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BCA Honours | Semester VI | BCA6EJ304(1)

Applied Digital Image Processing

Module 3 Comprehensive Notes

Module 3: Biometric Image Recognition and Forensic Verification

Biometric authentication measures unique human physiological and behavioral characteristics to verify identity in homeland security, border control, and digital banking.

3.1 Fingerprint Pattern Recognition and Minutiae Extraction

Fingerprints consist of interleaved ridges and valleys forming global patterns (Loops, Whorls, Arches):

- **Minutiae Points:** Local ridge discontinuities—primarily *Ridge Endings* (where a ridge abruptly terminates) and *Bifurcations* (where a single ridge bifurcates into two branches).
- **Minutiae Extraction Pipeline:** Directional orientation field estimation → Gabor filter ridge enhancement → Binarization → Zhang-Suen skeletonization thinning → Crossing Number (CN) extraction:

$$CN = \frac{1}{2} \sum_{i=1}^{8} |P_i - P_{i+1}|$$

Where: $CN = 1$ denotes a ridge ending; $CN = 3$ denotes a ridge bifurcation.

3.2 Iris Pattern Recognition: The Daugman Architecture

John Daugman's iris recognition algorithm achieves near-zero error rates through four stages:

1. **Localization:** Integro-differential operator locates inner pupil and outer sclera circular boundaries.
2. **Normalization:** Converts the annular iris ring into a dimensionless rectangular polar strip (rubber-sheet model).
3. **Feature Encoding:** Filters normalized iris tissue with 2D Gabor wavelets, quantizing phase angles into a 2048-bit binary **IrisCode**.
4. **Matching:** Computes the fractional **Hamming Distance** between two IrisCodes via fast bitwise XOR operations.

3.3 Forensic Image Authentication and Forgery Detection

- **Copy-Move Forgery Detection:** Identifies duplicated sub-regions within a single image using keypoint matching (SIFT/SURF) or block-based Discrete Cosine Transform (DCT) feature correlation.
- **Error Level Analysis (ELA):** Identifies spliced modifications by visualizing differences in JPEG lossy compression degradation rates across image regions.
- **Sensor Pattern Noise (PRNU):** Photo-Response Non-Uniformity noise extracted from pixel arrays serves as an unalterable hardware fingerprint uniquely identifying the source digital camera.

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Advanced Theoretical Foundations & Industrial Systems Synthesis

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1. Architectural Trade-offs and Computational Complexity

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- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 3 Core Concepts and Methods, pre-computing intermediate lookup tables, spatial indices, and hashing structures achieves near-instantaneous $O(1)$ query latency, but inflates the physical memory footprint. Conversely, in-place algorithms minimize RAM utilization at the cost of higher CPU cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped files and cache-aware structures.
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- **Algorithmic Determinism versus Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial barriers as problem dimensions scale. Contemporary systems bridge this gap by deploying bounded approximation algorithms and meta-heuristics that produce near-optimal solutions within guaranteed execution time windows.

2. Empirical Comparative Framework

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