EECE5698
Networked XR Systems

Lecture Outline for Today

- Tracking Fundamentals
  - Eyes
  - Face
  - Gestures
  - Hands
  - Head
  - Body

- Sensors and algorithms

Tracking in XR - Recap

- What is Tracking?
  - The process of continuously determining the position and orientation of a user's device or body parts within a given space, such as hands, face, or eyes.

Tracking in XR - Recap

- Why do we need Tracking?
  - Essential for creating an immersive and interactive experience, as it allows the virtual environment to respond dynamically to the user's movements.
  - E.g., hand tracking in AVP eliminates the need for controllers

Hand Tracking

- A system to detect, track, and interpret the movements and positions of a user's hands and fingers in real-time.

- Why?
  - Enables users to interact with digital environments and interfaces in a natural and intuitive way, using their hands and gestures directly, without the need for physical controllers or input devices.

Hand Tracking

Applications

Hand Tracking

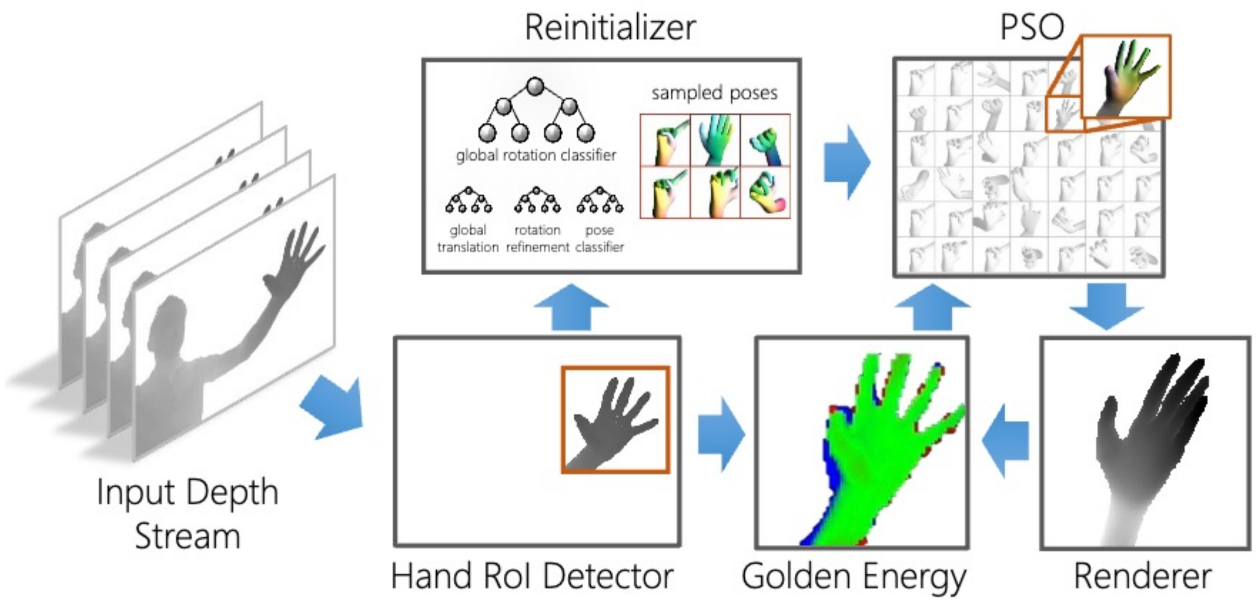
- **Early Developments:** Hand tracking roots in the 1960s with simple gesture recognition systems.
- **1990s to 2000s:** Evolution from wired gloves to marker-based optical systems.
- **Leap in Technology:** Leap Motion (2010) and Microsoft Kinect (2010) popularized hand tracking with advanced depth sensors and computer vision.
- **Recent Advances:** Integration in VR/AR headsets, e.g., Oculus Quest's hand tracking feature (2019).

