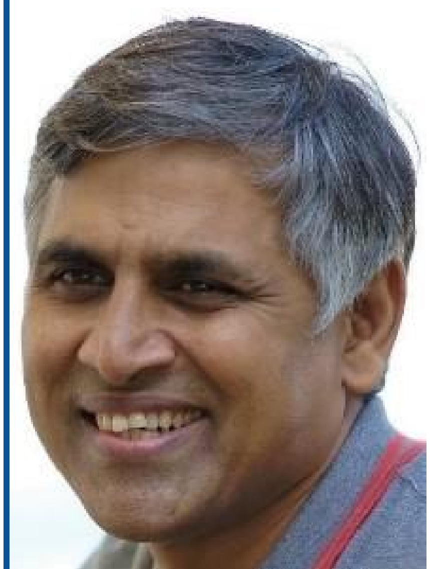
BIOMETRIC PIONEERS: *Ajay Kumar*

***Interview conducted by Andrew Teoh Beng Jin, Yonsei University, Korea, and Editor-in-Chief of the* IEEE Biometrics Council Newsletter**



Dr. Ajay Kumar is currently a Professor in the Department of Data Science and Artificial Intelligence at The Hong Kong Polytechnic University in Hong Kong. He received his Ph.D. from the University of Hong Kong in 2001. Kumar holds seven U.S. patents and has authored a book on *Contactless 3D Fingerprint Identification*. A past-president of the IEEE Biometrics Council, he has also served IEEE as vice president for publications (2011-2015), and on two editorial boards. Prof. Kumar is a Fellow of IAPR and the IEEE, and is the recipient of a 2018 Faculty Award for Outstanding Achievement in Research and Scholarly Activities.

TEOH: Your career spans contactless palmprint, palm-vein, finger-vein, and 3-D fingerprint recognition. What pivotal insight or problem first persuaded you to devote considerable effort to hand-based biometrics, and how has that initial motivation evolved over the years?

Kumar: I only started to work on biometrics after the September 11 attacks, when there was an enhanced emphasis on security. At that time, the application of fingerprint technology was largely confined to law enforcement, and initial research on palmprint identification relied heavily on ink-based impressions. I realized there were tremendous opportunities for civilian applications of these technologies, as well as some critical gaps in its use, including traditional contact-based systems that struggled with hygiene concerns, sensor degradation, and the emergence of low-cost digital cameras. The latter offers tremendous potential (and hope) for completely contactless hand-based biometrics. Over time, this evolved into addressing broader challenges, such as scaling accuracy across diverse demographics, countering

sophisticated spoofing, or enabling seamless integration into mobile ecosystems. It is immensely gratifying to reflect on a journey spanning more than 20+ years, from our initial work on contactless palmprint identification to the widespread deployment of these systems across financial technology, e-business, and access control applications today.

TEOH: You co-authored one of the earliest books on contactless 3-D fingerprints, and hold multiple U.S. patents in this area. Which technical breakthrough—algorithmic, sensing, or calibration-related—do you regard as most critical for making contactless hand biometrics deployment-ready?

Kumar: While advancements in sensing and calibration are foundational, I believe that the key breakthrough lies in algorithmic innovation. Contactless 3-D fingerprint biometrics face inherent challenges: significant variations in camera view angles, illumination changes, and distortions due to variable 3D shapes from contactless acquisition. Novel algorithms addressing 3-D reconstruction, noise reduction, and invariant feature extraction remain critical to transforming raw data into interoperable, high-fidelity templates. For instance, now deep learning techniques can enable robust matching across diverse conditions, bridging the gap between 3-D fingerprint acquisition and legacy 2-D databases. This adaptability can also ensure reliability in real-world deployments, where environmental variables are difficult to predict. Without algorithmic advances to mitigate these challenges, even precise sensors would struggle to deliver consistent accuracy, making advancement in algorithms the backbone for adoption of contactless 3-D fingerprint technologies.

TEOH: With palmprint, vascular, and fingerprint traits all captured from the same hand, what have your studies revealed about optimal fusion strategies? Are there interoperability challenges when combining contactless and contact-based templates, and how might template-protection schemes mitigate them?

Kumar: Studies reveal that optimal fusion combines surface (palmprint) and subsurface (palm-vein) traits using some dynamic quality-weighted strategies. For instance, vascular data excels in low-light conditions, while relatively high-resolution palmprint data can offer superior match accuracy in controlled settings. We can also see such trends in widely deployed contactless palmprint systems, i.e., from *Amazon One* or from *Tencent*.

Yes, we have found there are interoperability challenges that can largely be attributed to geometric distortions and resolution mismatches between contactless and contact-based systems. Deep learning techniques, like cross-modal feature alignment, can address such difficulties by normalizing disparate feature templates. Template-protection schemes, like cancellable biometrics or homomorphic encryption, secure individual modalities before fusion, and can thus ensure privacy without compromising match accuracy. This balance of security and interoperability is essential for complying with global data standards and building user trust in hybrid systems.

TEOH: As a former IEEE Biometrics Council President, you have witnessed growing concerns about spoofing, privacy regulation, and ethical AI. Which emerging attack vectors on hand biometrics worry you most, and what countermeasures or standards should the community prioritize?

Kumar: The most serious security risks arise from advanced spoofing technologies, such as multi-layered gloves designed to replicate both surface palmprints and subsurface palm vein patterns using near-infrared absorbing materials. There are also hyper-realistic deepfakes like those generated from diffusion or unknown models, and 3D-printed replicas that imitate biological features. These cutting-edge methods pose a formidable challenge to systems by exploiting weaknesses in liveness detection and sensor-agnostic systems.

