DEPARTMENT OF MECHATRONICS ENGINEERING

Inverse modeling refers to a class of techniques used to **estimate input parameters** of a system based on its **observed outputs**. Unlike **forward modeling**, which predicts outputs from given inputs, **inverse modeling** works in reverse:

Outputs→Estimate Inputs

Why is Inverse Modeling Important?

- **Useful in AI and machine learning** for tasks like system identification and decision-making.

- **Essential for ill-posed problems** where direct computation of inputs is difficult.

- **Widely applied** in engineering, robotics, geophysics, medical diagnosis, and computer vision.

Forward vs. Inverse Modeling

Feature	Forward Modeling	Inverse Modeling
Definition	Computes output from given input	Estimates input from given output
Example	Predicting temperature based on weather data	Finding cause of temperature change
Problem Type	Well-posed problems	Often ill-posed problems
Techniques Used	Analytical methods, neural networks	Optimization, AI-based learning
Applications	Simulation, prediction models	System identification, control systems

3. Challenges in Inverse Modeling

- ✓ **Ill-posedness** – No unique solution, multiple inputs may give the same output.

- ✓ **Noisy Data** – Observations often contain errors, requiring regularization.

- ✓ **Computational Complexity** – Requires iterative optimization and AI-based learning techniques.

4. AI-Based Approaches for Inverse Modeling

1. Neural Networks (Deep Learning)

- **Uses supervised learning** to map outputs to corresponding inputs.

- **Works well for complex, nonlinear systems**.

- Example: Using a convolutional neural network (CNN) to reconstruct images from sensor data.

2. Radial Basis Function Networks (RBFNs)

- **Good for function approximation**.

- Used in **system identification** where forward models are hard to define.

3. Support Vector Machines (SVMs)

- **Useful for inverse classification problems** where input patterns need to be recovered from outputs.

- Applied in **medical diagnosis and fault detection**.

4. Genetic Algorithms (GA) & Evolutionary Computation

- **Used in optimization-based inverse problems**.

- Example: Finding optimal material properties in engineering models.

5. Bayesian Inference & Probabilistic Models

- **Handles uncertainty in inverse problems**.

- Example: **Bayesian Networks** in medical diagnosis to infer diseases from symptoms.

6. Reinforcement Learning (RL)

- **Used for dynamic inverse control problems**.

- Example: **Inverse reinforcement learning (IRL)** estimates reward functions based on observed expert behavior.

5. Applications of Inverse Modeling in AI

1. Computer Vision & Image Reconstruction

- **Inverse Problems**: Estimating 3D shape from 2D images (depth estimation).

- **Techniques Used**: Neural Networks, Bayesian Inference.

2. Medical Diagnosis & Imaging

- **Inverse Problems**: Identifying disease from symptoms or MRI scans.

- **Techniques Used**: Machine Learning, Neural Networks, Bayesian Models.

3. Robotics & Control Systems

- **Inverse Problems**: Finding joint angles (inverse kinematics) to achieve a given end-effector position.

- **Techniques Used**: Neural Networks, Reinforcement Learning, Genetic Algorithms.

4. Geophysics & Environmental Science

- **Inverse Problems**: Estimating underground structures from seismic data.

- **Techniques Used**: Probabilistic Inference, Optimization Algorithms.

5. Manufacturing & Industry 4.0

- **Inverse Problems**: Identifying material properties from observed performance.

- **Techniques Used**: RBFNs, Deep Learning, Genetic Algorithms.