Hand Tracking

- **How It Works:**
  - Cameras and sensors capture the hand's position and movements.
  - Software analyzes images and sensor data to identify hand shapes and gestures.
- **Tracking Methods:**
  - **Optical Tracking:** Uses cameras to detect hand position and movement.
  - **Inertial Tracking:** Employs accelerometers and gyroscopes to measure motion.
  - **Electromagnetic Tracking:** Uses magnetic fields to detect hand position and orientation.

Hand Tracking

- Case Study: Microsoft's hand tracking



Sharp et.al, Accurate, Robust, and Flexible Real-time Hand Tracking, CHI'15

Hand Tracking

- Case Study: Microsoft's hand tracking

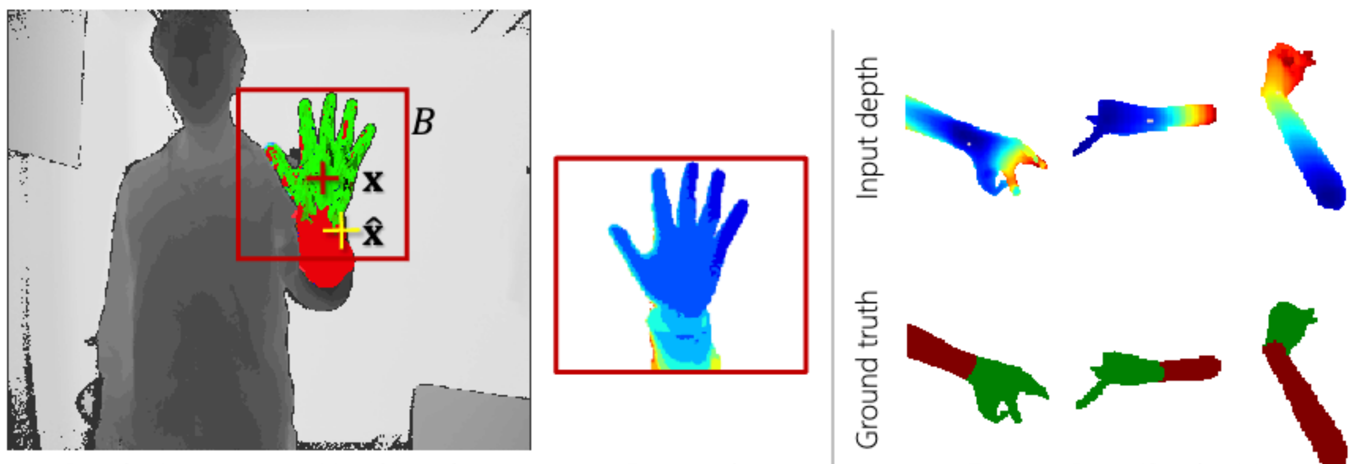
- **Hand RoI extraction**: Identify a square region of interest (RoI) around the hand and segment hand from background.
- **Reinitialization**: Infer a hierarchical distribution over hand poses with a layered discriminative model applied to the RoI.
- **Model fitting**: Optimize a ‘population’ of hand pose hypotheses (‘particles’) using a stochastic optimizer based on particle swarm optimization (PSO)

Hand Tracking

- 3D Hand Model
  - human hand as a 3D model, represented by a detailed mesh of triangles and vertices. The 3D positions of the M mesh vertices are represented as columns in a $3 \times M$ matrix V that defines the hand shape in a 'base' (rest) pose.
  - Includes wrist, finger, and thumb joints – e.g., rotations and translation matrices for all the joints (i.e., 3 joints per finger) and wrist, etc., comprising pose vector ($\boldsymbol{\theta}$)
  - Input: depth image
  - Output: $\phi(\boldsymbol{\theta}, V)$ i.e., hand mesh in a given pose

Hand Tracking

- RoI extraction



Input Depth, Approximate Hand Localization $\hat{\mathbf{x}}$, and Inferred Segmentation

