Iris recognition border-crossing system in the UAE

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The largest national deployment so far of iris recognition – the automatic recognition of persons by the complex patterns visible in the irises of their eyes – is now in its third year of operation in the United Arab Emirates (UAE).

Over a distributed network involving all 17 air, land, and sea ports into the Emirates, the iris patterns of all arriving passengers are compared in real-time exhaustively against an enrolled central database. According to the Ministry of Interior which controls the database, so far not a single False Match has been made, despite some 2.7 billion iris cross-comparisons being done every day.

On a typical day, more than 6,500 passengers enter the UAE via seven international airports, three land ports, and seven sea ports. By looking at an iris camera for a second or two while passing through immigration control, each passenger's iris patterns are encoded mathematically and the resulting IrisCodes sent over a distributed communications network to a central database controlled by the General Directorate of Abu Dhabi Police. There they are compared exhaustively against an enrolled database of 420,000 IrisCodes of persons who were expelled from the UAE for various violations, many of whom make repeated efforts to re-enter the UAE with new identities using forged travel documents. Thus the current daily number of iris cross-comparisons performed under the UAE expellee tracking and border-crossing control system is about 2.7 billion. It is the first system of its kind in the world, with more than 2.1 million arriving passengers already checked in this way. The time required for each passenger to be compared against the full database of registered IrisCodes is less than one second. So far more than 9,500 persons have been caught by this system, travelling with forged identities. According to Lt. Col. Ahmad Naser Al-Raisi, Director of the Information Technology Department at the General Directorate of Abu Dhabi Police, "We found the system to be very effective and extremely fast. Its speed, accuracy, and ease-of-use enabled us to deploy the project without difficulties."

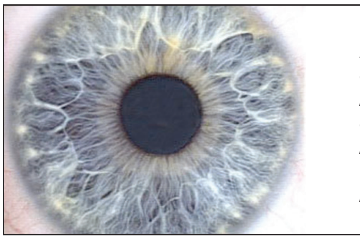

Figure 1: Example of a human iris, illustrating the complexity and randomness of these unique identifying patterns

Figure 2: Deployment map of the fully networked Iris Recognition System covering all 17 air, land, and sea ports into the United Arab Emirates

The UAE national iris recognition system is a synthesis of three core components: iris cameras with autofocus and autozoom, developed by LG; the iris recognition algorithms, developed by John Daugman of Cambridge University; and a networked distributed server and communications architecture called 'IrisFarm', developed by Imad

Malhas of IrisGuard Inc. It allows simultaneous enrollments into the central database without interrupting parallel search queries from multiple distributed stations; and it offers almost unlimited

Figure 3: An arriving passenger at Dubai Airport being compared against 420,000 registered iris patterns in about one second

scalability to national populations of registered persons and travellers without reduction in execution speed. Critical features of the IrisFarm architecture include:

- Ability to split the full national database of IrisCodes into an unlimited number of parallel search engines ('IrisEngines'). Each search engine can perform more than 500,000 complete iris comparisons per second
- Support of a diverse communications network, including very slow links. Even links as slow as 33.6 KBytes/sec are compatible with real-time performance on iris recognition requests
- Automatic synchronisation of IrisCode data from detached enrollment locations
- Uninterrupted search capability during synchronisation
- Use of separate hardware components for enrollment, central database maintenance, and recognition functions. This maintains predictable performance and allows load-sharing, distributing the computing workload to match demand with available resources and providing resilience against faults
- Adaptive modularity, allowing hardware to be added to support any requirements for response speed or database size
- Automatic backup procedures, together with 'hot standby' capability to switch the entire Farm to a second emergency location in mission-critical applications

Although this system was designed to prevent illegal immigrants and former expellees from entering a country using fraudulent travel documents, by comparing the iris biometric of all arriving passengers against a 'negative watch list' of detainees, all aspects of the IrisFarm architecture, cameras, and the core iris recognition algorithms are equally suited for 'positive' applications in which the main goal is to enhance the convenience, speed, and efficiency of border-crossing formalities for legitimate travellers. Such deployments (using the same Daugman algorithms) are already in place at airports in several countries, notably Schiphol Airport in The Netherlands, several Canadian airports, Frankfurt Airport, and at ten UK airport locations, starting in late 2004.

