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Gigapixel 1440-perspective display by sub-megapixel DMD

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ABSTRACT

Desirable fields-of-view, angular resolutions, and form factors of near-to-eye AR/VR/MR displays require order-of-magnitude increases in pixel count and pixel density of spatial light modulators (SLM). We present an in-plane angular-spatial light modulation technique to increase the independent output display pixels of a DMD by three orders of magnitude to achieve gigapixel output from a sub-megapixel device. Pulsed illumination synchronized to a DMD's micromirror actuation realizes pixel-implemented and diffraction-based angular modulation, and fine source array control increases angular selectivity. The gigapixel output is demonstrated in a 1440-perspective display, each perspective having the DMD's full native XGA resolution, across a 43.9°×1.8° FOV viewing angle. 8-bit multi-perspective videos at 30 FPS are demonstrated, and pixel-implemented multi-focal-plane image generation is realized. Implications for near-to-eye displays are discussed.

Keywords: Display, 3D, DMD, Digital Micromirror Device, perspective, gigapixel, multi-view, multi-perspective

1. ARCHITECTURE

Display applications like AR/VR/MR head-mounted near-to-eye displays have challenged Spatial Light Modulators (SLM) to achieve more pixels in smaller devices. While many advancements have relied on reducing pixel pitch in fabrication [1], the reported Digital Micromirror Device (DMD) based display implementation increases output pixel count by diffraction-based programmable blazed grating beam steering [2], diffraction-based programmable blazed grating pattern steering [2], and pupil-segmented pattern steering [3]. Our recent work achieves gigapixel output across 1,440 perspectives [4], each perspective having the native XGA resolution (1024×768) of the DMD for a total output of 1.13 gigapixels. The cascaded DMD system architecture is shown in Fig. 1 [4].

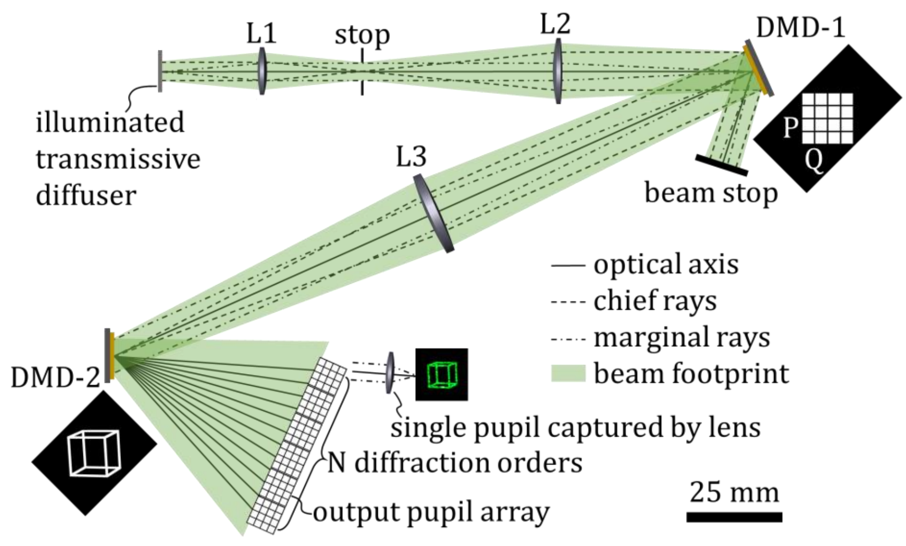

Figure 1. Cascaded DMD architecture for gigapixel output. Reprinted with permission from [4] © The Optical Society.

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2. SUPPLEMENTAL INFORMATION

We previously reported piecewise experimental verification of (1) 1,440-view output, (2) 8-bit 30 FPS XGA video output, and (3) open-loop multi-focal-plane projection by super multi view output [4]. The following sub-sections elaborate on the experimental setups, including challenges and solutions.

2.1 Experimental capture of wire grid cube

A Nikon D40 camera with a 35 mm focal length lens was used to capture images of 9 of the 1440 perspectives. The system was set to output a single pattern into the respective single direction using the corresponding source on DMD-1 and diffraction order output on DMD-2. The Nikon camera was pointed directly at DMD-2 and was positioned for each corresponding gaze angle. Visualization 1 shows the display output of the wire grid cube as the angle of observation changes [4].

