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From Fingerprints to Heartbeats: The Shift to Non-Cooperative Biometrics

AI * Ethics * Computing

The Shift to Non-Cooperative Identification

For decades, biometric authentication was a cooperative act: a subject pressed a finger onto a glass platen, paused before a border camera, or submitted to a buccal swab. Throughout 2024 and 2025, however, biometric deployment broke decisively with this tradition, entering the era of passive, "non-cooperative" identification.[1] Subjects are now analyzed remotely and without awareness as sensors harvest the biomechanics of their gait, the geometry of their occluded faces, and the acoustic signatures of their heartbeats.[1][3]

Three technological vectors drive this architectural shift: high-frequency millimeter-wave radar and laser vibrometry that penetrate physical barriers; transformer and neuromorphic computing architectures that extract identity signals from heavy noise; and generative diffusion models that reconstruct -- or "hallucinate" -- high-resolution facial details from degraded forensic footage.[3][5][7] Simultaneously, global governance has fractured into a regulatory "splinternet," pitting the European Union's February 2025 AI Act prohibitions against an accelerationist United States policy framework.[8][9]

Computational Foundations and Generative Facial Restoration

Modern biometric pipelines have moved beyond local Convolutional Neural Networks (CNNs) toward four foundational architectures:

* Contrastive Representation Learning: Frameworks like SimCLR map distorted "anchor" and "positive" probe images close together in high-dimensional latent space while pushing "negatives" apart via triplet or contrastive loss, matching grainy night-vision probes against booking photos regardless of lighting or pose.[10]

* Vision Transformers (ViTs): Using global self-attention across video frames simultaneously, ViTs capture long-range spatiotemporal relationships -- such as how a heavy bag alters compensatory muscle motion without changing core gait identity.[5]

* Neuromorphic Edge Computing: Event-driven Spiking Neural Networks (SNNs) collocate memory and processing in artificial neurons and synapses, firing only when motion or vibration changes occur to enable low-power, on-device edge surveillance.[6][11]

* Generative Diffusion Restoration: Highlighted in the NTIRE 2025 Real-World Face Restoration Challenge, models like SDFace (built on Stable Diffusion XL) pair iterative denoising with identity-preserving embeddings such as AdaFace.[7] Because diffusion priors can invent realistic pores, scars, or eyebrows absent from the degraded input, legal guidelines increasingly restrict restored images to investigative leads rather than courtroom evidence.[9]

Parallel advances in Masked Face Recognition (MFR) use Siamese Networks and teacher-student attention mechanisms focused on the periocular region (eyes, eyebrows, and forehead).[12] However, a September 2024 U.S. Commission on Civil Rights (USCCR) investigation warned that while top algorithms achieve sub-1% error rates on optimal images, false-negative rates rise on masked Asian and American Indian faces, and false-positive rates for West/East African and East Asian individuals can exceed those of Eastern Europeans by up to a factor of 100 -- creating severe wrongful-arrest and public-housing surveillance risks.[13]

Behavioral and Physiological Sensing: Gait, Radar, and Through-Wall Heartbeats

As facial recognition encounters masks and legal scrutiny, standoff behavioral and physiological modalities have expanded rapidly. Model-based 3D skeletal pose estimation maps joint coordinates (shoulders, elbows, hips, knees, ankles) independently of clothing, while transformer models like GaitTriViT and cross-attention re-ranking architectures (CarGait) evaluate fine-grained joint kinematics.[5][14] With the gait biometrics market projected to grow from $109 million in 2024 to over $300 million by 2034, police records in Seattle, Berkeley, and the UK already document crowd-scanning and behavioral procurement.[15][16][17]