The 420,000 registered UAE expellees represent more than 180 nationalities, and, of course, the 2,128,300 arriving passengers who all have been compared against that search database represent all nationalities. Since the majority of the world's people have dark brown irises, which in the visible wavelengths of light used (by definition) by our human visual systems appear to show little iris pattern structure or texture, it is often surprising to new observers of this technology that iris recognition can work at all with such populations,

Figure 4: An infrared wavelength iris camera, using the same Daugman algorithms for iris recognition at Schiphol Airport, NL

let alone work so well. But in the infrared wavelengths of illumination (700 nm – 850 nm) used by iris cameras, such as the one pictured, even dark brown eyes usually reveal a rich texture more complex in detail than fingerprints.

Most nationals of the Arabian Gulf states have dark brown eyes, like the one shown in Figure 5 illuminated in infrared light. But blue eyes are more common in the region than one might expect. This is deemed to be a legacy of the Crusades unleashed against the Middle East by medieval Christian Europe. Like invading armies everywhere, Christendom's Holy Crusaders left their genetic imprints behind in their wake.

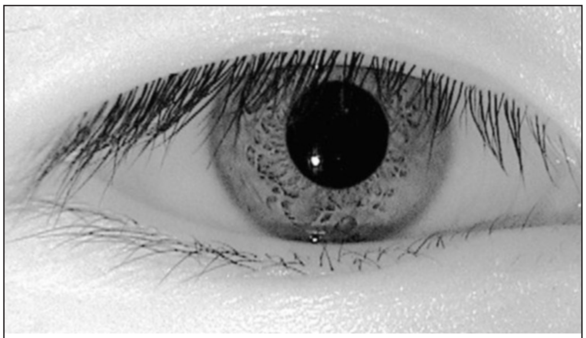

Figure 5: With infrared illumination, even dark brown eyes reveal rich iris texture difficult to see in visible wavelengths

How iris recognition works

As described in an earlier general article (International Airport Review, Issue 3 2003), the iris recognition algorithms begin with locating the iris in an image, and determining the boundaries of the iris and the eyelids. The iris texture is then encoded by a mathematical process called demodulation, creating a phase sequence that resembles a DNA sequence in that it extracts local phase in four states. This representation of an iris pattern is invariant to the size of the iris in the image, and hence invariant to the distance of the eye and the optical magnification of the camera. It is also invariant to changes in the size of the pupil within the eye, because the polar coordinate system is dimensionless and automatically compensates for the elastic deformations in the iris pattern as the pupil dilates or constricts.

Two examples of processed iris images, from two different eyes, are illustrated. All colour information is discarded, so the infrared images appear black and white. The white outline graphics show results of the automatical localisation operations, and the bit streams shown as 2D 'bar codes' are the actual IrisCodes, comprising 512 bytes each.

The algorithm for encoding and comparing iris patterns is illustrated schematically in the network diagram. Iris patterns A and B are demodulated into phase sequences using mathematical functions called wavelets, producing a unique bit stream for each iris. These IrisCodes are compared to each other bit by bit (notionally one IrisCode for an arriving passenger is compared exhaustively against every IrisCode enrolled in the database), to see if they match. This question is decided simply by counting the fraction of bits that disagreed between two IrisCodes, which is a measure of dissimilarity called their Hamming Distance. Because this measure has an extremely well-defined distribution, a simple threshold suffices to deliver a 'yes' or 'no' answer.

Performance in tests

The distribution of Hamming Distances between different eyes' iris patterns has a very stable and well-defined mathematical form called a Binomial Distribution, as illustrated in Figure 8 in the distribution plotted from 204 million such comparisons. The most important feature of this distribution is its very rapidly attenuating tails. These reduce to zero at an astronomical rate because the statistical probability of two independent bit sequences happening 'just by chance' to agree in significantly more or fewer than 50% of their bits theoretically decays by factorial

