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High speed single pixel imaging with advanced microLED digital light projector

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***Abstract*— We demonstrate high speed single pixel imaging using an advanced microLED-on-CMOS array. We show 128x128 pixel image reconstruction at an effective frame rate of 3.8fps and lower resolution reconstructions at over 120fps. The method is demonstrated to be compatible with common compressive imaging techniques.**

Keywords*— *digital light projector, micro-LED, single pixel imaging

I. INTRODUCTION

Taking images with a single-pixel detector relies on the image structure being generated by something other than a pixelated receiver array. This is usually done by spatially structuring the light from the scene, either at the illumination or the detection end, and subsequent image reconstruction from the time-dependent light intensity at the detector corresponding to the known illumination mask. A simple way to perform this is by raster scanning, illuminating only one part of a scene at a time and recording the brightness at each illuminated point, an image can then be reconstructed. However, the raster scan is an inefficient use of the available light and much more efficient imaging schemes have been developed where usually 50% of the pixels are on in each illumination pattern, originally demonstrated by Duarte *et al.* [1].

There are a number of applications where single pixel imaging is beneficial, such as when imaging at wavelengths where detector arrays would be prohibitively expensive or by making use of time resolved imaging that can enable ranging [2]. However, the relatively low speed of imaging is a barrier to more widespread adoption, with flexible single pixel imaging usually limited in speed by the hardware that is used for the pattern masks. The most frequently used equipment for this is the Digital Micromirror Device (DMD) and these are limited to about 32,000fps, meaning that 32x32 pixel images can only be generated at 15fps. There are numerous techniques that can increase the speed of imaging, such as etching the patterns on to a high-speed rotating disk [3], building a bespoke LED array [4] and laser scanning across a DMD [5]. These tend to result in less flexibility in the imaging by constraining the choice of illumination patterns and make the imaging system much more complex. One other possibility to improve the speed of imaging is to use compressive sensing, which uses fewer patterns than would normally be needed for a full image at a given resolution. However, this has the negative consequence of decreasing the quality of the reconstructed image and a trade-off must be made.

To perform simple, flexible and high-speed single pixel imaging, we make use of recently developed microLED projector. Our device is 128x128 pixel array of microLEDs capable of displaying digital patterns at 500kfps [6]. The light projector is fabricated from a c-plane GaN-on-sapphire wafer with a peak emission wavelength at 450nm using standard LED fabrication. It is then flip-chip bonded onto a custom-designed CMOS driver chip using an indium based bonding process.

II. METHODS

The single pixel imaging performed here is done with a relatively straightforward optical setup. The microLED projector is imaged onto a DMD with a simple spherical lens. The DMD is used only as an object to be imaged and displays a binary static image - in this case characters from the NIST special database 19 (normally used in testing for deep learning based handwriting recognition techniques) [7] are chosen for the imaging. The light reflected from the DMD is then gathered by a condenser lens and focused onto the single pixel detector, an Onsemi Silicon Photomultiplier.

The pattern set chosen for this work is the frequently used Hadamard patterns, but in principle any set of pattern masks suitable for single pixel imaging can be used on this light projector. The Hadamard matrices have elements that are either 1 or -1, which cannot be displayed directly on a binary projector. Therefore, for each Hadamard matrix, two separate patterns with elements of 0 and 1 must be displayed on the array, one pattern each for the positive and negative values in the matrix. The image I is then reconstructed using the equation,

$$I_{(x,y)} = \frac{1}{M}\sum_{m=1}^{M} S_m P_{m,(x,y)} \qquad (1)$$

where P is the mth Hadamard matrix, S is the difference in the measured signal from the two corresponding patterns displayed on the light projector and M is the total number of measurements.

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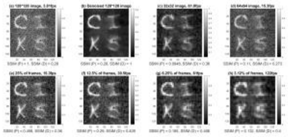

Fig.1 Single pixel imaging results. For each image, the effective frame rate is above the image and the comparison with SSIM below. SSIM (P) compares the image to (a) and SSIM (D) compares the image to (b). (a) is a 128x128 pixel image, (b) is the denoised version of (a), (c) is a 32x32 pixel image, (d) a 64x64 pixel image and (e-h) show the results of compressive sensing of the 128x128 pixel image, with the percentage of frames referring to the fraction included in comparison to image (a).

III. RESULTS

Examples of imaging with this setup are shown in Fig. 1. Figure 1(a) is a full 128x128 pixel image of four letters from the aforementioned database, which are clearly visible in the image. To enhance the image, a denoised version of the primary image 1(a) is shown in 1(b), where the denoising was performed using the Matlab function denoiseImage from the deep learning tool box. These two images are used as reference images for comparison with the structural similarity index measure (SSIM), where 1 is a perfect match and 0 is no similarity. In this work SSIM (P) is a comparison to the primary reconstructed image in 1(a) and SSIM (D) is a comparison to the denoised image 1(b). The latter should be closer to what was displayed on the DMD, however, it is possible that artefacts are introduced and therefore all images are also compared to both.

Images 1(c) and 1(d) show the image when the projector is used as an array of 32x32 pixels and 64x64 pixels, respectively (meaning the effective pixel for imaging consists of grouped sets of 4x4 or 2x2 projector pixels). Lower resolution images are generated with fewer patterns, with a decrease in the image quality, as shown in the resulting SSIM. The scene can still be easily discerned and there is a reduction in the noise, as fewer high spatial frequency patterns are part of the reconstruction. Figures 1(e-h) show the results of compressive sensing on this image, with the fraction of the total frames that have been included in each reconstruction. Images 1(e) and 1(g) use the same number of frames to reconstruct as the 64x64 pixel image and 32x32 pixel image respectively. In both, the compressive sensing image performs better than the corresponding normal image when comparing with SSIM, demonstrating the flexibility of this system that enables better imaging at lower resolution.

The full 128x128 pixel image shown in (a) is constructed with the microLED operating at 125kfps for 32768 displayed patterns, giving an effective frame rate of 3.8fps. Figure 1(h) is the fastest imaging shown here with only about 3% of the total number of frames used in this reconstruction while the letters are still readable, producing an effective frame rate of 122fps.

IV. CONCLUSION

The microLED light projector demonstrated in this work has made single pixel imaging at high speeds possible without having to resort to complex optical setups. The array is able to display any binary pattern set that one chooses and when working at below maximum resolution can improve imaging quality by being able to selectively choose the included patterns. The work demonstrated here is all performed at 125kfps, however, the projector is capable of operating at 400kfps for this application and with further optimization the imaging shown here will be able to be performed over three times faster.

V. REFERENCES

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