DMD-Based Infrared Scene Projection: A Comparison of MWIR and LWIR Modulation Transfer Function

William R. Folks, Dan Mullally, Guy Zummo, Arthur Weeks, Glenn Boreman

School of Optics/CREOL & FPCE, University of Central Florida, Orlando FL USA 32816-2700

ABSTRACT

We compare modulation-transfer-function (MTF) measurements for both mid-wave (MWIR) and long-wave IR (LWIR) bands for an IR-laser scene projector based on the digital micro-mirror device (DMD). We evaluate MTF for both IR-CO_2 (10.6 μm) and IR-HeNe (3.39 μm) laser systems. This gives a quantitative image-quality criterion for verifying system performance using identical configurations of the DMD, lens, and screen. Different angles of illumination for the MWIR and LWIR were used, to give an output beam always perpendicular to the DMD. For this experiment a set of bar-target images was used to measure the residual modulation depth at the fundamental spatial frequency of the bars. As expected, the MWIR projector system has better MTF than the LWIR system because of diffraction effects occurring at the 17-μm pixels of the DMD.

Keywords: Scene generation, infrared scene projection, spatial light modulator.

INTRODUCTION

Requirements for scene generation for the purpose of simulation and training[1] in the infrared are different than for hardware-in-the-loop (HWIL) scene projectors. The need to project imagery on a diffuse-reflecting screen that can be viewed from a wide range of angles necessitates a laser-based approach rather than the usual HWIL solution of a resistive array in order to satisfy radiometric requirements. We developed an IR projection system based on a reflective spatial light modulator, the Texas Instruments' digital micromirror device (DMD), which can operate in both the midwave-IR (MWIR, 3-5 μm) and longwave-IR (LWIR, 8-12 μm) bands. Our DMD device was retrofitted with a ZnSe window by the Optical Sciences Corporation. The DMD used in this study has 600 × 848 pixels each with binary on and off states and a pixel pitch of 17μm. It may be thought of as similar to an actively driven blazed grating. For IR scene-projection applications, the main performance issue using the DMD[2] is that the pixel size is comparable to the IR wavelength of the source. For this reason we investigated MTF using both MWIR and LWIR laser sources. Background radiation was also stronger for the LWIR band, which also affected the observed image contrast.

Figure 1 shows the experimental setup used. Two different lasers are used for the source, a CO_2 at 10.6 μm, and a HeNe at 3.39 μm. The beam was spatially filtered and expanded before illuminating the DMD. The input angle used for the two laser sources is different, and was adjusted so that the diffraction order collected for imaging propagates perpendicular to the DMD array. Radiation from the collected order was imaged onto a projection screen by a dual-band MWIR/LWIR projection lens. We use a sandblasted 215 mm × 280 mm aluminum screen, which has a diffuse reflectivity greater than 90% in the IR. The image on the screen was viewed with a LWIR (ferroelectric FPA) or a MWIR (PtSi) camera. For the measurements contained here the 10.6-μm laser produced about a 10 W output beam. The 3.39-μm laser used had a beam power of about 40 mW. Projection on larger screens would be possible at higher output powers for the lasers, with proper attention to heat-removal issues at the DMD.

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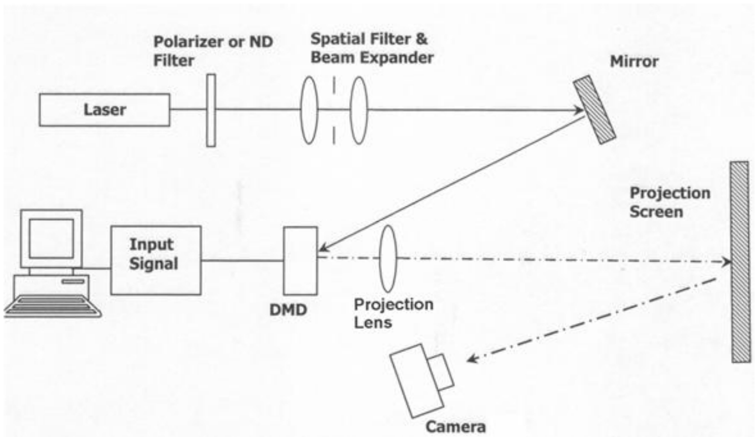

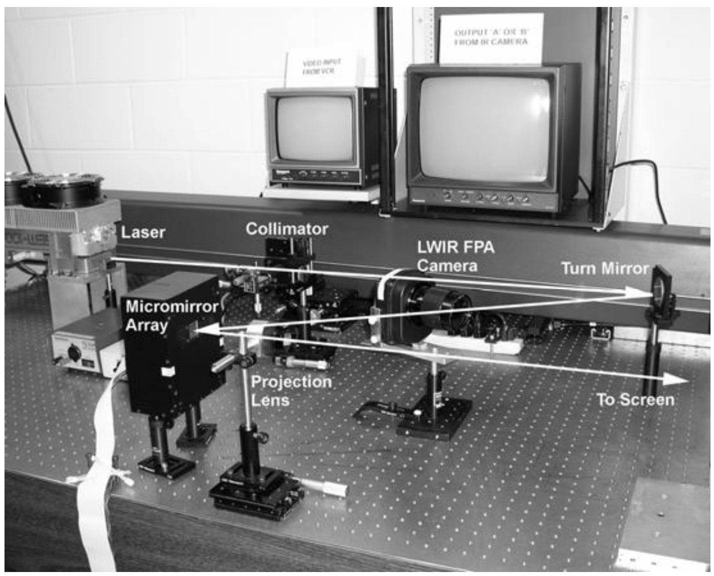

Fig. 1. Experimental setup. The FPA camera is focused onto the plane of the projection screen.