Extracted Hand RoI $Z_{\mathbf{d}}$

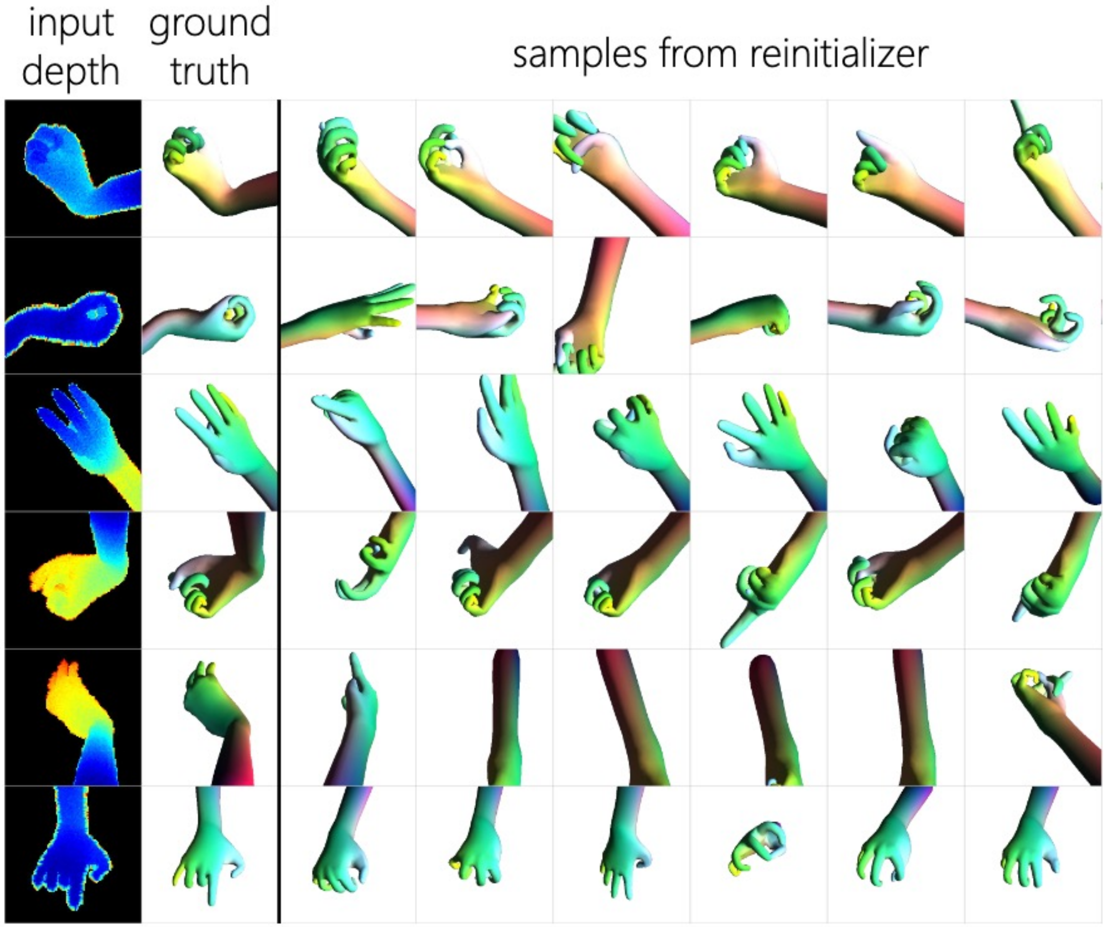
Training Data (Synthetic)

Hand Tracking

- Reinitialization
  - Output a pool of hypotheses of the full hand pose by observing just the current input depth image
  - It is difficult to predict a single good pose solution
  - Instead, predict a distribution over poses, and fit a model that will quickly sample as many poses as desired and use the golden energy to disambiguate the good from the bad candidate

Hand Tracking

- Sample poses output from the reinitializer



Hand Tracking

- Model fitting
  - PSO optimizes the following scoring function

$$E^{\mathrm{Au}}(Z_{\mathrm{roi}}, R_{\mathrm{roi}}) = \sum_{ij} \rho(\bar{z}_{ij} - r_{ij})$$

1.Evaluation and Scoring: The algorithm evaluates a scoring function across the particle population in parallel on the GPU, with each evaluation determining the hand pose's "energy."

