ADVANCE COMPUTER VISION

Code: CS33221CS	Course Type: Elective	Semester: II
Evolution Scheme (TA-MSE-ESE): 20-30-100	Total Marks: 150	L-T-P (Credits): 2-0-2 (3)

Pre-Requisites:

- Advanced Linear Algebra (SVD, Eigen-decomposition, Matrix manifolds)
- Multivariable Calculus and Calculus of Variations
- Probability Theory and Stochastic Processes
- Digital Image Processing fundamentals

Course Objectives:

1. To establish a rigorous mathematical foundation for image formation, projective geometry, and complex camera models.
2. To formulate and solve 3D reconstruction problems using the algebraic and geometric constraints of multiple views.
3. To study continuous/discrete optimization paradigms (Graph Cuts, Variational Calculus) and their application to visual motion dynamics.
4. To explore scale-space theory and the underlying mathematical frameworks of shape representation and volumetric rendering.

Course Outcomes: At the end of the course, the student will be able to

CO-1	Formulate projective transformations and execute rigorous camera calibration using intrinsic and extrinsic geometric parameters
CO-2	Derive the Fundamental and Essential matrices to constrain epipolar geometry and implement robust 3D bundle adjustment.
CO-3	Apply energy minimization techniques (Graph Cuts) and analyze variational optical flow for complex scene and motion dynamics.
CO-4	Investigate scale-space axioms and formulate shape-from-X theories alongside the foundational calculus of volumetric rendering.

Course Articulation Matrix:

PO	PEO-1	PEO-2	PEO-3	PEO-4	PEO-5
CO-1	3	2	1	-	2
CO-2	3	3	2	1	3
CO-3	3	3	2	-	3
CO-4	3	3	2	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Unit-1 Image Formation and Projective Geometry: Mathematical foundations of 2D and 3D projective geometry. Homogeneous coordinates, points, lines, and conics in and. 2D projective transformations (homographies) and their estimation (Direct Linear Transformation DLT). Image formation physics: Radiometry, Bidirectional Reflectance Distribution Function (BRDF), and color matching functions. The pinhole camera model, lens distortion, and orthographic/perspective projections. Camera calibration algorithms: Zhang's and Tsai's methods.

Unit-2 Multi-View Geometry and 3D Reconstruction: Epipolar geometry formulation: The Essential matrix () and the Fundamental matrix (). The 8-point and 5-point algorithms for matrix estimation. Robust estimation frameworks: RANSAC and its theoretical convergence guarantees. Triangulation methods for point recovery. Stereo vision math: Disparity maps, epipolar rectification, and depth optimization. Multi-view geometry: Trifocal tensors and N-view bundle adjustment using Levenberg-Marquardt optimization.

Unit-3 Variational Optimization Visual Motion Dynamics: Image analysis as an inverse problem. Discrete optimization: Markov Random Fields (MRF) and energy minimization via Graph Cuts (Max-Flow/Min-Cut theorem). Continuous optimization: Calculus of variations and the Euler-Lagrange equations. Differential motion analysis: The brightness constancy assumption and the aperture problem. Local differential methods (Lucas-Kanade) vs. Global variational methods (Horn-Schunck and regularization priors). Stochastic frameworks for visual tracking: Kalman filtering and Particle filtering.

Unit-4 Scale-Space Theory and Shape Representations: Linear scale-space theory axioms and the heat equation. The Laplacian of Gaussian (LoG) and the determinant of Hessian for scale-invariant feature detection (foundations of SIFT/SURF). Differential geometry of curves and surfaces. Shape-from-X paradigms: Shape from shading (Lambertian reflectance maps), shape from texture, and shape from focus. Mathematical foundations of volumetric rendering equations (Classical precursors to Neural Radiance Fields).

Learning Resources:

Text Books:

1. Computer Vision: A Modern Approach Forsyth D.A., Ponce J. Pearson 2011 (2nd Ed.

2. Multiple View Geometry in Computer Vision Hartley R., Zisserman A. Cambridge Univ. Press 2004 (2nd Ed.)

3. An Invitation to 3-D Vision: From Images to Geometric Models Ma Y., Soatto S.,Kosecka J., Sastry S.S. Springer

Reference Books:

1. Computer Vision: Algorithms and Applications Szeliski R. Springer 2022 (2nd Ed.)
2. Variational Methods in Image Processing Vese L.A., Le Guyader C. CRC Press 2015