) where the images are captured using a scanner or camera system.

The optical quality of a digital image capture system is characterized by several factors[2]:

- modulation transfer function (MTF) of device
- tonal response
- sensor noise

Although many factors can affect the optical image quality, in high quality image capture devices the dominant process controlling watermark detection is the MTF of the capture device. The capture device MTF is measured to characterize its ability to read a digital watermark. This provides a straightforward method of qualifying a device for watermark detection. Since the watermark can be inserted in an arbitrary color direction, the MTF of the device has to be measured in the same color direction. This is particularly important for devices, such as digital cameras, which have unequal sampling in red, green and blue. This leads to very different MTF curves in the different color directions.

The watermark used for this study consists of two signals, a synchronization signal and a spread spectrum payload. Both signals are embedded as repeating blocks so that they are robust to cropping as well as rotation and scale. The synchronization signal is a template that is used to realign the image into the original rotation, scale, and shift. The payload is coded in binary using error correction and convolutional codes to improve robustness against random noise and image content[3]. The coded payload is then XOR'd with a random sequence to whiten the signal and embedded into the image redundantly within each block using luminance variations. Once the image is realigned, the spread spectrum payload can be easily extracted by reversing the luminance modulation and coding operations. The result of this approach is that the watermark payload can be recovered over a wide range of rotation, scale, shift, and noise parameters. Furthermore, the coding and redundancy in the payload can be used to obtain a reasonable estimate of watermark signal to noise ratio (SNR) based on the known extracted payload and the statistics of the demodulated bits used for the decoding process. The SNR is defined in the standard manner as $10\log_{10}$((peak signal energy)/(peak noise energy)).

Since the watermark we are considering is embedded at 300 watermark cells per inch, the spatial frequency distribution is approximately flat up to150 cycles/inch. This flat frequency distribution is degraded by the MTF of the printer used to produce the watermarked document, and the capture image device. The aim of measuring the MTF of a capture device is to have a simple method of quantifying the ability of an imaging device to read a watermark.

MTF Measurements

Scanners and digital cameras are often used as a capture device. A standard camera capture device used by Digimarc is the Assuretec (400 dpi). Almost all color digital cameras use colored filters deposited on the pixel locations in a Bayer pattern to capture an RGB image.

The Assuretec returns a full color RGB image by interpolating between like colored pixels. This results in a significantly degraded spatial frequency response as can be seen in Figure 1 below. The reader device MTF was measured by capturing a standard sinusoidal gray test pattern as an RGB image and weighting the color channels, in the same way as the watermark detector, to obtain a grayscale image. The MTF was measured using software from Mitre Corporation[4].

The Assuretec MTF with 400 dpi sampling is compared to the TravelScan 662 MTF at 300 dpi. The measured MTF of the TravelScan is significantly better, since it is approximately the same for each color channel while the Assuretec is significantly worse for some colors because of the Bayer pattern. The effect of just using the blue channel is a large drop in MTF for the Assuretec, as can be seen in Figure 1.

It is straightforward to measure the luminance response of a device, by taking an RGB capture of a gray test target and using the correct weightings of red, green and blue to obtain a luminance grayscale image. However it is more involved to obtain the blue-yellow response of a device from a gray test target. The blue channel from the RGB capture is used to measure the blue MTF, and the red and green channels are averaged to measure the yellow MTF (see Figure 1). The average of the blue and the yellow MTF is then the blue-yellow response of the device. For devices which have the same MTF for red, green and blue this means that the luminance and the

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[1] 'On the use of mobile imaging devices for the validation of first and second-line security features', Tony Rodriguez and Matt Weaver, Proc SPIE Electronic Imaging, Optical Security and Counterfeit Deterrence Techniques VI, vol. 6705, pp 385-396, San Jose, CA, Jan 2006

[2] 'On the use of web cameras for watermark detection', John Stach, Trent Brundage, Brett Bradley, Tony Kirk and Hugh Brunk, Proc SPIE Electronic Imaging, Security and Watermarking of Multimedia Content IV, vol. 4675, pp 611-620, San Jose, CA, Jan 2002

[3] 'Smart images using Digimarc's watermarking technology', A.M.Alattar, Proc SPIE Electronic Imaging, Security and Watermarking of Multimedia Content II, vol. 3971, pp 264-273, San Jose, CA, Jan 2000

[4] 'Computer program to determine the sine wave modulation transfer function (MTF) of imaging devices', N.B. Nill, D.J. Braunegg and B.R.Paine, Mitre technical report, Nov 1996

blue-yellow MTF is the same. However for camera devices which have different MTF's for red, green and blue, the luminance and blue-yellow MTF is very different.

