Stereoscopic Imaging

EECS 208
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Overview

• Stereo Geometry
  – Rendering
  – Methods
  – Parameter

• Stereo Techniques
  – Anaglyph
  – Passive Stereo
  – Active Stereo
  – Auto Stereo Display

• Implementation
• Stereoscopic depth cues
  – Convergence
  – Binocular Parallax

• What are the limits / standard parameters?
  – What visual system will tolerate conflicting to what degree?
    • accommodation vs. convergence, ….
Stereo Geometry (Rendering)

• **Toe-in method (Incorrect)**
  
  - cameras have a fixed and **symmetric aperture**.
  - each camera is pointed at a **single focal point**.
  - The **vertical parallax introduced** will increased discomfort level (important as the camera aperture increases)

Popular for the lower cost filming because offset cameras are uncommon and it is easier than using parallel cameras
Stereo Geometry (Rendering)

- **Off-axis** method (Correct)
  - correct way to create stereo pairs
  - introduces no vertical parallax
  - less stressful stereo pairs
  - requires a non symmetric camera frustum (supported by OpenGL)
Stereo Geometry (Rendering)

- Dependencies
  - Objects that lie in front of the projection plane (PP) will appear to be in front of the computer screen.
  - Objects that are behind it will appear to be "into" the screen.
  - Generally, it's easier to view stereo pairs of objects that recede into the screen (but more dramatic when the object pops out).
  - Stereo effect depends on both the distance of the camera to the projection plane and the separation of the left and right camera.
Stereo Geometry

• Positive Parallax
  - projections are on the same side as the respective eyes
  - object is behind the projection plane
  - maximum positive parallax occurs when the object is at infinity, at this point the horizontal parallax is equal to the interocular distance.

Horizontal parallax = distance between projection
Stereo Geometry

• Negative Parallax

  – projection for the left eye is on the right and the projection for the right eye is on the left
  – a negative horizontal parallax equal to the interocular distance occurs when the object is half way between the projection plane and the center of the eyes
  – If object moves closer to the viewer the negative horizontal parallax increases to infinity.
Stereo Geometry

- Zero Parallax
  - object lies at the projection plane (physical distance) then its projection onto the focal plane is coincident for both the left and right eye, hence zero parallax
Stereo Geometry (Rendering)

- **Setup Parameters**
  - generally the maximum separation for comfortable viewing - 1/20 of the distance \(d\) to the projection plane.
  - ensure the negative parallax (projection plane behind the object) does not exceed the eye separation.
  - A common measure is the parallax angle \(\theta\) (For easy fusing, \(\theta\) should not exceed 1.5 degrees).
  - ! Note
    - \(\theta > 0\) for points behind PP
    - \(\theta < 0\) for points in front of PP

\[
\theta = 2 \tan^{-1}\left(\frac{DX}{2d}\right)
\]

\(DX\) is the horizontal separation of a projected point.
Stereo Techniques (Anaglyph)

Typical Setup

Demo Anaglyph
Stereo Techniques (Anaglyph)

• **Approach**
  – scene needs to be **rendered twice**, once for each eye position
  – resulting images need to be **filtered** and combined
  – **small things** that need to be **changed** in an existing OpenGL program in order to support anaglyphs.

• **Disadvantage**
  – We **lose the color** information
  – High **cross talk** (Ghosting) of information’s between left and right image. Far from the quality of passive or active projection.

• **Advantages**
  – **Easy** to produce
  – **No expensive** hardware required
Stereo Techniques (Passive Stereoscopy)

- **Linear Polarization**
  - Affected by head movement

- **Circular Polarization**
  - Additional quarter-wave filter
  - More expensive glasses and filter
Stereo Techniques (Passive Stereoscopy)

- **Approach**
  - Stereo pair are rendered
  - Hardware *splits the pairs with filters*
  - Recombination of the image with filter glasses

- **Advantage**
  - Cheap solution for bigger audience (Theater, …)
  - Allow color viewing.

- **Disadvantage**
  - Less robust & usable in interactive environments
  - Reduced brightness through filtering
Stereoscopic Imaging

Part II
Overview Stereo Techniques
(Active Stereoscopy)

- Interlacing
- Line-Blanking
- Page-Flipping
- Sync-Doubling
Interlacing

- Derived from TV standard
  - NTSC and PAL use interlacing

- Odd and even scan line separation
  - 1, 3, 5, 7,... and 2, 4, 6, 8,...
    (Odd Field)   (Even Field)

- V-Sync is used to control shutter glasses
  - odd = left eye
  - even = right eye
Interlacing

• **Approach**
  – Both the left and right *fields are stored together* as every other line in the *frame buffer* as a single image.
  – The combined (interlaced) image is output to the monitor as two scans of every other line, *each field* is displayed *separately*.