2.Particle Randomization and Updates:

1. Regular randomization of particles to prevent stagnation: per-generation adjustments for fingers and every-third-generation for broader pose variations.
2. Updates include standard PSO dynamics with added mechanisms for local minima attraction and momentum, plus custom extensions for better performance.

Hand Tracking

3. Particle Initialization and Aging:

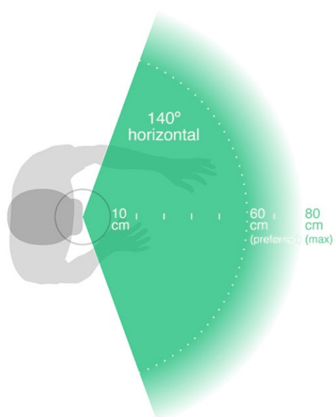
- Particles are initially set using a method similar to the every-third-generation randomization, with subsequent frames utilizing previous results for perturbations.
- A technique to counteract 'particle collapse' is implemented by assigning ages to particles, creating independent swarms within the population and resetting ages upon certain re-randomization events.

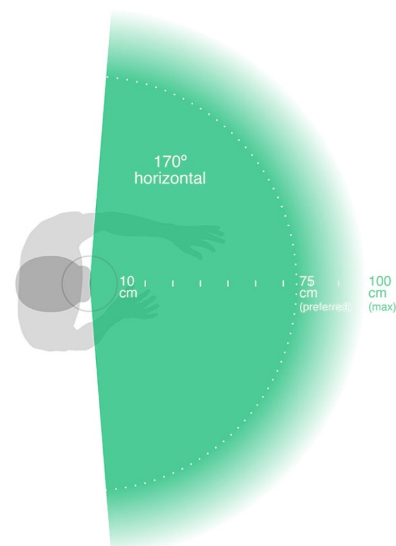
Hand Tracking

- Failure scenarios – why?

Hand Tracking

- Leap motion – ultra leap
  - Two cameras and some infrared LEDs. These track infrared light at a wavelength of 850 nanometers, which is outside the visible light spectrum.
  - Wide angle lenses are used to create a large interaction zone within which a user’s hands can be detected.



