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Optical Demonstration of a Medical Imaging System with an EMCCD-Sensor Array for Use in a High Resolution Dynamic X-ray Imager

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Abstract

Use of an extensible array of Electron Multiplying CCDs (EMCCDs) in medical x-ray imager applications was demonstrated for the first time. The large variable electronic-gain (up to 2000) and small pixel size of EMCCDs provide effective suppression of readout noise compared to signal, as well as high resolution, enabling the development of an x-ray detector with far superior performance compared to conventional x-ray image intensifiers and flat panel detectors. We are developing arrays of EMCCDs to overcome their limited field of view (FOV). In this work we report on an array of two EMCCD sensors running simultaneously at a high frame rate and optically focused on a mammogram film showing calcified ducts. The work was conducted on an optical table with a pulsed LED bar used to provide a uniform diffuse light onto the film to simulate x-ray projection images. The system can be selected to run at up to 17.5 frames per second or even higher frame rate with binning. Integration time for the sensors can be adjusted

from 1 ms to 1000 ms. Twelve-bit correlated double sampling AD converters were used to digitize the images, which were acquired by a National Instruments dual-channel Camera Link PC board in real time. A user-friendly interface was programmed using LabVIEW to save and display $2K \times 1K$ pixel matrix digital images. The demonstration tiles a 2×1 array to acquire increased-FOV stationary images taken at different gains and fluoroscopic-like videos recorded by scanning the mammogram simultaneously with both sensors. The results show high resolution and high dynamic range images stitched together with minimal adjustments needed. The EMCCD array design allows for expansion to an $M \times N$ array for arbitrarily larger FOV, yet with high resolution and large dynamic range maintained.

I. Introduction

The Electron Multiplying CCDs (EMCCDs) can dramatically suppress readout noise by using on-chip variable electronic-gain, which yields high signal to noise ratio and high dynamic range. We previously demonstrated a single EMCCD imager successfully applied to a medical imaging system and that it provides superior images compared to conventional detectors [1], [2].

The EMCCD sensor used has an $8 \mu\text{m}$ pixel size with a matrix of 1046×1004 , yielding an effective field of view (FOV) of $8 \text{ mm} \times 8 \text{ mm}$. This limits the EMCCD in clinical applications, where much larger FOVs are required. To expand the FOV, we use fiber optic tapers to increase the effective pixel size and FOV by approximately 3 times larger than the inherent EMCCD pixel and FOV. The resulting FOV has been sufficient for a region-of-interest (ROI) imager. Prototype ROI imagers have demonstrated superior x-ray image resolution. However, to be able to use the EMCCD-based detector to cover the full clinical FOV, an array of EMCCD-based modules is being developed.

The front end of the x-ray imaging chain uses a phosphor to convert the x-ray energy into light followed by a fiberoptic taper that optically couples it to the fiberoptic input window of the EMCCD. In this work, we simulate this front end using light from an LED bar array, lenses, and clear glass windows to enable light to reach the array of EMCCDs. The back end consists of output signal processing and the digital image stitching/combining is similar to what would be observed in imaging of x-rays. We can thus assess objective performance parameters such as signal to noise ratio, dynamic range, etc.

II. Materials and Methods

The entire system has been built based on the EMCCD sensor model TC285SPD from Texas Instruments Japan (TIJ). The system includes an FPGA board, power board, driver boards, head boards with the EMCCD, CameraLink board and computer user interface.

Figure 1 below is a picture of the system supporting two EMCCD sensors simultaneously. Details of this module design have been reported previously [3]. The system runs in full resolution mode ($2k \times 1k$ pixels) at 17.5 frames per second with an exposure time of 64 ms.

In order to obtain the optical image, a mammogram film was used to serve as the object. Although the designed EMCCD detectors are capable of dynamic fast frame-rate neuro-vascular imaging, mammography is also one of the most challenging modalities with regard to spatial resolution and dynamic range requirements. A mammographic film provides a very high resolution image to capture so it is a good test of the resolution capabilities of the camera. Figure 2(a) shows an entire mammogram film and Figure 2(b) is the region-of-interest of this film, where the two EMCCD modules will scan it to form a video-like image sequence in the following section.

To enable the two sensors to acquire adjacent areas of the film, two identical focal lenses were used between the sensors and the film. A little overlap of the acquired images in each of the EMCCDs was achieved by carefully align the optical lenses. Instead of moving sensors in one direction to scan the film, a moving stage was used to move the mammogram film. The entire setup was placed on an optical table to ensure experimental accuracy. A diagram of the system setup is shown in Figure 3 below.

III. Results and Discussions

The enhanced dynamic range using EMCCD gains are demonstrated in Figure 4 below. Two $1K \times 1K$ images were stitched together with no further image processing. They represent gains of 1, 10 and 20, respectively.

A slight mismatch between these images is apparent at the border between the two sensors. With these initial images there was no attempt at contrast adjustment or gray-scale matching, yet the image quality is still acceptable. Variations in brightness were noticed due to the non-uniformity of the film illumination.

In order to demonstrate the fluoroscopy-like videos, six frames acquired at a rate of 17.5 frames per second are listed in figure 5 below.

IV. Conclusion

A high resolution dynamic x-ray imager based on EMCCD sensor arrays is demonstrated for the first time. This designed medical imaging system is functional with two EMCCD detectors working together to expand the field of view. The optical tests reveal that the EMCCD 2×1 array needs minimal stitching work and no further imaging processing. The system runs at a 17.5 frames per second and even higher with binning, thus enabling its application in the field of fluoroscopy. This EMCCD array design allows an extension to an $M \times N$ array for an even larger field of view, yet with high resolution and large dynamic range.

Acknowledgments

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Fig. 1.
EMCCD-based high resolution dynamic x-ray imager module, holding two sensors
operating simultaneously.

Fig. 2.
(a) An entire mammogram film. (b) The region-of-interest of the film showing calcified ducts.

Fig. 3. Diagram of the optical testing setup, which includes (from left to right): two EMCCD sensors, focal Lenses, Mammogram film and pulsed LED bar.

Fig. 4.
Same part of mammogram film taken at same light intensity but with different EMCCD gains of 1, 10 and 20 from top to bottom.

Fig. 5.
Asset of images showing calcified ducts from a mammogram as it was moved across the field of view.