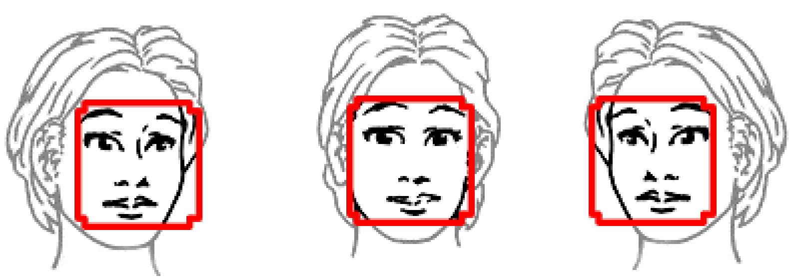
AcSys Biometrics Corp.

The AcSys Face Recognition System

Applied Biomimetic Intelligence



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Overview

The AcSys Face Recognition System (AcSys FRS) is a revolutionary biometric technology based on the most advanced neural network platform available today. AcSys FRS is enabled by Holographic/Quantum Neural Technology (HNeT), which is modeled on the functional and neurophysiological characteristics of the human brain.

John Sutherland, chief scientist for AcSys Biometrics Corp. and AND Corporation, developed HNeT through many years of research in the field of Artificial Intelligence. The result of his research is an artificial neural network with the ability to learn and recall that is magnitudes greater than that of other neural networks. Simply put, HNeT emulates human cognition: it learns and recalls in the same manner as you or I do. It absorbs the world around it as a child does.

HNeT is complex in its use of mathematical abstraction, and in its analogies to neurophysiology and quantum mechanics. What follows is a simplified account of these abstractions and analogies, and how AcSys FRS uses them to provide the most effective face recognition technology available today.

History of an Idea

The history of science and technology is both evolutionary and revolutionary.[1] In order to understand the truly revolutionary nature of AcSys FRS and HNeT, we need to view them in the context of history. The history of face recognition technologies is brief but eventful. The rapid development of computers and computerized methods of analysis has allowed what was once a fanciful notion from science fiction to become, in little more than twenty years, a very real and practical technological fact.

Face recognition has long been regarded as an extremely difficult task for a computer - a technological challenge worthy of Artificial Intelligence research. It is the kind of cognitive process which is hardest for machine intelligence to emulate, because, of all biometric methods, face recognition is the most human: although we use many physiological and behavioral cues to recognize other humans, chief among these is the appearance of the face.

Early Face Recognition Paradigms

Two technologies developed in the late 1980s and early 1990s have dominated the debate on face recognition until recently:

- Eigenface
- Local Feature Analysis

These technologies were developed at MIT and Rockefeller University, respectively. Although developed in different labs, they bear some resemblance.

[1] T. S. Kuhn, *The Structure of Scientific Revolutions*. Kuhn argues that the history of science is marked by paradigm shifts – revolutions in the way we perceive the world, and which we associate with figures such as Copernicus, Newton, Einstein, and Planck. Paradigm shifts are followed by evolutionary periods in which we “normalize” the new paradigm.

Eigenface/Principal Component Analysis

In the late 1980s, scientists at MIT developed the eigenface method of face recognition. The word ‘eigenface’, half German and half English, can be translated roughly as “one’s own face”. In terms of a technical definition, an eigenface is a two-dimensional, grayscale image representing distinctive characteristics of a facial image. The distinctive features are stored by the system as coefficients.

Advocates of this technology maintain that most human faces can be reconstructed by combining features drawn from a set of between 100 and 150 such eigenfaces. In other words, although there are more than 5 billion individual human faces on this planet, they can all be reconstructed from fewer than 150 eigenfaces. Eigenface components are used to build facial images. Software applications using this technology analyze a facial image, calculate its eigenface value using distinctive feature coefficients (essentially deconstructing the face into its eigenface components), and compare that value to a template or database of templates to find matching or similar eigenface values.

The ability of systems using this technology to match faces to templates is highly dependent on lighting and facial angle. Since the templates generally do not incorporate a variety of images taken in different lighting conditions and at different angles, eigenface technology works best when the system views faces frontally and in consistent lighting conditions. Its ability to generalize across facial poses has been found to be rather poor.[2] Generalization refers to the technology’s ability to view a face in less than optimal conditions (such as from an angle other than frontal) and find a matching template – in other words, its ability to move from the specific representation (the facial image) to the general representation (the template).