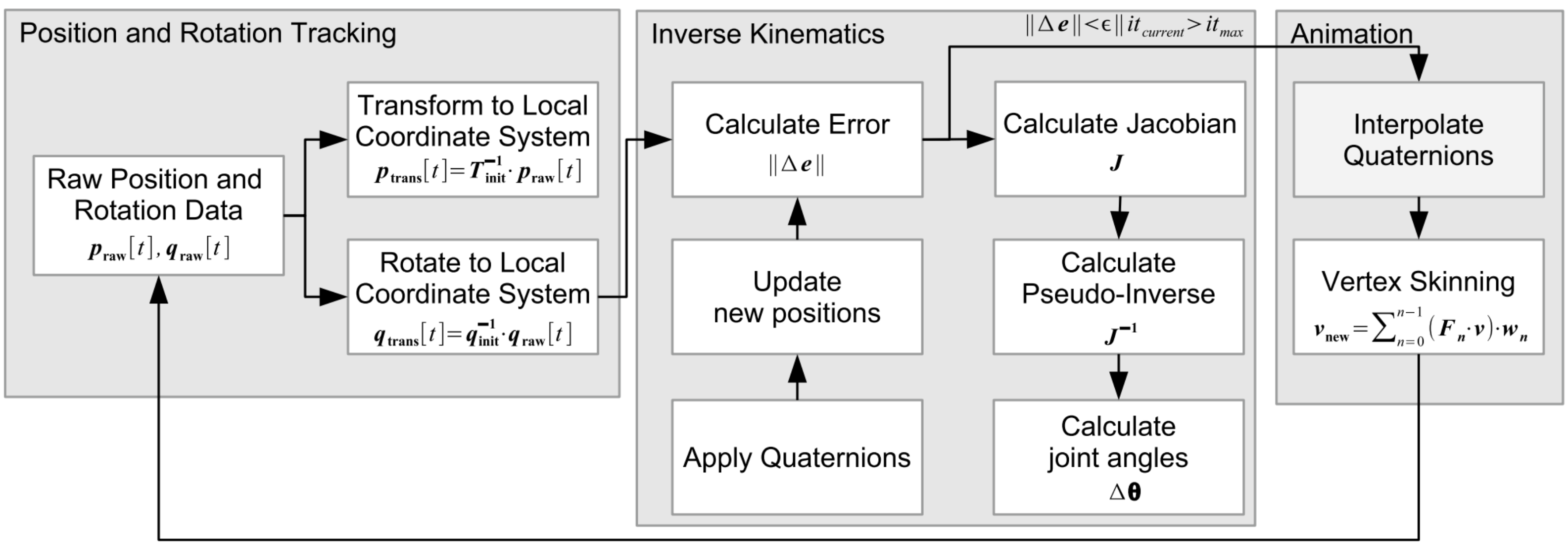


Full Body Tracking

- Capture or track the movements of a person's entire body in real-time.
- Applications

Full Body Tracking

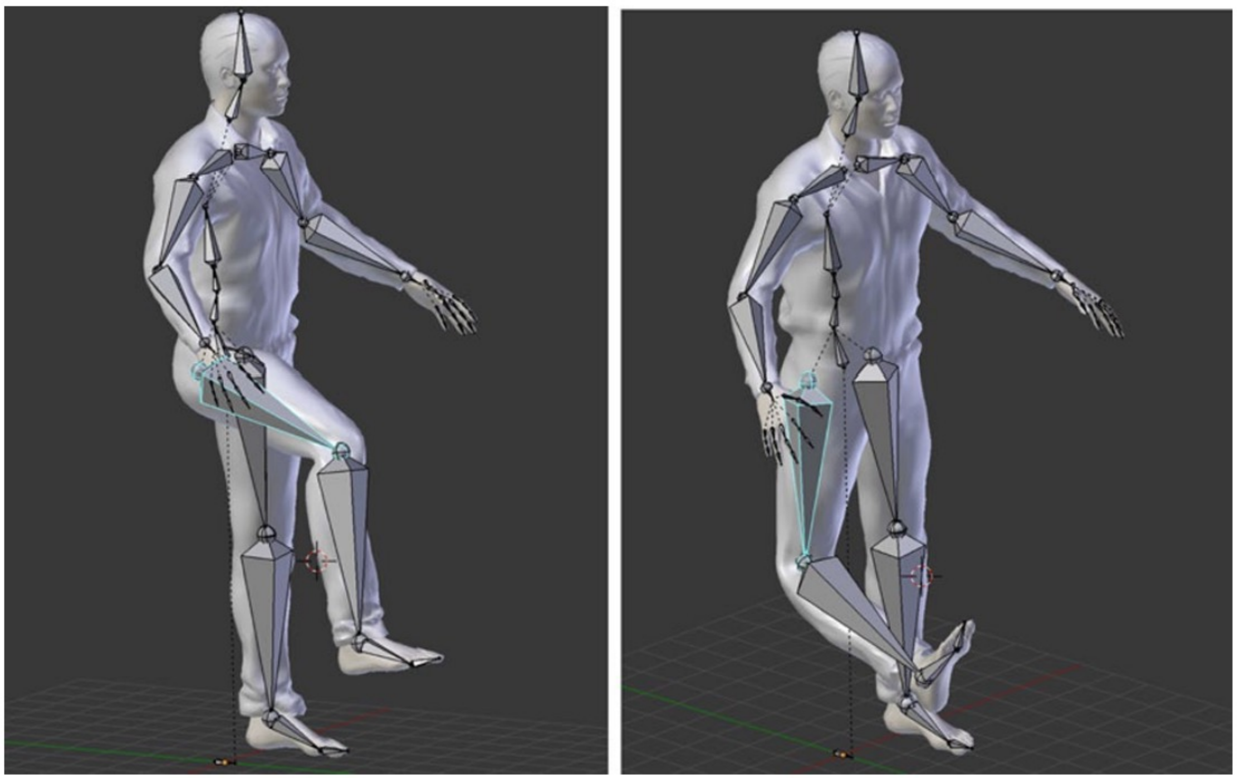
- Inverse Kinematics
  - Find positional and orientational constraints of each specific joint