• **Problems:**
  – Some video cards won't switch to interlace mode.
  – You only get *half vertical resolution*.
  – Poor image quality on low cost systems.

• **Advantages:**
  – relatively *simple* software-wise to implement.
  – *Hardware* can be relatively *simple*
  – very *easy to display* stereo images by using 3D interlaced images (such as appropriately generated gifs)
Line Blanking

- Uses processed scan-line frames
  - blank-even
  - blank-odd
- V-sync for shutter glasses
- Vertical resolution is reduced
Line Blanking

• **Approach**
  – A row-interleaved 3D image is displayed by the video card in progressive-scan video mode (i.e. not interlaced-scan)
  – *dongle* between VGA adapter and Monitor actively blacks out alternate lines of the video signal.
  – The dongle usually also *drives* a pair of Shutter glasses.

• **Problems:**
  – *Half* vertical *resolution*
  – Dongle hardware is relatively *complicated*

• **Advantages:**
  – relatively *simple* software-wise to implement.
  – can be used with *video cards* which won't switch into an interlaced video mode
  – very easy to display stereo images by using 3D row-interleaved images (such as appropriately generated gifs)
Page Flipping

- Alternating left-eye right-eye images
- V-sync controls shutter glasses
- 120 Hz v-scan frequency desired
  - 60 fps
  - avoid flickering
- Quad-buffering
Page Flipping

• Approach
  – uses a Video Adapter that can quickly alternate between frame buffers that each contain an entire field
  – left and right fields are stored in a high-performance video adapter that can rapidly switch the display between the two views

• Problems:
  – Your video card needs to support page flipping in the BIOS, or you need a resident device driver to do the page flipping.
  – Your video card memory will need to accommodate two images (the left and right) to allow the page flipping to occur. [not a problem with modern video cards].

• Advantages:
  – Glasses hardware can be relatively simple
  – full vertical resolution.
Sync-Doubling

- **Split image (on screen)**
  - top-bottom
  - Use external device to get double sync. signal

- **Insert additional frame v-sync**
  - images will be "expanded" and "fused" in the screen

- **Doubles original v-sync frequency**
Sync-Doubling

• **Approach**
  – dividing existing screen into halves (the top half and the bottom half).
  – After video card generates its normal video signal, an external black box adds an extra vertical sync pulse to the video signal (at the vertical mid-point of the screen).
  – monitor will now see the video signal differently from before and will display the first half of the video signal as a full screen image

• **Problems:**
  – Half vertical resolution
  – Hardware is relatively complicated
  – **Software** needs to be smart to maintain compatibility with existing graphical user interfaces (like Windows).
  – images need to be squashed vertically before writing to video memory.

• **Advantages:**
  – software is relatively simple (apart from compatibility with GUIs).
  – you don't need a high speed video card to display flicker-free stereoscopic images.
Stereo Techniques (Auto-Stereo)

- **Auto stereo**
  - No glasses needed
  - Limited viewing angle (works only in specific regions)
  - Can be combined with tracking system.
  - Expensive

![Auto Stereo Monitor](image)
Comparison of different 3D stereoscopic visualization techniques

<table>
<thead>
<tr>
<th>Technology</th>
<th>Color information</th>
<th>Resolution</th>
<th>Suitable for projection</th>
<th>Monitor based visualization</th>
<th>Number of observers</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaglyph</td>
<td>complete lose</td>
<td>middle</td>
<td>yes</td>
<td>yes</td>
<td>high</td>
<td>very low</td>
</tr>
<tr>
<td>Active stereoscopy</td>
<td>full</td>
<td>high</td>
<td>yes</td>
<td>yes (no LCD)</td>
<td>restricted</td>
<td>high</td>
</tr>
<tr>
<td>Passive stereoscopy</td>
<td>full</td>
<td>high</td>
<td>yes</td>
<td>no</td>
<td>high</td>
<td>middle</td>
</tr>
<tr>
<td>Autostereoscopic monitor</td>
<td>full</td>
<td>middle</td>
<td>no</td>
<td>yes</td>
<td>very restricted</td>
<td>high</td>
</tr>
</tbody>
</table>
gluPerspective(fovy, aspect, near, far) vs. glFrustum(left, right, bottom, top, near, far)

