**Augmentation using projectors**

Vorlesung „Augmented Reality“  
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**Ein Generisches AR-System**

- **Sensorik**
- **Realität**
- **Tracking** (Ortsbestimmung)
- **Virtualität**
- **Rendering und Realitätserweiterung**
- **Feedback an Benutzer**
- **Einbeziehung der Ortsinformation in virtuelle Welt**
- **Kombination realer und virtueller Inhalte**
Augmentation using projectors

- Projectors and their working principles
- Using projectors as shader lamps
- Combining two projectors
- Steerable projectors
- Projection on structured surfaces
- Combining many projectors

Projectors

- Key Criteria
  - Resolution
  - Brightness
  - Weight
  - Noise
  - Lens
  - Image correction
  - Projection distance
  - Connections
  - Lamp life time

- E.g. Toshiba TLP-T720U
  - Wireless 802.11B

- E.g. WiJET
  - [http://www.otcwireless.com/802/wijet.htm](http://www.otcwireless.com/802/wijet.htm)
**CRT projector**

- Use R, G+B CRTs as light sources
- Good black areas
- Low brightness
- Fast
- Need to calibrate convergence!

[www.projektoren-datenbank.com/rohre.htm](http://www.projektoren-datenbank.com/rohre.htm)

**LCD projector**

[www.projektoren-datenbank.com/lcd.htm](http://www.projektoren-datenbank.com/lcd.htm)

[www.projectorpoint.co.uk/projectorLCDvsDLP.htm](http://www.projectorpoint.co.uk/projectorLCDvsDLP.htm)
DLP projector

DLD projector (movie)

http://www.dlp.com/
Technological side effects

- Screen door effect
  - Caused by LCDs
  - Less prominent in DLP

If a DLP projector is moved, color seams appear.

Lens shift

- Optical construction
- No loss of resolution
Keystone correction

- Computed correction
- Loss of resolution!

Shader Lamps: Basic Idea

Rearranging terms in optical path

Plain Light

Checkered Light

Checkered Surface

Plain Surface
Image based Illumination

- Basic Idea
  - Render images and project on objects
  - Multiple projectors
  - View and object dependent color

Shaderlamps: Example
Problem: shadow areas  
Solution: two projectors

Every visible surface must be illuminated by at least one lamp (projector)

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Projector alignment

- Position projector roughly
- Adapt to geometric relationships between physical objects
- Take fiducials on physical object and find corr. projector pixels
- Compute 3x4 projection matrix
- Decompose into intrinsic & extrinsic projector params
Occlusion and Overlaps

• Several problems:
  – No color equivalence between two projectors (manufacturing & temperature color drift)
  – Minimize sensitivity to small errors in calibration parameters or mechanical variations

• Relatively good solution: Feathering

Feathering

• Normally the overlap region is a well-defined contiguous region
• Intensity of every pixel weighted proportional to Euclidian distance to nearest boundary pixel of image
• Weights in range $[0,1]$ multiplied with intensities in the final image
Feathering

1. Sum of intensity weights of projector pixels is 1 ➔ Intensities normalized
2. Weights along physical surface change smoothly in and near overlaps ➔ suppress discontinuity due to color differences
3. Smooth distribution of intensities per projector ➔ suppress sharp edges due to small errors in calibration or mechanical variations
Feathering

- Non-convex objects
- Collection of disjoint objects
- Shadows
- Fragmented overlaps
- Depth discontinuities

Feathering

- Find regions illuminated by one projector and assign weight=1
- Use shortest euclidian distance to a pixel with weight=1 to compute weight
Examples

- Objects illuminated by direct and indirect light
- Parts of an object can scatter light onto other parts of object and other objects
- High computational effort to calculate correctly
- Often approximated by „ambient light“
- Comes for free with shaderlamps!

