Light field Capture, Modeling, Compression and Display

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Outline

• Light field concept
  – Introduction & properties
  – Parameterization
  – Capture
  – Epipolar images (EPIs)
• Parameterization of light field (light field analysis)
• Light field compression
• Rendering and display
Light field

• Function describing the amount of light in every point in space and in every direction
• Most completely described by the continuous 7-D Plenoptic Function $P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$
  – $(V_x, V_y, V_z)$ – location in 3D space
  – $(\theta, \phi)$ – angle
  – $\lambda$ – wavelength
  – $t$ – time
Light field

- 7-D Plenoptic Function is not very practical due to large amount of data
- Adding simplifications & assumptions
  - Light wavelength ($\lambda$) can be replaced by RGB
  - Time (t) can be dropped if static scenes are considered
  - We do not need 360 degree light field
  - Sampling parameters
  - Air is transparent - radiance along any ray stays constant

4-D function
Light field

- 4-D Function $L(u,v,s,t)$
Light field

- Parameterization benefits
  - Reduces dimension and size of data set
  - Uniform sampling  – efficient calculation
  - “Straightforward” mitigation of aliasing artifacts (inter-perspective aliasing, spatial aliasing)
  - Various other light field models (e.g. concentric mosaix)

- Still many open questions
  - Reconstruction of ’missing’ views
  - Artifact mitigations
  - Etc...
Light field capture

- Arrays of cameras
- Combination of cameras and depth sensors
- Plenoptic cameras
Epipolar images

• Capture scenario → Array of $N$ (by $M$) cameras

$N=7$
Epipolar images

- $N$ images, each with resolution $R_x$ by $R_y$

- Stack images on each other – cube $N$ by $R_x$ by $R_y$
Epipolar images

7 cameras

600 cameras

1

7

???
Epipolar images - properties

- Objects (points) in the scene are converted to lines
- Slope (gradient) of the line is related to:
  - Distance to the objects
  - Camera resolution
  - Number of cameras

Regular structure – convenient for analysis in the frequency domain
Epipolar images - properties

- Two extreme cases:
  - Object at infinity – Vertical line in EPI
  - Object (almost) at camera plane – (almost) Horizontal line in EPI

- All other objects result in lines between those two extremes
**Frequency domain analysis**

- Frequency support vs. depth of the scene
  - infinite number of cameras and infinite resolution

\[ f/d\Omega \downarrow v + \Omega \downarrow t = 0 \]
Frequency domain analysis

- Finite number of cameras with finite resolution
Light field modeling and compression in PROLIGH project

• Goal
  – Light field representation of a scene
    • Completeness of the scene
    • Amount of required data
    Compromise!

• Outcome
  – Tools for ‘manipulating’ light fields tailored to different stages of light field processing

• Divided into two tasks
  – Task 2.1 Parameterization of light field (Light field analysis)
  – Task 2.2 Light field compression (coding)
Parameterization of light field (Light field analysis)

- Finding the best representation of the light field, under given conditions, that enables a distortion-free representation of the scene under consideration.

  - What is the "best" representation?
  - Which conditions?
  - Without any distortions?

Compact data  
Fast processing  
Progressive coding

Lambertian space  
Occlusion free  
Limited depth

Finite pixel size  
Numerical precision  
Aliasing
Parameterization of light field (Light field analysis)

• Traditional approach

• Planned approach
  – Considering the light field representation and processing methods simultaneously

• Tailored vs. generalized light field models
  – Deriving relevant signal processing methods
Light field compression

- **State of the Art**
  - Compressing multiview content (not light field)

- **Planned approach**
  - Directly compressing the light field
  - Developing hybrid-type multi-dimensional decorrelation transforms for light fields (e.g. in EPI type domain)

- **Efficient compression methods**
  - Holografika displays – taking into account rendering requirements
3D Display technologies – Light Field

• The goal of displaying is to provide perfect representation of real/synthetic scenes
  – life-like view
  – the ultimate display will be like a window...

• True 3D displaying - reconstructing the **light-field** as present in the natural view
  – producing light beams with the same parameters the human perception is capable to process: direction, position, intensity, color (**but polarization, phase**)  
  – „…Let the display work, not the brain…”
3D Display technologies – Light Field

• General representation of 3D information that considers a 3D scene as the collection of light rays that are emitted or reflected from 3D scene points. (M. Levoy, and P. Hanrahan, “Light Field Rendering”, 1996.)

• The visible light beams are described with respect to a reference surface (screen) using the light beams’ intersection with the surface and angle.