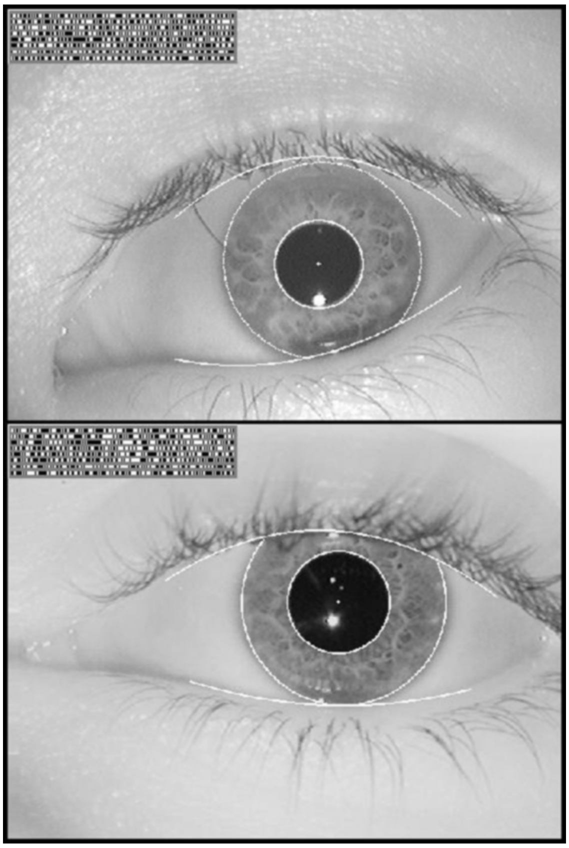

Figure 6: Examples of the IrisCode bit streams computed for two different eyes. The white outlines illustrate automatic localisation of the iris and eyelid boundaries

functions, which are among the most mathematically severe functions known. Thus, for example, among the 204 million different eye comparisons plotted in this distribution, no two IrisCodes had a Hamming Distance smaller than 0.290, which means that no two different eyes could agree by chance in more than 71% of their bits (hence disagree in fewer than 29% of their bits).

This extraordinary property is the reason why iris recognition has no rival among biometrics in terms of accuracy and in reliability against making

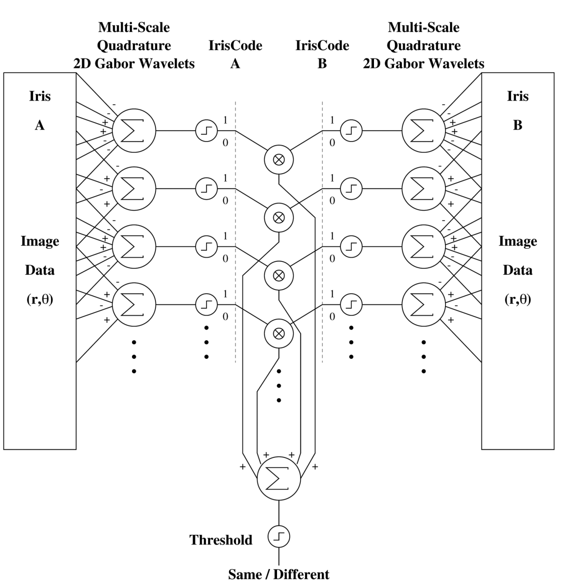

Figure 7: How iris patterns are compared. Bit streams that encode the complex random iris textures of two eyes, A and B, into phase sequences are fully compared bit-by-bit. If the total fraction of disagreeing bits (Hamming Distance) is smaller than some threshold, adapted to database size, then the two iris patterns are deemed to be the same

False Matches. Physically, this is due to the amount of randomness contained in iris patterns as extracted by the algorithms, which can be calibrated mathematically in terms of the 'number of degrees of freedom.' Statistically, iris patterns (at least as demodulated and encoded by the Daugman algorithms) contain about 250 degrees of freedom, which is far greater than that extracted by face

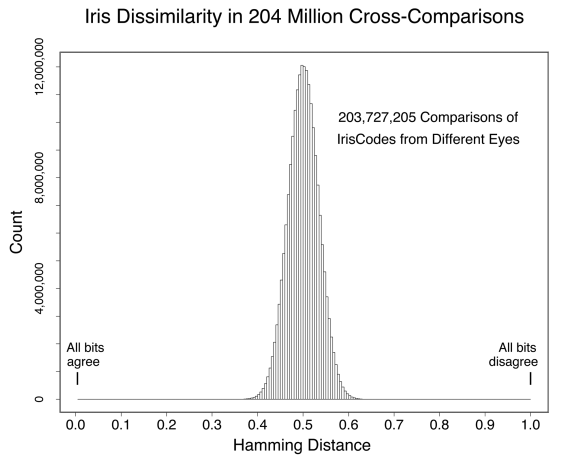

Figure 8: Distribution of dissimilarity scores (Hamming Distances) obtained from comparisons between 204 million different iris pairings. Any given bit in two different IrisCodes is equally like to agree or disagree, so the average score is near 0.5, and very few can be far from this score

recognition or fingerprint algorithms from faces and fingerprints.