Caserman et.al, Real-time body tracking in virtual reality using a Vive tracker, virtual reality 2019

Full Body Tracking

- Natural body pose



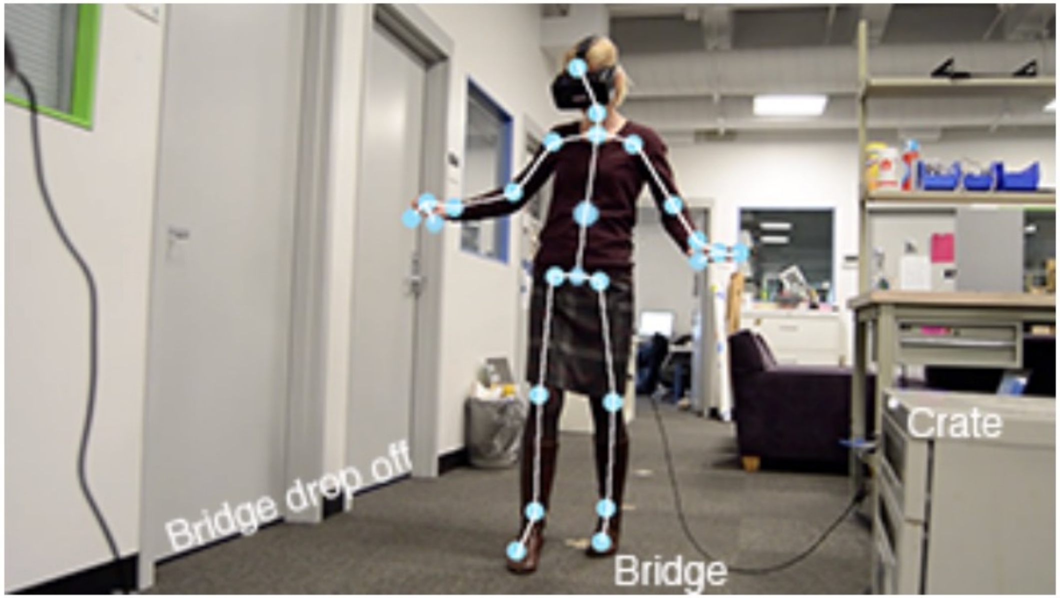
Full Body Tracking

- Algorithm
  1. Calculate error between desired and actual position as well as rotation
  2. Check for convergence
  3. Calculate Jacobian
  4. Calculate Pseudo-Inverse
  5. Calculate joint angles for each bone joint
  6. Apply quaternions to the transformation matrix
  7. Update new positions

Caserman et.al, Real-time body tracking in virtual reality using a Vive tracker, virtual reality 2019

Full Body Tracking

- Kinect sensor



Sra et.al, https://arxiv.org/pdf/1512.02922.pdf

Full Body Tracking

- **Optical Tracking**
  - Description: Uses cameras to capture movement, often with markers placed on the body.
  - Pros: High accuracy and fine detail capture.
  - Cons: Can be expensive and requires a controlled environment to prevent occlusion and ensure visibility of markers.
- **Inertial Tracking**
  - Description: Employs accelerometers and gyroscopes to measure movement and orientation, often used in wearable devices.
  - Pros: Portable and does not require an external camera setup.
  - Cons: Subject to drift over time and may require regular recalibration.
- **Magnetic Tracking**
  - Description: Uses magnetic fields to track the position and orientation of sensors relative to a base station.
  - Pros: Not affected by occlusions and can work in various environments.
  - Cons: Can be disrupted by nearby metal objects or magnetic fields.