• The LF is defined as a function of position (2 parameters) and direction (2 parameters): $L(x,y,[z],\Theta,\Phi)$
3D Display technologies - basic rules

- Additional independent variant to X, Y : Φ
  - emission range - FOV
  - number of independent beams in the range – Angular resolution (φ) determining FOD

\[
\text{FOV} / n = \phi
\]

- Vertical / horizontal parallax
  - reducing the number of beams by omitting the vertical parallax
  - systems with different horizontal and vertical angular resolution – HOP systems
3D Display technologies - basic rules

- Direction selective light emission
  - Common for all systems having a screen, (also for the outer surface of volumetric systems)
  - 3D displays always have some optical means

- General approach: to create a light emitting surface to emit different light beams from each point in a controlled way - defining the output
  - Diffractive or refractive manner
3D Display technologies - basic rules

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HoloVizio system

- Optical modules
  - project light beams to hit the points of a screen with multiple beams under various angles of incidence

- Holographic screen
  - direction selective property
  - the screen diffusion angle $\delta$ is equal to the angle $\gamma$ between the neighboring modules

- Emission angle geometry determined
  - no optical road-blocks like at Fresnel, or lenticular lenses
The HoloVizio System

• Horizontal-only-parallax arrangement
  – Omitting the vertical parallax, win a factor of 102
  – The modules are arranged horizontally and the screen have asymmetric diffusion character

• Screen
  – Hologram screen, precise hat-shaped highly-selective diffuse profile eliminates crosstalk and provides proper intensity uniformity
The HoloVizio System

- Light field reconstruction instead of views
- Specific distributed image organization
  - A module is not associated to a direction
    - The projected module image not a 2D view of the final 3D image
  - Each view of the 3D image comes from more modules
    - The number of contributing modules does not change over the FOV (no point in the FOV where only one single module image would be seen, like at multiview)
  - Distributed changes within the 3D image on different image areas
    - Smooth and continuous transition, no single border occur between views
    - Continuous motion parallax
Light-field displays
HoloVizio displays

• The HoloVizio monitors
  – **HoloVizio 128 WD, WLD**
    10 Mpixel, 32" (16:9)
  – 50 degrees FOV
  – angular resolution 0.8 degrees
  – 2D equivalent image resolution
    512x320
  – up to 4 DVI inputs
HoloVizio displays

- The large-scale HoloVizio systems
  - **HoloVizio 640RC, 720 RC**
    - 50 Mpixel, 72”, (16:9)
  - 50–70 degrees FOV
  - angular resolution 0.9 degrees
  - 2D equivalent image resolution
    - 1344x768
  - Dual Gigabit Ethernet input
  - Control system+PC based render cluster
HoloVizio displays

- The digital signage HoloVizio kiosk system
  - **HoloVizio 240P**
    - 11,5 Mpixel, 45” standing format
  - 40 degrees FOV
  - 2D equivalent image resolution 600 x 800
  - LED colors
  - Gigabit Ethernet input
  - Control system + 3 PC
  - Easily adaptable for various installations
HoloVizio Cinema System

- The world first glasses-free 3D cinema system
  - HoloVizio C80
    - 3.5 m reflective holoscreen (140")
    - 63 Mpixels
    - LED based 3D projection unit
    - exceptional 1500 Cd/m² brightness
    - 40 degrees FOV
    - PC based render cluster
    - no perspective distortion
    - 2D compatible
    - fitting cinema rooms, 3D simulators
    - also with portable mechanics for event rental
HoloVizio displays

- The full-angle HoloVizio monitor
  - **HoloVizio 80WLT**
    - 78 Mpixel, 30” (16:10)
    - ~180 degrees FOV
    - total freedom 3D experience, no invalid zones, no repeated views
  - 2D equivalent image resolution
    - 1280 x 768 (WXGA)
  - LED colors
  - Multiple DVI inputs
Professional applications

- Oil & gas – exploration, geological data visualization → no-glasses, true 3D tool
- Medical – surgical planning → authentic visualization
- Museums, Edutainment, Entertainment, Theme parks → real 3D, interactions
- Military, Security, Simulation, Air traffic control → enhanced information content
- Event rental → visually striking appearance
- Scientific visualization, VR → precise displaying of large 3D datasets
- CAD – automotive, molecular → collaborative use
- 3D Telepresence → realistic feeling of presence, direction selective communication in multiplayer scenarios, eye contact
Viewing angles of 3D display technologies

- 2 View Stereoscopic: 6-8°
- Multiview
- HoloVizio: 70-180°