This basic mathematical advantage was reflected in performance tests conducted in 2001 by the UK Government, comparing the accuracy of many different biometric technologies. Their results were summarised in the multi-curve plot showing the trade-off between False Reject Rate and False Accept Rate for each biometric tested. Such curves are called ROC (Receiver Operating Characteristic) curves, and they are generated by varying the decision threshold to be more liberal or more conservative, revealing a trade-off: the extent to which any improvement in one of the two rates of error must be 'paid for' by a worsening of the other error rate. Clearly the goal is to get as far into the lower left-hand corner as possible, since that corresponds to achieving simultaneously the minimal number of False Accepts and False

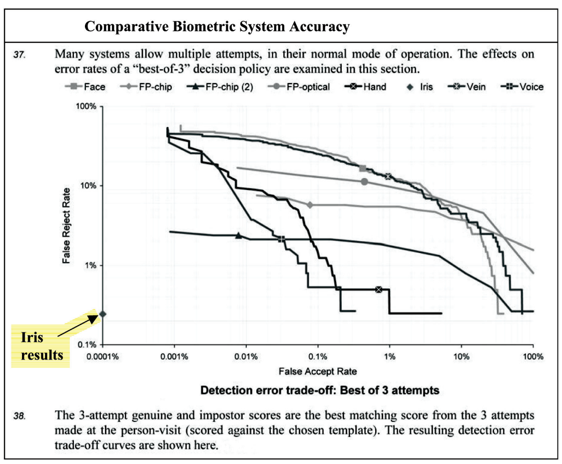

Figure 9: Independent tests conducted by the UK Government in 2001, comparing the accuracy and reliability of many different biometric technologies. By achieving simultaneously 0 False Matches and the lowest rate of False Rejects, the study showed that the Daugman algorithms described in this article (yellow) were without rival among biometrics

Rejects. As the UK Government report (Figure 9) clearly shows, the Daugman iris recognition algorithms (represented by the isolated point plotted in the lower-left corner) were without rival among all the biometrics tested. In 2.3 million iris comparison tests, there were no False Matches made, and only 0.2% False Rejections on the third attempt.

The UAE deployment of iris recognition technology is currently the largest in the world, both in terms of number of persons enrolled (420,000) and number of iris comparisons performed daily (2.7 billion) in 'all-against-all' search mode. An important aspect of its successful performance is the fact that the decision thresholds are automatically adjusted according to the size

