Institution:
University of Cambridge

Unit of Assessment:
UoA11

Title of case study:
Iris Recognition

1. Summary of the impact (indicative maximum 100 words)

Professor Daugman's algorithms for automatically recognising persons by their iris patterns are the basis of all publically deployed iris recognition systems. Worldwide some 400 million people have been enrolled since 2004, nearly all during the impact period. Deployments have included automated international border-crossings *in lieu* of passport presentation; watchlist screening; access control; and detainee identification. The algorithms are also used in several national identity card schemes, including the Indian *Aadhaar* programme that, in 2010, began enrolling the iris patterns of all 1.2 billion Indian citizens to ensure fair access to entitlements. By the end of July 2013, 393 million Indian citizens had been enrolled in the programme, and each day a further million are enrolled across 36,000 stations nationwide.

2. Underpinning research (indicative maximum 500 words)

Professor Daugman has been an academic staff member of the University of Cambridge throughout the REF period, beginning his employment at Cambridge in 1991. He was promoted to Professor of Computer Vision and Pattern Recognition in 2009. His research has focused on computer vision, artificial intelligence, and statistical pattern recognition. One major outcome of his research has been an automatic and rapid method for determining a person's identity with very high confidence, by mathematical analysis of the random patterns that are visible in the iris of an eye. No such method existed previously.

The core ideas were developed between 1993 and 2003 and are bracketed by two papers. Daugman's 1993 paper "High confidence visual recognition of persons by a test of statistical independence" [1] set out the theoretical idea that the *failure* of a test of independence could be a very strong basis for pattern recognition, if there is sufficiently high entropy among samples from different classes. Daugman was able to illustrate this principle using a small set of iris images, showing that their variation spanned enough entropy to support identification decisions with extremely high confidence. Daugman's 2003 paper "The importance of being random: statistical principles of iris recognition" [2] confirmed the earlier hypothesis with more than 9 million iris comparisons, inferring about 249 degrees-of-freedom in iris patterns when encoded with complex-valued multi-scale wavelets, a transform that Daugman had pioneered previously in computer vision and in neuro-computing. This coding of complex random patterns into phase sequences revealed a discrimination entropy (information density) of about 3.2 bits/mm^2.

Daugman was granted patents, starting in 1994, in the USA, Europe, Japan, and elsewhere. Once the patents were granted, commercialisation and international deployments began in earnest. Some of these enabled much larger scale evaluations of the core ideas. Daugman's 2006 paper, "Probing the uniqueness and randomness of IrisCodes: results from 200 billion iris pair comparisons" [3], was based on a national deployment of his algorithms in the United Arab Emirates at all 32 air, land, and seaports for watch-list screening. Sheikh Saif bin-Zayed presented to Cambridge University the UAE database of (then) nearly a million enrolled iris patterns from people of 152 nationalities, for mathematical analysis of uniqueness and "collision" probability. This database enabled 200 billion cross-comparisons between the iris patterns of different eyes, generating a definitive binomial distribution with rapidly attenuating tails. The binomial form of the distribution arises from the Bernoulli-trial nature of the phase sign-bit comparisons, and this is critical to collision avoidance in large, national-scale biometric deployments. The 200 billion cross-comparisons remained the record until 2011, when NIST (the US National Institute of Standards and Technology) surpassed it with 1.2 trillion iris comparisons, still confirming exactly the statistical analysis in [3], a point that NIST especially highlighted.

Daugman's 2007 paper "New methods in iris recognition" [4] made the technology more forgiving of poor image acquisition, and his 2008 paper "Effect of severe image compression on iris recognition performance" [5] presented means whereby raw iris images could be compressed to as little as 2,000 bytes without degrading performance. Both are important for the Indian national deployment because of limited bandwidth and infrastructure in remote rural regions. The severe compression methodology became a new international data format Standard, ISO/IEC 19794-6:2011 of which Daugman was editor, published in 2011.

3. References to the research (indicative maximum of six references)

*Indicates those papers most representative of the quality level of the research.