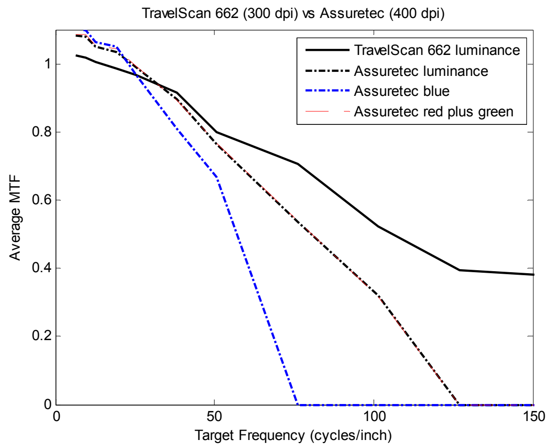

Figure 1: Comparison of TravelScan 662 and Assuretec

Watermark Signal Strength

The watermark message should be approximately equally spread over all spatial frequencies up to150 cycles per inch. Thus by comparing the integrated area under the black curve compared to the dotted black curve in Figure 1, should give a measure of the relative ability of the two devices to read the watermark. The ratio of TravelScan to Assuretec luminance integrated area was measured to be approximately 1.23. The noise of the two capture devices was also measured to be about the same. An image watermarked with the same signal energy in red, green and blue was measured on the two devices and the SNR values were compared (see table 1).

Table 1: SNR Comparison for Luminance Watermark

	SNR (luminance watermark)
TravelScan 662 (300 dpi)	6.77
Assuretec (400 dpi)	5.4

The difference in SNR of 1.37 dB, implies that the $10^{1.37/10}$ = 1.37 more signal is measured by the Assuretec. This is similar to the 1.23 difference predicted by the ratio of the area under the MTF curves.

A similar measurement was performed using a blue-yellow chrominance watermark (see table 2 below).

Table 2: SNR Comparison for Chrominance Watermark

	SNR (blue-yellow watermark)
TravelScan 662 (300 dpi)	7.94
Assuretec (400 dpi)	6.04

The difference in SNR of 1.9 implies that the $10^{1.9/10}$ or 1.56 times more signal is measured by the TravelScan. The ratio of TravelScan to Assuretec integrated area for blue-yellow was measured to be 1.44 as shown in Figure 2. Once again the increase in area under the MTF curve approximately predicts the increase in detection of the watermark signal.

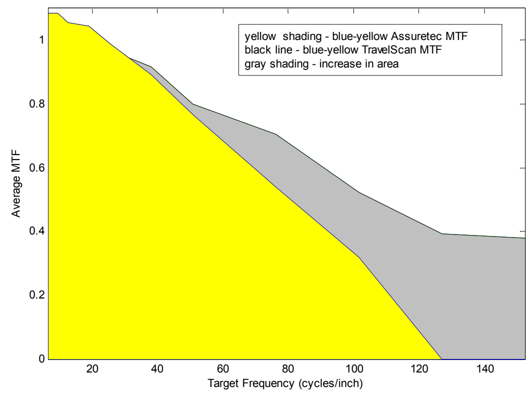

Figure 2: Comparison of Area Under MTF Curves

Conclusions and Implications for Device Characterization

Image capture devices such as digital cameras have unequal sampling in red, green and blue. In order to characterize the device for its ability to detect a digital watermark, the color direction of the watermark needs to be taken into account. For example a luminance based watermark will be detected differently than a chrominance based watermark. In order to predict the capability of a device to read a watermark, the MTF of the device needs to be measured in the same color direction as the watermark.

MTF measurements of a camera based digital capture system were used to predict watermark detection performance for a watermark embedded in both luminance and chrominance. The predicted watermark detection performance was confirmed by the measured SNR improvement.

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