Stereoscopic Vision and Haptic Rendering

* Fundamentals of the Human visual system.

=> The Human visual system is responsible for processing visual information.

(i) Depth Cues:

Depth cues help the human brain perceive the three dimensional structure of objects From two-dimensional retinal images.

This cues is categorized into Two:

A. Monocular Depth Cues:

- Also Known as One-Eyed Perception

- These cues allow us to perceive depth with just one eye.

B. Binocular Depth Cues:

- Also known as Two-Eyed Perception

- These cues depend on the input from both eyes and contribute significantly to depth perception.

(ii) Stereopsis:

Stereopsis is a fundamental aspect of binocular vision and is responsible for our 3D depth perception.

Each eyes captures a slightly different image.

The Brain processes these images and calculates the distance of objects based on differences.

This Fusion creates a depth-rich perception of world.

(iii) Retinal Disparity:

Retinal Disparity is a binocular depth cue that arises because our two eyes are horizontally separated by 6 cm.

This results in each eye capturing a slightly different images of an object.

- Greater Disparity = Closer Object: If the difference b/w the images seen by eye is significant.
- Smaller Disparity = Farther Object: If the difference b/w the images is minimal.
- Zero Disparity = Same Distance as the Focus Point.

* What is Haptic Sense and Devices?

=) Haptic Sense:

Haptic Sense refers to the ability to perceive and interact with environment through the sense of touch, pressure, vibration and temperature.

It involves two types of Feedback:

(i) Tactile Feedback: Sensing surface properties like texture, temperature and vibration.

(ii) Kinesthetic Feedback: Sensing force, weight and motion through muscles and joints.

=> Haptic Devices:

Haptic Devices are hardware system that provide force, vibration or motion feedback to simulate the sense of touch.

This devices are widely used in virtual Reality, robotics, gaming etc.

-> Types of Haptic Devices:

(i) Tactile Haptic Devices: Provide surface texture, vibration and temperature feedback.

(ii) Force Feedback Haptic Devices: Apply resistance or force to simulate physical interactions.

(iii) Exoskeletons and Wearable Haptics: Provide force feedback for military training and VR application.

-> Applications:

A. Virtual Reality

B Gaming

C. Robotics and Teleoperation

D. Automotive Industry

* Synthesis of Stereo Pairs:

=> Stereo Pair synthesis involves generating two images - one for the left eyes and one for the right eyes - to create a 3D depth perception effect.

This method enable immersive experiences in fields like VR, AR and computer vision.

=> Methods:

A. Depth-Based Rendering:

Uses a monocular image along with a depth map to generate stereo pairs.

Technique: Shifts pixels based on depth to create the right and left eye images.

B. Image Warping Using Depth Maps:

Uses depth maps to warp a single image into two viewpoints.

Technique: Forward Warping and Inverse Warping.

C. Ray Tracing for Stereo Synthesis:

Generates realistic stereo images by simulating light rays from a scene to the left and right camera positions.

D. Binocular Disparity Computation:

Uses a disparity map, which represents pixels shifts b/w left and right images.

E. Multi-View Synthesis:

Instead of just two views, multiple images from different angles are synchronized for free-viewpoint rendering.

F. AI-Based Stereo Synthesis:

Uses deep learning models to generate stereo images from a single image.

=> Application:

A. 3D Movies and Displays

B. Virtual Reality

C. Medical Imaging

D. 3D Reconstruction.

* Algorithms For Haptic Rendering:

=> Haptic Rendering refers to the process of simulating touch sensations by computing forces and feedback in virtual environments.

=> The main Algorithms:

1 Gold-Object Algorithm:

Used for simulating rigid object interactions.

Ensures a virtual tool remains in contact with the surface of objects.

2. Proxy-Based Algorithm:

Similar to the God-Object algorithm but maintains a proxy or intermediate virtual object that follows user movements while respecting object boundaries.

Forces are calculated based on the proxy's position relative to the user's real input.

3. Force Shading Algorithm:

Enhances the realism of surface interaction by interpolating force directions based on surface normals.

Used to create smooth transitions when moving across surfaces.

4. Constraint-Based Haptic Rendering:

Applies geometric and force constraints to limit object penetration and ensure realistic

touch Feedback.

5. Finite Element Method for Haptic Rendering:

Simulates soft-body deformations by modeling and material properties.

Used in medical simulation and soft tissue interactions.