*[1]. Daugman, J. (1993) "High confidence visual recognition of persons by a test of statistical independence." *IEEE Transactions on Pattern Analysis and Machine Intelligence* **15**(11):1148–1161. DOI: http://dx.doi.org/10.1109/34.244676

[2]. Daugman, J. (2003) "The importance of being random: statistical principles of iris recognition." *Pattern Recognition* **36**(2):279–291.
DOI: http://dx.doi.org/10.1016%2fS0031-3203(02)00030-4

*[3]. Daugman, J. (2006) "Probing the uniqueness and randomness of IrisCodes: results from 200 billion iris pair comparisons." *Proceedings of the IEEE* **94**(11):1927–1935.
DOI: http://dx.doi.org/10.1109/JPROC.2006.884092

*[4]. Daugman, J. (2007) "New methods in iris recognition." *IEEE Transactions on Systems, Man, and Cybernetics*, B, **37**(5):1167–1175.
DOI: http://dx.doi.org/10.1109/TSMCB.2007.903540

[5]. Daugman, J., and Downing, C. (2008) "Effect of severe image compression on iris recognition performance." *IEEE Transactions on Information Forensics and Security* **3**(1):52–61.
DOI: http://dx.doi.org/10.1109/TIFS.2007.916009

For his iris recognition algorithms, Daugman won the British Computer Society's IT Award and Medal in 1997, the UK Design Council's "Millennium Product" Award in 1998, the Smithsonian Award in 2000, the Time 100 Innovators Award in 2001, and he was honoured with an OBE in 2000. In 2009 he was a Finalist (one of three) in the "European Inventor of the Year" Awards of the European Patent Office, and in 2013 he was inducted into the USA National Inventors Hall of Fame. In 2010 he was awarded the Wavelet Leadership Award by the International Society for Optical Engineering; in 2011 he was made a Fellow of the Institute of Mathematics and its Applications, and in 2012 a Fellow of the International Association for Pattern Recognition.

4. Details of the impact (indicative maximum 750 words)

All publicly operational iris recognition systems worldwide deploy, as licensed executables, the Daugman algorithms. Today they are owned by the French conglomerate Safran-Morpho, for whom Daugman serves in a consultancy role as Chief Scientist for Iris Recognition. From 2007 through 2011 they were owned by L1, for whom Daugman served in the same capacity, until L1 was acquired by Safran-Morpho. This pattern of successive corporate acquisitions with Daugman as Chief Scientist extended prior to 2007 with the companies Securimetrics, Iridian, and IriScan (who were the first to commercialise the technology).

Many device integrators and camera makers became licensees during the past decade, whose brand names include Panasonic, Oki, LG, Sagem, IrisGuard, Unisys, Sarnoff, Privium, BI2, PIER, and CLEAR. Government deployers use the brand names IRIS (the UK Home Office **I**ris **R**ecognition **I**mmigration **S**ystem); UIDAI (**U**nique **Id**entification **A**uthority of **I**ndia); CANPASS (in lieu of Canadian Passport presentation at all eight of Canada's international airports); and NEXUS (bi-directional USA/Canadian border crossings).[7]

There have been various civilian applications of the iris recognition algorithms based within airports during 2008–2013, in five different modes of use, with the following beneficiaries and impacts:
(1) Arriving passengers who are enrolled in automated iris recognition systems (such as IRIS, trialled at 10 UK airport terminals; Privium at Schiphol Airport; CANPASS and NEXUS at several USA and Canadian airports; and ABG at Frankfurt) avoid waiting in long queues for passport presentation and immigration clearance. The UK Border Agency describes iris recognition as a 'secure biometric,' but has now chosen to decommission its IRIS scheme because the new

biometric e-passports do not include iris information. Nevertheless, the IRIS system proved influential in informing the debate about biometric identification. (2) Departing passengers at several airports enjoy expedited security screening, if they have been deemed low-risk by US agencies in “Registered Traveller” programmes such as CLEAR; iris recognition at such gates establishes or confirms their identity. At Tokyo Narita Airport, expedited iris-based check-in and “e-Airport” guidance is given to passengers. (3) Airline crew members use iris recognition at special portals to gain expedited access to the secure air-side, at airports such as Schiphol and Charlotte-Douglas, avoiding the long queues of departing passengers. (4) Airport employees gain access to restricted areas such as the tarmac, baggage handling, and maintenance facilities, using iris recognition at Schiphol and JFK airports. (5) Watch-list screening of arriving passengers based on the iris recognition algorithms continues with more than 2 billion iris comparisons daily in the United Arab Emirates and also in other Gulf States, with persons of some 170 nationalities enrolled. The UAE system began deployment in 2002. During the REF impact period, new deployments were launched in Qatar, Oman, and Jordan. Expellee databases are exhaustively searched in real-time to detect persons who are deemed dangerous or for other reasons excluded from entering a country, for the benefit of security and law-enforcement. For example, in the first nine months of 2012 there were more than 20,000 detections of persons travelling with forged documents, who were matched to their true identities as *persona non grata* by the iris recognition systems.[10]

