Overview

Full GPU Image Processing Pipeline for Camera Applications

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Problem to Solve

Real time image processing

- Industrial cameras with high resolution and high frame rate
- Multiple camera systems
- Broadcasting solutions
- High speed cameras

What is common for all cases: data rate up to ~GPix/s
Image Processing in Realtime

Modern machine vision cameras

- Image sensor resolution from VGA to 30 Mpix
- Frame rate up to 500 fps
- Bit depth: 8 – 12 bits
- High speed interface to PC
- Multiple camera systems
Key Points

- Implementation of full image processing pipeline on GPU for real time camera applications
- We can do that faster and with better quality in comparison with solutions on CPU, DSP, FPGA
- Image Processing SDK from Fastvideo
Possible Solutions for Image Processing

- In-Camera HW processing on FPGA, DSP, CPU
- Image processing on frame grabber
- Image processing on CPU with SSE/AVX
- Image processing on GPU
Basic Image Processing Pipeline

- Image Acquisition
- Preprocessing
- Demosaicing
- Resize / Sharp / OpenGL output
- JPEG compression
Preliminary Stages

- In-Camera HW image processing
- Camera-to-PC data transfer over cables
- Image acquisition on PC side
  - Data transfer to CPU memory
  - RDMA GPUDirect
Image Preprocessing on GPU

- Image data unpacking and rearranging
- Fixed-Pattern Noise subtraction
- Vignetting
- Bad pixels removal
- White balance
Image Demosaicing (Debayer)

Demosaicing means image color interpolation from Bayer image sensor
(input data 8 bits, output data 24 bits)
Performance of Demosaic Algorithms

- Bilinear – bilinear interpolation for each pixel
- HQLI – High Quality Linear Interpolation with 5x5 kernels
- AHD – Adaptive-Homogeneity-Directed algorithm
- DFPD – Directional Filtering with a Posteriori Decision

<table>
<thead>
<tr>
<th></th>
<th>Bilinear</th>
<th>HQLI</th>
<th>AHD</th>
<th>DFPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastvideo on Titan GPU</td>
<td></td>
<td>2400 MB/s</td>
<td></td>
<td>1770 MB/s</td>
</tr>
<tr>
<td>IPP on CPU Core i7 3770</td>
<td></td>
<td>2800 MB/s</td>
<td>14 MB/s</td>
<td></td>
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<tr>
<td>GPU kernel performance</td>
<td></td>
<td>21000 MB/s</td>
<td></td>
<td>6000 MB/s</td>
</tr>
<tr>
<td>SSIM</td>
<td>0.873</td>
<td>0.965</td>
<td>0.968</td>
<td>0.978</td>
</tr>
<tr>
<td>PSNR (dB)</td>
<td>30.4</td>
<td>36</td>
<td>37.4</td>
<td>39</td>
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CUDA JPEG Codec

In 2011 we have created the first fully parallel CUDA JPEG codec.

**Main idea:** JPEG algorithm consists of consecutive stages and it’s applied to blocks 8x8 or 16x16 pixels. Parallel block handling for all stages is a must for fast JPEG codec.

**Key for fast decoding:** presence of Restart Markers in bitstream.

Results for GeForce GTX Titan

JPEG Encoding: 2500 – 5500 MB/s, JPEG Decoding: 2000 – 5000 MB/s
CUDA JPEG results for 580/680/Titan

- Host-to-Device and Device-to-Host transfers are included
- Win-7 (32-bit), NVIDIA drivers 332.21
JPEG and Image Distortion

- JPEG is not always guilty for insufficient image quality
- There are other lossy stages in the pipeline:
  - Preprocessing
  - Demosaicing
  - Denoising
  - LUT
  - Resize / Sharp

Solution: use “visually lossless” JPEG quality 85-100% and always check quality losses for other stages of the pipeline
Combined Demosaic + JPEG

- Data after demosaic are tripled
- Transfer time over PCI-Express bus is important
- Combined solution saves time for CPU-GPU transfers
- Low-quality demosaic is unacceptable

Benchmarks for Demosaic and JPEG Encoder

<table>
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<tr>
<th></th>
<th>1920 x 1080</th>
<th>2048 x 2048</th>
<th>4096 x 4096</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demosaic (DFPD)</td>
<td>1.6 ms</td>
<td>3.0 ms</td>
<td>10.2 ms</td>
</tr>
<tr>
<td>JPEG (90%, 4:2:0)</td>
<td>2.3 ms</td>
<td>3.2 ms</td>
<td>10.5 ms</td>
</tr>
<tr>
<td>Demosaic + JPEG</td>
<td>2.6 ms</td>
<td>3.7 ms</td>
<td>11.7 ms</td>
</tr>
</tbody>
</table>
Final Benchmark on GPU (Titan)

- CMOSIS image sensor CMV20000, 5120x3840, 12-bit, 30 fps
- GeForce GTX Titan GPU
- Host to device transfer ~1.5 ms
- Demosaic ~3.1 ms
- JPEG encoding (90%, 4:2:0) ~7.8 ms
- Device to Host transfer ~1.3 ms
- Total: ~13.7 ms

P.S. This is the benchmark for PCIE camera CB-200 from XIMEA
Camera Applications

- Machine vision and computer vision
- XIMEA solutions – www.ximea.com
- Imperx solutions – www.imperx.com
- Multi-camera image processing on single GPU
- Real time image processing for broadcasting and surveillance
- Video conferencing
- High speed imaging
Non-Camera Applications

- Image processing speedup to image viewers, photo editors
- High performance batch image processing
- Fast resize and thumbnail generation
- Cloud solutions for image processing
- Medical imaging
Solution for Photo Hosting

Task description: load-decode-resize-encode-store

- Image load ~1.5 ms for 2048x2048 jpg image
- JPEG decoding ~3.4 ms
- Downsize to 1024x1024 with bicubic algorithm ~0.7 ms
- JPEG encoding (quality 90%, 4:4:4) ~3.4 ms
- Image store ~1.0 ms
- GPU processing time ~7.5 ms
- Total time ~10 ms
What we could offer to our customers

- Standard SDK
  - Preprocessing functions
  - Demosaic
  - JPEG Encoder and Decoder
- Custom SDK for particular task
- Algorithm design
- Software optimization
More Features of SDK

- Image acquisition module from a camera
- GPU Direct option to get images on GPU from a camera
- Unpacking module for various raw formats
- Wavelet denoising
- Color correction
- Image tiling and batch processing
- Crop/Resize/Sharp and pyramid images
- OpenGL output
- MJPEG integration with FFMPEG
Long Term Strategy

- More image processing algorithms in our SDK
- More complicated parallel algorithms with higher quality
- JPEG2000 and more lightweight custom codecs
- Code optimization, use of the latest GPUs and APIs
- Parallel algorithm design and implementation
Links & Contacts

- Fastvideo site for GPU image processing - www.fastcompression.com
- Contacts: info@fastcompression.com

Camera manufacturers with GPU image processing software

- XIMEA GmbH – www.ximea.com
- Imperx Inc. – www.imperx.com