Facial Metrics/Local Feature Analysis

In the early 1990s, researchers at Rockefeller University developed a face recognition technology that came to be known as Local Feature Analysis (LFA). This technology extracts a set of local features from a set of sample human faces and uses them as building elements. It then combines these elements, as well as their relative arrangement, as a means of verifying and/or identifying faces.

This technology is similar to Eigenface technology, but is said by its proponents to be less sensitive to facial expressions and changes in pose and lighting. It measures a face according to a subset of nodal points within the inner region of the face (e.g. the distance between the inside corners of the eyes, the distance between the outside corners of the eyes and the outside corners of the mouth) and the relationship between these measurements. However, it still takes a mechanical approach to the problem of face recognition, differentiating faces according to a small set of measurements and relations between points.

HNeT Concepts: From Biometrics to Biomimetics

Using HNeT neural network technology, AcSys FRS applies artificial intelligence to the problems of lighting conditions and facial orientation for an increased ability to authenticate identity in adverse conditions. The application of HNeT to the problem of face recognition represents a revolution that the word “biometric” can no longer contain. We refer to AcSys FRS

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[2] Space-Time 3D Body Biometrics for Human Identification, Carnegie Mellon University (DARPA sponsored), 2001.

as a *biomimetic* technology, because it actually emulates the way the human brain learns and recalls faces.

Biomimetic intelligence is the science of understanding and replicating the processing mechanisms and structure of the brain. Traditional neural networks have little or no resemblance to actual neurological structures, and more importantly, have proven to be very limited in capability. HNeT technology, however, applies the power of digital holography within synthetic neuron cells. Assemblies comprised of such cells have one-to-one correspondence with the primary cell structures of the brain. These biomimetic structures provide the capability for real-time learning, and present a vast increase in memory storage capacity.

The key to the human brain's ability to recognize faces is its ability to generalize. If you meet a person before he or she vacations in the Caribbean, you are still able to recognize that person's when he or she returns with a tan. You continue to recognize the person because your brain applies biomimetic intelligence. Your brain does not simply measure the distance between nodal points. Instead, you gather an overall impression of the face – an abstract understanding of what makes that face unique. When you see that face with minor variations, whether due to lighting conditions, angle of reception, or cosmetics, you generalize from the specific information received to that abstract understanding of identity.

Understanding Through Analogy

For a better understanding of how AcSys FRS emulates the human brain's cognitive abilities with regard to the problem of face recognition, we need to use some of the analogies explicit in the HNeT name. We use words such as "holographic" and "quantum" not because we literally build holographic images or employ sub-atomic particles in some novel way, but because such analogies are the easiest way to convey the truly revolutionary nature of this technology to those who do not have graduate degrees in mathematics.

These terms are used as analogies – aids to understanding. If you have ever tried to describe the taste of a strawberry, you'll know that it is not an easy thing to do. Have you ever wondered why so many foods are described as tasting like chicken? The reason is that it is practically impossible to describe such simple sensations as taste in literal terms, so we rely on analogies – figurative language - to convey our impressions. We never ask what a food's taste *is*. We ask what a food tastes *like*.

Similarly, we experience some linguistic difficulty when we attempt to describe the mathematical abstractions that make HNeT and AcSys FRS possible. Those of us with no more than a high-school education in mathematics need some help. To allow us to describe this technology, and to allow a substantial portion of the public to grasp it, we need to use analogies from holography, neurophysiology, and quantum mechanics. We need these analogies to express just how revolutionary this technology is.

The Holography Analogy

AcSys FRS is often referred to as a 3D recognition system, because it looks at the whole face, rather than at a fixed number of points. It sees the entire face as you would. However, AcSys FRS does not literally construct a holographic image using multiple cameras.

AcSys FRS captures a number of images of the face from multiple angles (up to 45 degrees from frontal) using a single camera. It then uses HNeT to 'train' on these images. The resulting engram, or memory trace, is not a 3D image of the user, but rather a biometric template that can be used to verify or identify a user whose 2D image is presented from varied angles in varied lighting conditions. The solution provided by AcSys FRS is not a physical hardware solution, but a software solution based on HNeT.

The holography analogy is the key to understanding how AcSys FRS is able to generalize from a facial image received via 2D video feed to an abstract mathematical expression of that face.