Full Body Tracking

- Meta Quest3

Face Tracking

- Identify and monitor the movements and expressions of a face in real-time.
  - It involves detecting key facial features, such as the eyes, nose, mouth, and jawline, and tracking these features' movements and changes in expression.

Face Tracking

- **Cameras**: 2D and 3D depth cameras are crucial for capturing detailed facial features and movements. 3D cameras provide depth information, essential for accurate tracking in three-dimensional space.
- **Infrared Sensors**: Used in environments with variable lighting to capture the thermal signature of the face, enhancing accuracy in feature detection.

Face Tracking

- **Facial Landmark Detection**: The system identifies key points on the face, such as the corners of the eyes, nose, and mouth, establishing a base for tracking movements.
- **Initial Calibration**: Importance of the initial setup where the system learns the neutral state of the user's face for more accurate tracking.

Face Tracking

- **Feature-to-Model Mapping**: Details on how detected facial landmarks are mapped onto a digital model, allowing the system to understand and replicate facial movements.
- **Expression and Gesture Interpretation**: How different facial expressions and head movements are interpreted and translated into digital actions or reactions.

Face Tracking

- **Avatar Animation**: Use of face tracking data to animate avatars in real-time, reflecting the user's expressions and movements in the virtual environment.
- **Realistic Interactions**: Enhancing XR experiences by enabling natural and intuitive interactions, such as nodding, winking, or smiling, to control or influence the digital environment.

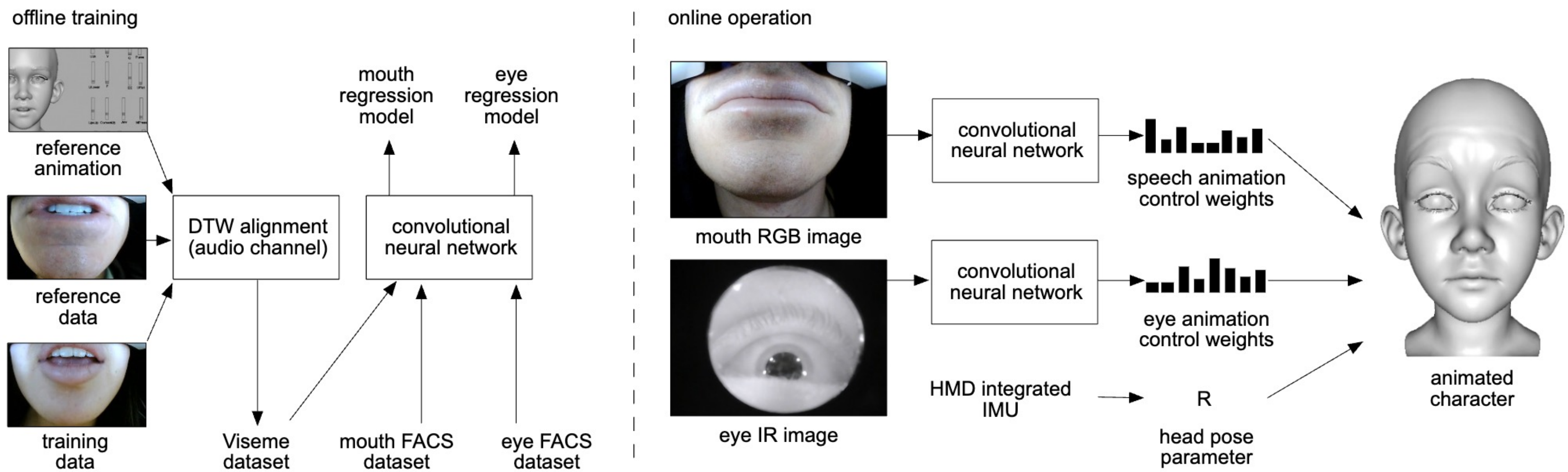
Face Tracking

Captured image | Normal map | Fully-lit avatar | Relit avatar | Relit avatar under different viewpoints

Meta

Face Tracking

Face and speech animation



K. Olszewski et al

Summary of the Lecture

- Hand Tracking
- Full Body Tracking
- Face Tracking

Next up: RF Tracking