In 2011 the Government of India launched the national UIDAI [6,14,15] project to enrol the iris patterns of all 1.2 billion citizens within three years in an ID entitlements scheme. This followed a successful pilot in 2010 enrolling and confirming identities of tens of millions of citizens in the state of Andhra Pradesh, using the Daugman algorithms. The goal of UIDAI is to issue every person with a biometrically provable unique entitlement number (Aadhaar) by which a host of benefits and services may be accessed, which are currently inaccessible because of lack of means to prove one’s identity (only 4% of Indians hold a passport, and fewer than half the population hold a bank account; the problem is especially acute in rural areas). Daugman’s iris recognition techniques were chosen for this purpose because they were found to be significantly faster and more accurate than other biometric modes such as fingerprints.[14,15] UIDAI aims to enhance social inclusion. It is noteworthy that the scheme is voluntary yet millions of people perceive the advantages of the scheme and queue to enrol. Similar national projects are underway in Indonesia and several smaller countries.

One significant challenge of the UIDAI system, successfully addressed by the Daugman methods, is detection of multiple identities. UIDAI requires this during enrolment to prevent fraudulent acquisition of multiple entitlement identities. Each new registrant must be compared with all existing ones, so the problem scales as the square of the population, requiring 10^{18} pairings. The Daugman methods provide both enormous resistance to false matches, and enormous speed of matching. With 389 million persons enrolled as of July 2013 and a further million enrolments every day, some 10^{14} iris comparisons are performed every day. The bit-parallel logic in the matching algorithms allows 64 bits of two IrisCodes to be compared in a single clock cycle. The factorial term domination of the binomial distribution resulting from comparisons between different eyes (as strongly confirmed independently by NIST in 2012) generates the rapidly attenuating tails which cause the extreme resistance to false matches, as discussed in all of references 1–5.

In addition to its technical impact, Daugman's iris recognition system has had impact on social and political policy, informing the debate about identity systems [11,12,13]. As an example of a robust identity system, it made concrete the previously-abstract debates about the use of biometrics for identity controls and spawned a debate in India and beyond about the morality and ethics of such an ID system.

5. Sources to corroborate the impact (indicative maximum of 10 references)

6. Indian UIDAI website and dashboard :
http://uidai.gov.in
https://portal.uidai.gov.in/uidwebportal/dashboard.do

7. L1 / MorphoTrust: Director Biometric Research

8. Licensee LG: CEO

9. History of acquisitions IriScan/Iridian/Securimetrics and LG/AOptix major airport deployments: Vice President, Market Development, Biometrics Programs

10. UAE Government article on iris scan preventing entry of 20,000 deportees into UAE: http://www.id.gov.ae/en/media-centre/news/2012/11/4/iris-scan-prevented-entry-of-20000-deportees-into-uae-director-general-of-abu-dhabi-police-central.aspx

11. "Ten Reasons Why IRIS Needed 20:20 Foresight: Some Lessons for Introducing Biometric Border Control Systems" Anthony J. Palmer and Chris Hurrey, 2012 European Intelligence and Security Informatics Conference
PDF: http://www.csis.pace.edu/~ctappert/dps/EISIC2012/data/4782a311.pdf
Debate about biometric identification at borders

12. BBC Radio 4 *In Business* broadcast 21st April 2012
http://www.bbc.co.uk/programmes/b01rw3yw
Debate about the ethics and morality of ID systems

13. BBC Radio 4 broadcast One Billion Digitally Identified Indians, 10th July 2013
http://www.bbc.co.uk/iplayer/episode/b036kscl/One_Billion_Digitally_Identified_Indians/

14. Statement from UIDAI former designer, UID Authority of India

15. Statement from UIDAI Advisor, UID Authority of India