Recent Advances in Smartphone Computational Photography

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Smartphone Photography

- Physical limitations
  - Small sensor
  - Limited optics
  - Usually no optical zoom
- User expectations
  - Speed
  - Ease-of-use
New Computational Photography Techniques

Handheld super-resolution
Uses natural hand movement to improve resolution in burst images

Handheld low-light photography
A system of new techniques using burst imaging to improve phone photography in very low light
Background
Burst Photography

- Series of raw exposures merged together
- Zero-shutter-lag mode
  - Frames continuously captured
  - Recent frames saved when shutter button pressed
- Hasinoff et al. [1] burst processing pipeline
  - Bursts of constant low-exposure frames
  - HDR+ feature
Handheld Super-Resolution
Animation demonstrating hand motion in a raw burst [6]
Hand Movement

- Hand movement produces subpixel offsets
- Pixels in each frame can be considered samples of “true” value
Animation demonstrating hand motion in an aligned burst [6]
Merge Algorithm Overview

RAW Input Burst → Kernels → Accumulation → Merged Result

Motion Robustness
Kernel reconstruction algorithm

- Each output pixel is a result of a combination of the pixels in a $3\times3$ area around it
- Weighted based on the presence of edges and sharp features
Exaggerated example of very sharp kernels on a real captured burst [4]
Merge Algorithm Overview

RAW Input Burst → Kernels → Accumulation → Merged Result

Motion Robustness
Motion Robustness

- Alignment of burst images isn’t perfect
- Motion in the scene and occlusion
- Need to consider motion when merging to prevent artifacts

- Confidence level assigned to neighborhood of each pixel with statistical robustness model
A photograph of a moving bus demonstrating the robustness model [4]
Merge Algorithm Overview

RAW Input Burst

Kernels

Motion Robustness

Accumulation

Merged Result
Google Pixel 3 XL - 2.37x zoom [5]
Left: Crop of 7x zoomed image on Pixel 2. Right: Same crop from Super Res Zoom on Pixel 3. [5]
Handheld Low Light Photography
Handheld Low Light Photography

● Builds on Hasinoff et al. [1] burst pipeline
● Uses “handheld super-resolution” merging in most cases
● Night Sight feature on Google Pixel
● Positive-shutter-lag
● 3 main improvements to the pipeline
  ○ Motion metering
  ○ Auto white balance
  ○ Tone mapping
Handheld Low Light Photography

Motion metering → Burst capture → Super-resolution merge → White balance → Tone mapping → Final image
Motion Metering

- Target brightness
- Exposure time, gain (ISO), and number of frames needs to be selected for the shot
  - Exposure time increases motion blur
  - Gain increases noise
- Motion metering selects exposure time based on motion in scene and camera
Traditional static exposure schedule compared to motion metering [3]
Comparison of exposure schedules with subject motion [3]

Static exposure schedule
100 ms exposure

Dynamic exposure schedule
49 ms exposure (motion: 0.38 pix/ms)
Comparison of exposure schedules with subject motion [3]

**Static exposure schedule**
- 100 ms exposure

**Dynamic exposure schedule**
- 49 ms exposure (motion: 0.38 pix/ms)
Handheld Low Light Photography

1. Motion metering
2. Burst capture
3. Super-resolution merge
4. White balance
5. Tone mapping
6. Final image
Auto white balance

- Humans are good at color constancy
- We perceive color accurately even under colored illumination
- Breaks down when the light in a photo is different than the light it is being viewed in

- Cameras use **auto white balancing (AWB)** to correct this
- Adjust the colors to compensate for illumination color

- Low light scenes often have very tinted illumination
Liba et al. [3] trained a neural network based AWB algorithm

- New set of 5000 examples
- Manually tagged white balances by experts
- “Aesthetically preferable” vs empirical
Comparison of the default white balance in the Pixel and the low-light optimized implementation (Marc Levoy) [2]
Handheld Low Light Photography

Motion metering → Burst capture → Super-resolution merge → White balance → Tone mapping → Final image
Tone Mapping

- Mapping colors from high-dynamic-range image to a medium with lower dynamic range
- Can be accurate to human vision or more creative
- Humans stop seeing color and lose spatial acuity in low light
- How can we create sharp, colorful low-light images that still look like nighttime?
Yosemite valley at nighttime, Canon DSLR, 28mm f/4 lens, 3-minute exposure, ISO 100 (Jesse Levinson) [2]
Tone Mapping

Artists evoke a nighttime aesthetic with

- Darker pigments
- Increased contrast
- Suppressed shadows

A Philosopher Lecturing on the Orrery, by Joseph Wright of Derby, 1766
Tone Mapping

Liba et al. [3] adapted these principals into a set of heuristics for their tone mapping

- Higher overall gains
- Limit boosting shadows
  - Keep darkest regions near black
- Boost color saturation inversely to scene brightness
Comparison of tone mapping techniques [3]

Baseline

CLAHE

Liba et al.
Handheld Low Light Photography

- Motion metering
- Burst capture
- Super-resolution merge
- White balance
- Tone mapping
- Final image
iPhone XS

Pixel 3 Night Sight
Conclusions
Conclusions

- Software first photography
- Google Pixels have had same main camera sensor for last 3 generations
- New camera features get released on old hardware
Thanks

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Questions
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References


