HDR videos acquisition

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How to capture?

- Videos are challenging:
  - We need to capture multiple frames at different exposure times
  - … and everything moves
How to capture?

- Different technologies based on exposure bracketing:
  - beam-splitter; i.e. many sensors one lens
  - stereo/multi-view HDR capturing
  - varying exposure per pixel; i.e. bayer pattern
  - varying shutter speed
Multi-sensors cameras

- **Idea**: to use more sensors to capture the same scene

- The light path is divided using beam splitters:
  - careful alignment
Multi-sensors cameras
Multi-sensors cameras

- Debayering after HDR-merging
  - why not before?
    - It can corrupt colors in saturated regions
    - It makes less visible sub-pixel misalignments of sensors
Multi-sensors cameras

Multi-sensors cameras

• Advantages:
  • no ghosts
  • no misalignments

• Disadvantages:
  • high costs: sensors + calibration
  • fixed dynamic range that can be captured
  • reconstruction before debayering: complex reconstruction algorithms
Multi-cameras systems

- **Idea**: to use more cameras in a rig to capture the same scene:
  - each camera has a different shutter-speed/ISO
  - A synchronization system is required
Multi-cameras systems

Camera

Linear pattern

Square pattern
Multi-cameras systems: Geometric Calibration

- Geometric calibration of each camera:
  - Intrinsic parameters: optical center, focal length, pixel size in mm, field of view (angle), and aspect ratio.
  - Extrinsic parameters: world position: position and rotation
Multi-cameras systems: Alignment

• There is the need to align other images onto a reference image (well-exposed one again!)

• How?
  
  • Compute disparity map

  • Warp images
Multi-cameras systems: Disparity Computation

$$SSD(u, v, d) = \sum_{k=-n}^{n} \sum_{l=-m}^{m} \left( I_1(u + k, v + l) - I_2(u + k + d, v + l) \right)^2$$

$$d_\circ(u, v) = \arg \min_d SSD(u, v, d)$$

**Note:** typically $n = m$
Multi-cameras systems: Disparity Computation
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: Disparity Computation
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: Disparity Computation

$I_1$

$I_2$
Multi-cameras systems: disparity computation

http://vision.middlebury.edu/stereo/data/
Multi-cameras systems: disparity computation

http://vision.middlebury.edu/stereo/data/
Multi-cameras systems: warping

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Multi-sensors cameras

• Advantages:
  • no ghosts

• Disadvantages:
  • misalignments + occlusions
  • high costs: sensors + sync
  • fixed dynamic range that can be captured
Varying exposure per pixel

- **Idea**: to apply bayer pattern not only for RGB colors but also to exposure

- Two possible solutions:
  - varying gain
  - a mask with varying neutral density filters:
    - shutter time is not modified!
Varying exposure per pixel

interleaved rows

checkboard pattern
Varying exposure per pixel
Varying exposure per pixel
Varying exposure per pixel: reconstruction

$\hat{Z}$

$Z_o$

$Z_r$
Varying exposure per pixel: reconstruction

\[ \hat{Z} \]

\[ Z_o \]

\[ Z_r \]
Varying exposure per pixel: reconstruction

- How can reconstruction be carried out?
- Linear interpolation can lead to artifacts
- Cubic interpolation; close to ideal sinc:

\[
Z_r(x, y) = \sum_{i=0}^{3} \sum_{j=0}^{3} f(1.5 - i, 1.5 - j)Z_o(x - 1.5 + i, y - 1.5 + j)
\]
Varying exposure per pixel: reconstruction

Let’s see the matrix form:

\[ Z_r = FZ_o \]
\[ \hat{Z} = FZ_o \]
\[ Z_o = F^{-1}\hat{Z} \quad F^{-1} = F^T(FF^T)^{-1} \]
Varying exposure per pixel
Varying exposure per pixel
Varying exposure per pixel
Varying exposure per pixel

• Advantages:
  • low cost hardware: programmable videocameras; e.g. Canon DSLR with Magic Lantern
  • no ghosts
  • no misalignments

• Disadvantages:
  • limited to 2-3 exposure images
  • masks may be expensive to manufacture and difficult to align to an existing bayer pattern
Varying Shutter Speed

• **Idea**: to program the shutter speed or ISO; i.e., varying it at each frame

• Requirements:
  
  • high frame rate videocamera
  
  • programmable hardware
Varying Shutter Speed

Courtesy of Jonas Unger
Varying Shutter Speed: reconstruction

• There is the need to align other images onto a reference image (well-exposed one again!)

• How?

  • Compute Motion Estimation

  • Warp images
Varying Shutter Speed: Motion Estimation

\[ I_t(i, i) = I_{t+1}(i + u, i + v) \]
Varying Shutter Speed: Motion Estimation

$$SSD(i, j, u, v) = \sum_{k=-n}^{n} \sum_{l=-m}^{m} \left( I_1(i + k, j + l) - I_2(i + k + u, j + l + v) \right)^2$$

$$OF_o(i, j) = \arg \min_{u,v} SSD(i, j, u, v)$$

Note: this is a generalization of the disparity problem
Varying Shutter Speed: Motion Estimation

Image courtesy of Jonas Unger
per block motion estimation
Varying Shutter Speed: Warp

Image courtesy of Jonas Unger
Varying Shutter Speed: Warp

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Image courtesy of Jonas Unger
Varying Shutter Speed: Warp

• Advantages:
  • low cost hardware: high frame rate and programmable videocameras; e.g. Canon DSLR with Magic Lantern

• Disadvantages:
  • limited to 2-3 exposure images
  • moving camera and scene:
    • camera alignment
    • moving scene
Questions?