Equally concerning are adversarial attacks on the neural networks used in feature extraction, which can subtly bypass authentication. To counter these attacks, the community must prioritize multi-modal liveness checks that consolidate physiological and behavioral cues, like micro-movements cues, and the adoption of adversarial training in AI models. Standards like *IEEE P2790* for biometric liveness (see https://ieeexplore.ieee.org/document/9080669), and *ISO/IEC 30107-3* for presentation attack detection (see https://www.iso.org/standard/79520.html), need to be rigorously expanded to cover hand-based contactless 2D/3D biometric systems. Embedding privacy-by-design principles, such as decentralized template storage and zero-knowledge proofs, can also mitigate systemic risks while aligning with evolving regulations.

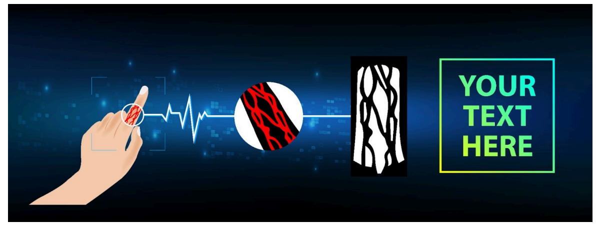
TEOH: Many hand-vein and palmprint datasets remain comparatively small, or lack cross-device variability. Based on your recent experiments, what benchmark characteristics (e.g., illumination invariance, sensor diversity, demographic balance) are still missing, and how can we incentivize broader data sharing?

Kumar: Yes, current datasets often miss three crucial characteristics: sensor diversity (different devices and view angles), illumination invariance (consistent performance under uneven or ambient illumination), and dynamic occlusion (partial hand obstructions in real-world usage). Demographic balance is also sparse, increasing the likelihood of biased models. Our experiments have recently highlighted how synthesized biometric data, e.g., simulating diverse skin tones, ages, and environmental conditions, can partially fill these gaps.

To incentivize data sharing, the community should consider establishing federated learning frameworks, allowing contributors to retain data control while pooling insights. IEEE or NIST could spearhead certification programs that reward large and compliant datasets with visibility or research grants. Availability of open source tools for anonymizing vein patterns and palm textures can further lower privacy barriers, and foster collaborative innovation.

TEOH: Deep learning and self-supervised methods are now ubiquitous. Looking five to ten years ahead, which research directions—such as generative modeling for synthetic data, multispectral sensing, or privacy-preserving federated learning—do you expect to redefine hand biometric performance ceilings?

Kumar: Over the next decade, I expect three key factors to redefine performance ceilings. First, physics-informed generative models will synthesize hyper-realistic, demographically balanced hand biometric data that can overcome dataset scarcity while embedding anti-spoofing imprints during generation. Second, adaptive multispectral sensing fusion, such as the combination of near-infrared for deeper vein patterns with polarization-resolved surface textures, will enhance liveness detection and invariance to ambient noise or high degrees of intra-class variations in completely contactless scenarios. Third, privacy-preserving federated learning is



expected to evolve beyond encryption to neuromorphic architectures, which will enable decentralized, energy-efficient training across devices without raw data exposure.

Crucially, these advances must be paired with standardized benchmarks (e.g., NIST's FRVT extensions for synthetic data validation) to ensure equitable progress. By merging sensing physics, synthetic biology, and decentralized AI, we'll surpass today's accuracy-privacy tradeoffs, and achieve biometrics that are both impervious to attack and inherently trustworthy.

TEOH: You have served as an Area Chair for Computer Vision and Pattern Recognition conferences, an Editorial Board member for *IEEE Transactions on Pattern Analysis and Machine Intelligence*, and an organizer of major biometrics workshops. What mentoring philosophies or governance practices have you found most effective in cultivating rigorous, collaborative research communities, and what advice would you give to early-career scholars entering this field today?

Kumar: My mentoring philosophy centers on fostering an environment of intellectual curiosity, open communication, and mutual respect. I prioritize individualized guidance, encouraging students to pursue their unique interests while upholding high standards of ethical responsibility. Governance-wise, curating workshops with balanced representation (industry, academia, and other demographics) helps tremendously in fostering trust and innovation.

For early-career scholars, my advice is to remain persistent, seek diverse perspectives, and build strong networks. Focus on mastering foundational techniques while staying adaptable to emerging technologies. Prioritize problem-first curiosity over tool-chasing. Engage actively with the broader scientific community through top conferences and publications. Above all, always prioritize integrity in your work and maintain a passion for discovery. These drive meaningful, impactful research in biometrics and beyond.

TEOH: Your portfolio includes several U.S. patents and industry collaborations. What are the principal hurdles in translating laboratory prototypes of hand-based biometric systems into large-scale commercial or governmental deployments. How can academia-industry partnerships best overcome these challenges while preserving scientific rigor and user privacy?

Kumar: The main hurdles in scaling hand-based biometric systems from lab prototypes to large-scale deployments include ensuring robustness across diverse populations, maintaining accuracy under varying environmental conditions, and addressing privacy and security concerns. Additionally, systems need to interoperate with legacy systems, balance accuracy with latency in high-throughput deployments, and comply with regulatory standards. Academia-industry partnerships excel when structured as iterative feedback loops: academia pioneers novel algorithms while industry provides field-testing under diverse conditions. Collaborative pilot studies and joint workshops can help to bridge the gap, ensuring solutions remain scientifically rigorous while prioritizing user privacy or regulatory considerations throughout the deployment process.