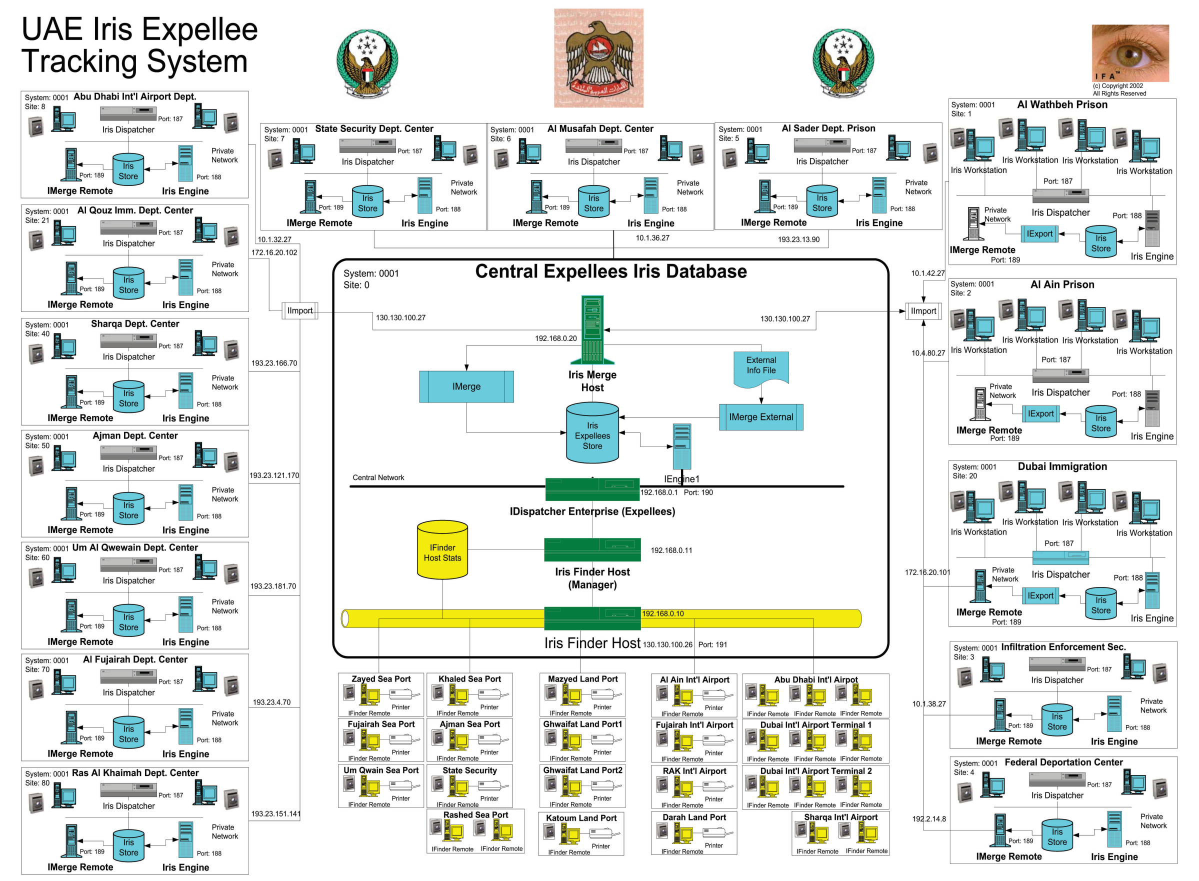

Figure 10: The distributed and fully networked 'IrisFarm' architecture developed by IrisGuard Inc. for the UAE border crossing and expellee tracking system. An unlimited number of parallel IrisEngines ensure scalability over national databases regardless of size, while synchronisation of data enrolled over diverse locations occurs without interruption of simultaneous real-time identification search requests

of the enrolled database, and hence the number of comparisons performed, so that there is no net accumulation of probability of False Matches despite such a vast number of opportunities. Indeed, all of the 9,506 matches made so far between arriving passengers and former detainees or expellees on the 'watch list' have been subsequently confirmed by other records, exposing the fraudulent travel documents.

Biometrics lacking the very favourable binomial distribution tails discussed earlier cannot afford to operate in this 'all-against-all' identification search mode; they suffer from net accumulation of error probability and therefore make False Matches, just like playing a game of Russian Roulette an increasing number of times. When these favourable mathematical aspects of the iris recognition algorithms are combined with the sophisticated database management, distributed hardware, and communications network of the IrisFarm architecture, as summarised in Figure 10, the result is an extremely efficient and accurate system for identification of persons on a national scale. Having proven itself decisively in the Emirates, this system is ready for service in diverse types of large-scale national deployments.■

John Daugman, OBE, is a permanent member of the Faculty at Cambridge University, UK, where he teaches courses in Computer Vision, Information Theory, and Pattern Recognition. He received his AB and PhD degrees at Harvard University, USA, where he also subsequently taught on the Faculty. Daugman is the inventor of iris recognition for personal identification, for which he received US Patent 5,291,560 in 1994. These algorithms have won several awards and medals from computer societies, and they are the software running in all current public deployments of iris recognition. For more information about this technology, its uses, and how it works, visit http://www.CL.cam.ac.uk/users/jgd1000/

Imad Malhas is a founding member of IrisGuard Inc. and is the main designer of the IrisFarm Architecture for real-time iris recognition, enrollment, and database management on a national scale. Mr. Malhas has an extensive technical background in the field of information technology and is considered a pioneer in software development in the Middle East. He received his B.Sc. degree in Computer Science from the University of Wisconsin (Milwaukee, USA) in 1984, thereafter holding various IT managerial positions until founding IrisGuard Inc. in 2001. IrisGuard is today the world leader in large-scale iris recognition systems deployment and integration, and has offices in the UK and the Middle East. For more information, visit http://www.irisguard.com/

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