DATA PROCESSING PROCEDURES

Modulation transfer function (MTF) is defined as the modulus of the complex optical transfer function (OTF) and is a convenient figure of merit used to measure system image quality.[3] It may also be defined as the absolute value of the Fourier transform of the point spread function (PSF),

$$MTF = \left|\mathcal{F}(PSF)\right|.$$

The advantage of the MTF approach is that the total system MTF is simply expressed as the product of each of the subsystem MTFs:

$$MTF_{System} = \prod_{i=1}^{n} MTF_i \ .$$

This cascade property allows for the MTF of each subsystem to be studied independently. In this work, we measured the MTF of the MWIR and LWIR cameras separately from the MTF of the projection-and-imaging system, using transparency bar-targets with square-wave emissivity[4] placed at the projection screen. This allowed us to divide out the IR-camera MTF from the data, to leave just the MTF of the projection system (DMD and projection lens). We used the approach of a square-wave data set,[5] and measuring MTF as the magnitude of the fundamental component,[6] as a function of the spatial frequency of the bars. This avoided the necessity of a series correction to convert square-wave to sine-wave data.

A line-by-line series of horizontal slices were extracted from the images such as seen in Fig. 2, and the absolute value of the Fourier transform of each line scan is taken and averaged. This procedure is repeated for each frequency of interest. To avoid nonlinearity in the camera responses, the square-wave data sets used were at 40% modulation depth at the input to the DMD.

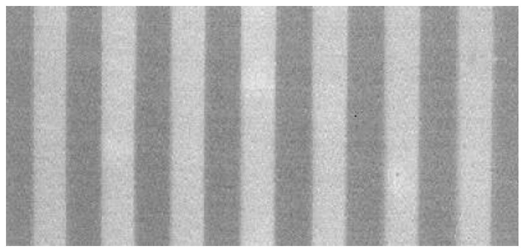

Fig. 2. Typical bar chart pattern captured by the IR camera reflected from the diffuse aluminum screen.

EXPERIMENTAL RESULTS

As can be seen from Fig. 3, the projector system had better MTF performance when used at MWIR than at LWIR. The spatial frequency specified is at the projection screen. The MTF of the projector, when used with LWIR illumination drops off more rapidly because of diffraction at the DMD pixels. The measured low-frequency contrast ratio of the imagery in LWIR was quite low, about 12:1, mainly because the projection screen itself was a room-temperature graybody at about 10% emissivity. For MWIR illumination, the low-frequency contrast ratio increased to 25:1.

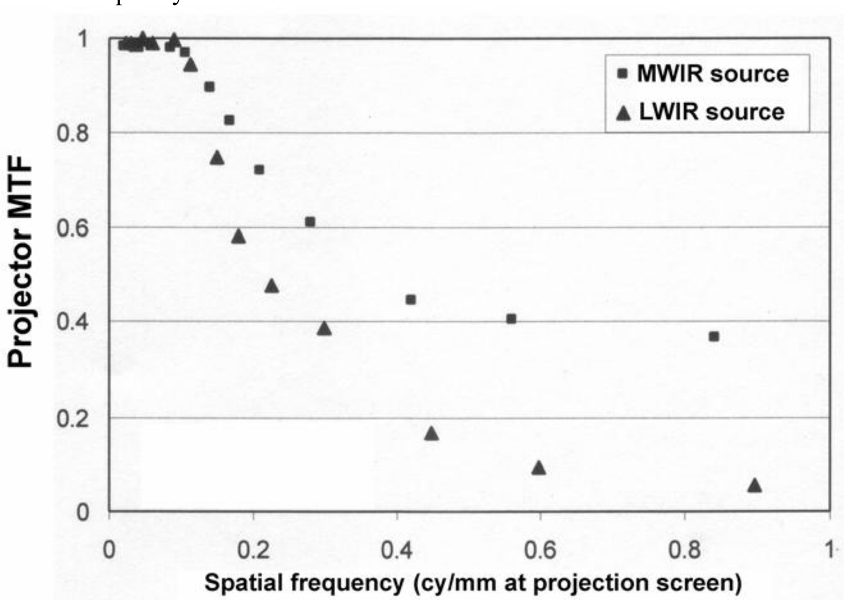

Fig. 3. MTF of the projector (camera MTFs divided out) for MWIR and LWIR sources using an aluminum screen.

SUMMARY

As expected, MTF performance of the projector was higher for MWIR than for LWIR radiation, because at LWIR, the 17-μm pixel size of the DMD is only slightly larger than the wavelength of the illuminating radiation. Also, lower contrast levels overall were noted for the LWIR projector because of thermal radiation arising at the projection screen itself.

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