2.2 Experimental capture of 8-bit humanoid and tiger

8-bit, 30-frame animations at DMD-2 native resolution (1024×768) were projected at 30 FPS by sequencing 255 binary frames per 8-bit frame at constant-level illumination. A single 3-dimensional perspective animation was output at a single angle at a time to achieve an overall framerate of 30 FPS. Delays in the Arduino programming were adjusted to achieve the required DMD-2 reset rate of 30 FPS × 255 binary frames × 2 (interleaved black pattern [3]) = 15.3 kHz. The first 8-bit frame of the 30-frame sequence, comprising 255 binary frames, was looped to be photographed at 1/4 second exposure to ensure the entire 1/30 second integration time was captured. Since the multi-bit-depth display relied on time-integration, the static diffuser was replaced with a rotating diffuser to time-integrate across illumination irregularities and speckle on DMD-1. The humanoid was captured with a Nikon D3300 camera and 55 mm Micro-Nikkor-p prime lens with a Nikon M2 extension tube, and the tiger was captured with an Olympus E-PL6 and 55 mm Micro-Nikkor-p prime lens with a Nikon-Olympus adapter extension tube. Angle-accurate captures of the humanoid and tiger [4] are shown in Fig. 2.

Figure 2. Angle-dependent single-frame 8-bit captures of a humanoid (left) and tiger (right). 30 FPS videos shown in Visualization 2 and Visualization 3, respectively [4]. Humanoid artwork and animation by Michał Hokiroya Korczyk (artstation.com/hokiroya), and tiger artwork and animation by Daniel Bystedt (artstation.com/dbystedt). Both animations used with permission and rendered in Blender.

2.3 Experimental capture of 8-bit super multi view

A 4×4 array of sources were programmed into DMD-1, each source comprising a 7×7 array of diamond-clocked pixels on DMD-1 and spaced at 160 diamond-clocked pixel increments. Equivalently, mapped by the 192 mm focal length Koehler illumination lens L3, each source corresponded to a 0.03°×0.03° angular extent at 0.5°×0.5° increments for a total array diagonal angular extent of 2.2°.

The 16 angle-dependent renderings of the two-socket scene were rendered in POV-Ray [5] at 8-bit then converted to 255 binary patterns for projection. The further socket was rendered at -30 mm and the nearer socket was rendered at +12 mm with the rendering camera located at 100 mm.

An Olympus E-PL6 with 55 mm Micro-Nikkor-p prime lens and Nikon-Olympus adapter extension tube captured the 16 overlapping images. The stop on the prime lens was reduced to F/11 to block higher-order diffraction orders when the camera was 100 mm from DMD-2. The single 8-bit frame (comprising 255 binary frames) was projected at 30 FPS, for the same 15.3 kHz DMD-2 binary reset rate, and was captured with 1/4 second exposure to prevent time integration clipping.

2.4 Binary frame sequencing problem and solution

Constant-level source illumination required the 8-bit projections to consist of 255 sequentially-projected binary frames. Time delays were adjusted in the Arduino programming to achieve 30 FPS output, but the recording video camera was not synchronized to the projection system. The population order across the 255 sub-frames was therefore cause for concern, as front-loading or back-loading the integration time could cause power level errors across successive frames captured by the camera.

By example, the following population order for 3-bit would front-load the time-integrated frames: 1234567. Power levels of 1, 2, and 3 are projected by integration of 1000000, 1100000, and 1110000. Similarly, the population order could back-load the time-integrated frames: 7654321. Front-loading or back-loading the integration time can cause greater errors in multi-bit pixel captures. Other non-order-based algorithms can distribute pulse-width modulation power evenly, such as 0101010 for a level of 3 and 1010101 for a level of 4. However, these algorithms desynchronize pixels spatially: a pixel of power 3 next to a pixel of power 4 would be out of sync, despite being neighboring power levels. (Displaying a single static binary frame is an important troubleshooting step to assess single-frame accuracy and quality, but it is less effective if spatial information is already lost.) We report our concise algorithm, written in Matlab and based on bit-reversal permutation, to equally distribute power across time integration:

```
order = bin2dec(fliplr(dec2bin(0:2^bit_depth-2,bit_depth)))+1;
```

The order, 1537264 at 3-bit, distributes power more evenly across the integrated frame with greater bit depths. For instance, at 4-bit (population order written in hex): 195D3B7F2A6E4C8. We can achieve more accurate captures with more evenly distributed pulse-width modulation.

3. IN CONTEXT

Marketing for display resolution commonly follows a "K" system, for instance "2K", "4K", and "8K", referring to the approximate number of horizontal pixels in the display. The ASLM display technique has been shown to arbitrarily map the sub-FOVs across the total system output [3]. If a typical 1.9:1 aspect ratio was assumed, the 1.13 gigapixel (1,132,462,080 pixels) output from the presented display could be mapped to a resolution of 46,386×24,413, or "46K".

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