Radiosity

- Objects illuminated by direct and indirect light
- Parts of an object can scatter light onto other parts of object and other objects
- High computational effort to calculate correctly
- Often approximated by „ambient light“
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Limitations

- Must have neutral physical surface (white, pure diffuse color)
- Dark ambient lighting
- Secondary scattering makes it difficult to mimic low reflectance surfaces
- Projectors have limited depth of field, reduced dynamic range and non-uniformity
- Shadows can disturb the view

Example
Example

Implementation

• 2 Projectors with 1024x768 resolution
• Rendering with OpenGL
• Vase 12 cm x 12 cm x 35 cm
  – 7000 Triangles
• Taj Mahal 70 cm x 70 cm x 35 cm
  – 21 000 Triangles
  – 15 Texture Maps
• Calibration about 5 min per projector
• Re-projection error less than 2 Pixels
• Intensity weights computation in preprocessing
  (10 sec per projector)
• Application of weights with alpha-blending
Setup

Cartoon Dioramas in Motion
Painting on Movable Objects

http://www.cs.unc.edu/~debug/papers/DSLpaint/

- Objects hand-held or set on table.
- Tracked stylus with spherical tip
  - facilitates contact painting
- Projected touch palette, modeled as a static object with behavior:
  - choose contact, spray or texture paint
  - choose brush color

Dynamic Shaderlamps: Setup
Dynamic Shaderlamps: Video

Everywhere Display Projector (IBM)


Claudio Pinhanez

www.research.ibm.com/ed/
Everywhere display (cont.)

Output: a projector and a rotating mirror
Input: a camera for interaction, NOT for image rectification!

Undistorting the projected image

- Place original image in the 3D model
- Virtual camera image shows it distorted
- Project the distorted image from 3D model with the Real projector into the real world

- Distortions cancel each other out IF virtual camera and real projector are in the same location
Everywhere display (cont.)

- Correct distortions
  - Use the fact that camera and projectors are geometrically the same (optically inverse)

- Use standard HW components
  - 3D-Graphics board and VRML-world

![Diagram of Everywhere display](image)

BLUESPACE office scenario
Everywhere display (cont.)
Collaborative experience at SIGGRAPH 2001

**Video**

Everywhere display (cont.)
Other Applications

SearchLight: Basic Idea

- Build a search function for physical objects
- A tool for directing the user’s attention
- No 3D model of the environment

Ideas for realization:
- Optical markers for object recognition
- Highlighting by a projected spot

Step 1: Room Scanning

- Projector/camera unit moving and taking pictures
  - Until the whole room is covered
  - Neighbouring pictures slightly overlap
- Recognized marker IDs are stored with:
  - pan/tilt values when taking the picture
  - position of the marker in the picture
Step 2: Showing objects

- Retrieve object's marker ID
- Move unit to stored pan/tilt position
- Project a spot around the marker's position

Smart Projectors
[Oliver Bimber et al., IEEE Computer, January 2005]

- Projection onto curved surfaces can be solved by 3D rectification, ...but:
- What if the projection surface is not uniformly colored?
- See Video (scientific) or Video (TV)
Luminance Attenuation Map
[Majumder & Stevens, VRST 2002]

• Large display wall with 5x3 projectors
• Linear ramps (feathering) don’t work perfectly
• Goal: get rid of the remaining unevenness
• Strategy: don’t assume, but measure!

Calibration step

• Measuring the Luminance Response: The luminance response of any pixel is defined as the variation of luminance with input at that pixel. We measure the luminance response of every pixel of the display with a camera.

• Finding the Common Achievable Response: We find the common response that every pixel of the display is capable to achieving. The goal is to achieve this common achievable response at every pixel.

• Generating the Luminance Attenuation Map: We find a luminance attenuation function that transforms the measured luminance response at every pixel to the common achievable response.
**Measured luminance response**

- Gives a factor for multiplication of the final images (just as in feathering)
- Can be done in graphics hardware via alpha channels

**LAM: results**
PixelFlex2
[Raij, Gill, Majumder, Towles, Fuchs, ProCams 2003]

- Uneven brightness and arbitrary geometry:
  - Rectify each projector by calibrating 4 points
  - Used LAMs for brightness
**Graphic Shadow**
[Kato et al. Ismar 2003]

- Creative use of two projectors and a camera:
- Can remove physical shadows
- Can add artificial shadows
- Can animate shadows
- See video

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**What we saw today**

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Info-Veranstaltung Hauptstudium

- Informationsveranstaltung zum Hauptstudium für Studierende der Medieninformatik ab 5. Semester und für andere Studierende der Informatik mit Interesse an der LFE Medieninformatik
- Themen f. Proj.- & Diplomarbeiten
- Termin: Di, 5.12., 16 Uhr c.t. (ca. 1h)
- Raum: C 112, Theresienstr.