The Neurophysiology Analogy

As HNeT emulates human cognition, it is quite natural that it also emulate the language of human cognition. HNeT cells have been given biological names due to their similarity to specific classes of neuron cells in the neo-cortex, cerebellum, and hippocampus (Purkinje, Granule, Pyramidal, and Stellate cells). HNeT also uses functions designed to emulate cell assembly characteristics such as neural plasticity. Neural plasticity guides the process of synaptic pruning and regrowth. This process automatically adapts and optimizes the neurological structure during stimulus-response learning, providing a dramatic improvement in accuracy and generalization.

HNeT allows a synthetic neuron cell to learn tens of thousands of stimulus-response memories in less than a minute, and respond to tens of thousands of stimulus patterns in less than a second. AcSys FRS combines large numbers of holographic/quantum neural cells into cell assemblies, much like the cell assemblies found in the human cortex, to process myriad images simultaneously and provide a highly reliable means of differentiating individuals.

The Quantum Analogy

HNeT is based on Hilbert space mathematics, as is quantum mechanics. HNeT extends the concept of Hilbert space from the realm of quantum mechanics to that of information processing. A Hilbert space has been defined as an inner product space, which, as a metric space, is complete.[3] If you are like me, that definition does not help you much. David Hilbert's work is far too complex to discuss here, but it should suffice to say that his work on infinite-dimensional space, known as Hilbert space, became the foundation for the quantum wave equation, which is itself the basis of quantum mechanics.

In a simplified way, the operations performed by an HNeT cortical cell are identical in form to the quantum wave equation. In other words, the wave equation describes the learning process that takes place when AcSys FRS learns a face. Both of these processes make use of the concept of *enfolding*.

In the case of HNeT, learning enfolds multiple stimulus-response memory elements – perhaps thousands – onto a single waveform, or engram, which serves as the biometric template used to authenticate the individual's identity. This enfolding (or training) process is the reason that the size of a template in AcSys FRS remains constant regardless of the number of images used to build it, and why AcSys FRS can retrain on an individual (i.e., update the user's template with additional images) without increasing the size of the template. It is this ability which allows AcSys FRS to retrain automatically and maintain its ability to recognize a face in different conditions from various angles.

The concept of enfolding originates in David Bohm's work on *implicate order*. He saw sub-atomic reality as an enfolded, implicate order constantly unfolding into what we see as objective reality – the "explicate" order. Interestingly, the works of both Hilbert and Bohm are quite metaphysical – both speculate heavily on the nature of reality. One of Hilbert's contemporaries,

[3] See C-I Tan, Notes on Hilbert Space, Brown University, for an online discussion (http://jcbmac.chem.brown.edu/baird/QuantumPDF/Tan_on_Hilbert_Space.html)

Paul Gordan, once said of Hilbert's work "That's not mathematics; that's theology." Some time later, after Hilbert's work became widely accepted, Gordan commented: "I have convinced myself that theology also has its merits."[4]

What Actually Happens When You Use AcSys FRS

AcSys FRS face recognition consists of a number of processes, including:

- Enrollment
- Training (and Retraining)
- Tracking
- Authentication

When an individual "enrolls" in the system, the system "trains" on the user. When the enrolled individual steps into the system's field of view, the system begins to "track" him or her. To "authenticate" the individual, the system captures multiple images from the live video feed and compares them against the engram representing the claimed identity (in one-to-one, verification mode), or against a database of engrams representing the entire user base (in one-to-many, or identification mode).

Enrollment

Before the system can differentiate an individual, the individual must exist within the system's database. That is, the system must have an engram, or biometric template, against which to authenticate video images of the user's face, and it must know the identity with which the engram is associated. The engram is a mathematical abstraction based on a set of images of the individual. The act of capturing images of an individual and training on them to create the engram representing that individual is known as *enrollment*.

Training and Retraining

After the system has received the initial images, it performs an operation on these images known as *training*. Training is the process in which HNeT performs multiple comparisons of the biometric data represented by these images to a large set of facial images contained in a training database. Using HNeT, AcSys FRS literally learns to differentiate the individual's face from the faces represented in the training database.

The training database for any given organization will represent a demographic cross section of society, as well as all of the individuals within the organization that are currently enrolled. The larger the database, the better AcSys FRS is able to differentiate the individuals within it and compared to it.