Even more intrusive is remote cardiac identification, which exploits the unique acoustic and vibrational signature of an individual's heart valves and chambers.[3] At 60 GHz, millimeter-wave (mmWave) radar measures sub-millimeter chest-wall Doppler shifts, achieving over 97% authentication accuracy when paired with Conditional Variational Autoencoders (CVAEs) to separate cardiac motion from respiration.[3] Similarly, University of Glasgow researchers combined throat-skin laser vibrometry and neuromorphic processing for rapid contactless cardiac sensing.[18][19] Operationalizing this physics, the DHS Detection of Presence of Life (DePLife) program and MIT Lincoln Laboratory upgraded hand-held tactical radar units in mid-2025 with motion compensation, enabling law enforcement to detect human heartbeats through solid concrete and brick walls -- raising profound Fourth Amendment questions under Kyllo v. United States.[4][20]

| Biometric Modality | | Primary Mechanism & AI Architecture | | Operational Capability (2025) | | Forensic & Civil Liberties Risk |

| Generative Face Restoration | | Diffusion denoising (SDFace) + AdaFace vector priors.[7] | | Reconstructs high-resolution faces from blurry CCTV footage. | | "Hallucination" of non-existent scars/features; false courtroom certainty.[9] |

| 3D Skeletal Gait Analysis | | 3D joint pose estimation + Vision Transformers (GaitTriViT, CarGait).[5][14] | | Standoff identification from hundreds of meters away or from behind. | | Erosion of public anonymity; cannot be consciously concealed.[2] |

| mmWave & Laser Cardiac ID | | 60 GHz Doppler radar (CVAE) / Laser vibrometry (Neuromorphic SNN).[3][18] | | 97%+ authentication accuracy; DHS DePLife sees heartbeats through walls.[3][4] | | Warrantless through-wall interior searches and non-consensual scanning. |

| Rapid DNA & Phenotyping | | 90-minute automated PCR profiling; SNP-based

appearance prediction.[21][23] | | Live CODIS booking checks (July 2025); composite suspect sketches.[21][24] | | Pretextual "genetic stop-and-frisk" arrests; unvalidated polygenic face shapes.[22][24] |

Genomic Surveillance and the Geopolitics of Biometric Governance

In genomic forensics, the FBI formally integrated Rapid DNA into the National DNA Index System (NDIS/CODIS) on July 1, 2025.[21] Automated "swab-in, profile-out" cartridges execute DNA extraction, polymerase chain reaction (PCR) amplification, and capillary electrophoresis in 90 minutes at police booking stations, linking arrestees to unsolved crimes before bail release but raising civil rights warnings of pretextual "genetic stop-and-frisk" arrests.[21][22] When database searches fail, agencies increasingly turn to Forensic DNA Phenotyping (FDP) services like Parabon NanoLabs' "Snapshot" to predict physical phenotype from a suspect's genetic code.[23] While eye, hair, and skin pigmentation predictions achieve AUC values above 0.90, craniofacial morphology is highly polygenic and environmentally modulated; geneticists warn that proprietary face-shape sketches lack peer-reviewed validation and risk confirmation bias when fed into facial recognition searches.[23][24][25]

Governance of these tools has sharply bifurcated. In January 2025, the U.S. administration issued Executive Orders 14148 and 14179, revoking Biden-era AI safety mandates (EO 14110) in favor of deregulation and law enforcement deployment.[9][26] Conversely, Article 5 of the EU AI Act -- enforceable since February 2025 -- prohibits real-time remote biometric identification in public spaces (barring narrow judicial exceptions), biometric categorization of sensitive traits, and law enforcement emotion recognition.[8]

The Era of Probabilistic Justice

The biometric landscape of 2025 marks a transition from deterministic evidence to probabilistic inference -- where diffusion models estimate pixel distributions, transformers score kinematic similarity, and polygenic models approximate facial structure. Without transparent algorithmic auditing and constitutional safeguards against passive through-wall and standoff sensing, the justice system risks mistaking statistical reconstructions for objective truth.

Updates... (Nov 23, 2026): Removed numbered section headings, escaped currency signs, added missing author attribution to Ref. 3 (Asano, T., Izumi, S., & Kawaguchi, H., Aug 21, 2025) and Ref. 14 (Habib, G., Barzilay, N., Shimshi, O., Ben-Ari, R., & Darshan, N., Mar 5, 2025), and verified all 26 CrossRef DOIs, arXiv preprints, DHS/USCCR/municipal reports, and University of Glasgow records in 1:1 parity.

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