What we have:

- near
- far
- focal length
- width
- height
Calculating the Viewing Frustum

Mono (Top View)

- focal length
- width
- near
- far
- Projection plane
- left
- right
- \( (0,0,0) \)

- \( \text{aspect ratio} = \frac{\text{width}}{\text{height}} \)
- \( \tan\left(\frac{\text{fovx}}{2}\right) = \frac{\text{width}/2}{\text{focal length}} \)
- \( \tan\left(\frac{\text{fovy}}{2}\right) = \text{aspect ratio} \times \tan\left(\frac{\text{fovy}}{2}\right) \)
- \( \text{left} = \text{right} = \text{near} \times \text{aspect ratio} \times \tan\left(\frac{\text{fovy}}{2}\right) \)
Calculating the Viewing Frustum

Mono (Side View)

\[ \text{aspect ratio} = \frac{\text{width}}{\text{height}} \]

\[ \tan\left(\frac{\text{fovy}}{2}\right) = \frac{\text{height}/2}{\text{focal length}} \]

\[ \tan\left(\frac{\text{fovx}}{2}\right) = \text{aspect ratio} \times \tan\left(\frac{\text{fovy}}{2}\right) \]

\[ \text{top} = \text{bottom} = \text{near} \times \tan\left(\frac{\text{fovy}}{2}\right) \]
Calculating the Viewing Frustum

Stereo (Top View)
Right eye

\[ \text{left} = \text{near} \times \text{aspect ratio} \times \tan\left(\frac{\text{fovy}}{2}\right) + \frac{1}{2} \times \text{ios} \times \frac{\text{near}}{\text{focal length}} \]

\[ \text{right} = \text{near} \times \text{aspect ratio} \times \tan\left(\frac{\text{fovy}}{2}\right) - \frac{1}{2} \times \text{ios} \times \frac{\text{near}}{\text{focal length}} \]
Calculating the Viewing Frustum

• Given
  – \textbf{Near} = 75
  – \textbf{Focal Length} = 100
  – \textbf{Aspect Ratio} = 4/3
  – \textbf{Aperture (fovx)} = 45°
  – \textbf{Ios} = 40

Calculate \texttt{glFrustum()} values for left and right eye.

\texttt{gluLookAt(,……)}
General Steps

- **Anaglyph**
  
  *Concrete*

  Pseudo Code

  ```
  glClear(GL_COLOR_BUFFER_BIT);
  
  // Right Eye (red)
  glColorMask(GL_TRUE, GL_FALSE, GL_FALSE, GL_TRUE);
  glMatrixMode(GL_PROJECTION);
  glLoadIdentity();
  glFrustum(…)
  glMatrixMode(GL_MODELVIEW);
  glLoadIdentity();
  glLookAt(……...);
  DrawGeometry();
  
  // Left Eye (blue)
  glColorMask(GL_FALSE, GL_FALSE, GL_TRUE, GL_TRUE);
  …
  
  glColorMask(GL_TRUE, GL_TRUE, GL_TRUE, GL_TRUE);
  glutSwapBuffers();
  ```
Calculate Eye Position
Left and Right
/* Derive the "right" vector */

CROSSPROD(camera.vd,camera.vu,right);
Normalise(&right);
right.x *= camera.eyesep / 2.0;
right.y *= camera.eyesep / 2.0;
right.z *= camera.eyesep / 2.0;

/* Determine the focal point */
Flickering (The ifs and buts)

- A person's sensitivity to flicker varies with image brightness but generally from about 40Hz (refresh rate of stereo field pair) the perception of flicker starts to drop to an acceptable level. The optimum is 50 to 60Hz (stereo field pair refresh rate).
- Flicker can be overcome with both the interlaced and page flipping methods by increasing the refresh rate which the video card generates. But this depends upon the capabilities of the video card (and the monitor).
- For the same resolution and output frequency, non-interlaced modes will require twice the pixel rate of that needed by interlaced modes. Therefore you will need a higher quality card to achieve 100Hz stereoscopic display with an non-interlaced (progressive) mode than you will for interlaced.
- The best image quality will be achieved with page flipping at non-interlaced 120Hz - this should not be a problem with most new cards (depending upon software/bios support).
References / Material / Links

[Gal06] www.gali-3D.com

[Cat06] Catalyst Corporation and Jonathan R. Gross
http://www.frostbit.com/Catalyst/