During training, HNeT runs through the training database several times, each time enfolding a refined understanding of the individual's face onto the individual's engram. With each pass, the system refines its ability to differentiate the user. This process is also the key to the system's ability to update its understanding of the individual's appearance through retraining.

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[4] Cited by John S. Garavelli, *Hilbert Space: aspects of one century and prospects for the next*, Retiring President's Lecture, Philosophical Society of Washington, January 14, 2000. (http://home.earthlink.net/~jsgaravelli/MYTALK.HTML)

Retraining is the process of capturing additional images of a user and enfolding the new biometric data onto the existing engram. Because people change – a face is variable rather than constant – AcSys FRS includes retraining capabilities. In effect, the system continues to learn and refine its ability to recognize individuals as they change. It enfolds new perceptions of the individual onto the existing engram without altering the size of that engram. If you so choose, you can configure AcSys FRS to retrain on users automatically when it verifies their identities.

It is important to note that the engram representing an individual does not actually contain images of the individual: it is a mathematical abstraction created that cannot be reverse engineered to produce an image of the individual.

Authentication

AcSys FRS operates in both verification and identification modes, and includes configurable thresholds that allow you to adjust recognition sensitivity.

Verification Mode

Verification occurs when the individual provides both biometric and non-biometric input and the system verifies the biometric evidence against the non-biometric. For example, an individual might swipe a card that represents him as “John Smith”. The individual then stands in front of a video camera and the system captures images and compares them against the mathematical abstraction, or engram, of John Smith on record. If the individual is indeed the John Smith on record, the system verifies his identity. This verification scenario is also known as “one-to-one” face recognition, because the system matches one user to one engram in order to authenticate the user’s identity.

Identification Mode

Identification occurs when the individual provides only biometric input and the system compares that biometric input against all engrams on record to determine the individual’s identity. For example, an individual steps in front of a camera and the system captures multiple images of him. The system then compares this biometric sample against the set of engrams in the database and eliminates engrams until it is certain of a match. When the system matches the sample to an engram, then the system identifies the individual as the person represented by the engram. Systems that identify in this manner are said to use “one-to-many” face recognition, because they compare a biometric sample representing one individual to many engrams in order to authenticate the user’s identity.

Configurable Thresholds

One of the advanced features that differentiates AcSys FRS from many other biometric solutions is its configurable thresholds. With AcSys FRS, you can set various thresholds that control the sensitivity of the system. This feature allows you to determine the appropriate level of security for each implementation of the system. Being able to configure these thresholds is vital, because you need to be able to balance the user’s experience and convenience with your security needs. For example, you would likely set these thresholds higher to control access to a sensitive facility than you would for a time & attendance application.

Conclusion

AcSys FRS revolutionizes the science and technology of face recognition. Using HNeT, it provides speed, accuracy, and intelligence by approximating the way the human brain learns and recalls.

AcSys FRS represents a substantive advance over earlier face recognition technologies based on Eigenface/Principal Component Analysis (PCA) and Facial Metrics/Local Feature Analysis (LFA). While these earlier technologies take a mechanistic approach to the problem of face recognition, AcSys FRS takes a holistic approach, much as you or I do when we recognize the face of a friend or coworker.

Because HNeT, the technology underlying AcSys FRS, emulates the way the human brain works, we refer to it as a biomimetic technology. Understanding the mathematical principles that makes this technology possible is difficult, especially for those of us without advanced mathematical training. To facilitate understanding of this revolutionary technology, we use analogies from holography, neurophysiology, and quantum mechanics. Only through the use of such analogies can we express how truly revolutionary this technology is.

- AcSys FRS is holographic in that it forms an impression of the whole, three-dimensional face, and does not simply recombine elements or measure features.
- AcSys FRS emulates neurophysiology in structure and process to provide real-time learning with speed and accuracy.
- AcSys FRS applies the quantum wave equation to learning, enfolding large amounts of data onto a single waveform, or engram, which serves as the biometric template used to authenticate identity.

What these analogies mean in real terms is that AcSys FRS:

- Learns to recognize an individual's face by repeated exposure in a variety of conditions and poses - the same way you or I learn to recognize a face
- Continues to refine its understanding of facial identity with each exposure
- Easily differentiates faces from background noise and tracks up to four faces simultaneously
- Authenticates identity with more speed and accuracy than any other system available today

AcSys Biometrics

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Contact us if you want to find out more about the possibilities for AcSys FRS within your organization.

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