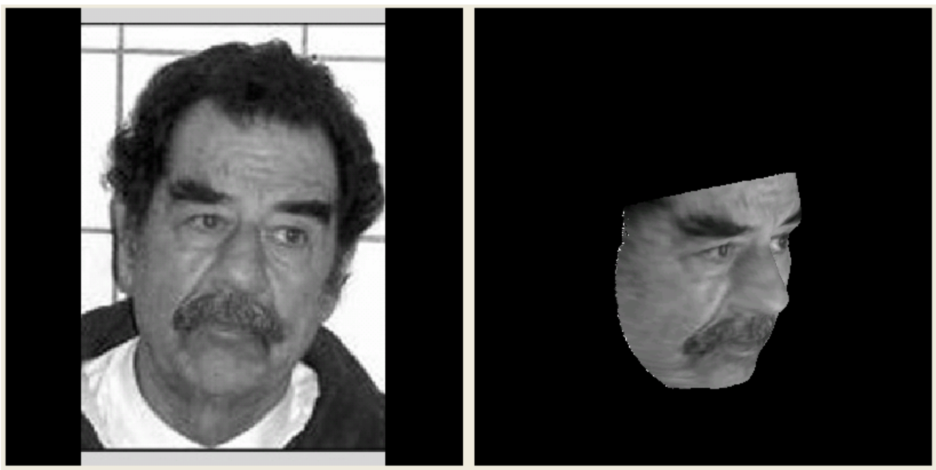
WHITEPAPER:

ANIMETRICS' 3D Facial Mapping Technologies:



Anatomic Diffeomorphic Mapping via Computational Anatomy with Infinite Vectorspace Environment Mapping

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Mapping Anatomical Structures into Facial Imagery

Current facial recognition systems are all based upon the analysis and manipulation of information present in 2D imagery from photographs and video. Photos and video, however, are fundamentally image-plane representations of underlying 3D geometry; limiting facial analysis to the visible projection of that geometry is the fatal flaw of all currently available facial identification systems. This constraint presents manifold problems for the analysis of live data, the most serious of which is that even minor variations in pose or lighting environment cripple the performance of current systems. For facial recognition systems to progress, along with the facial recognition market in general, a paradigm shift is necessary: specifically, a movement to systems which recognize image-plane data as a 2D representation of a 3D world. Animetrics has developed the technological basis for this evolution in facial recognition technologies through a novel implementation of the emergent science of Computational Anatomy. The implementation is two-fold: (1) a method for the automatic and accurate mapping of anatomically correct 3D facial geometry into regular 2D images; and (2) an unrivaled solution for lighting estimation using an infinite vectorspace representation of the photometric environment. Together, these technologies provide the complete solution for a new generation of image-based facial identification and analysis.

Computational Anatomy and Diffeomorphisms

Computational Anatomy was developed as a method to analyze and, in fact, *know* anatomical structures by their shape and potential states and range of deformation. Its original implementation has served to dramatically advance the state of the art in computational neurosurgery and computational neuropsychiatry through the 3D mapping of brains[1]. The computational study of shape is inherently different from other forms of measurement in that shapes are not manipulated through *additive composition* like vectors, but through *functional composition*. For example, in an effort to construct a larger chair one does not add two similar chairs, but a geometric transformation of scale is applied: a scale function is applied to an arrangement of variables (a manifold) representing "chair" to produce a small chair. By compositing the given chair with an additional scale function it is possible to transform the small chair into a larger one. The principal tools for such computational study and manipulation of shapes are diffeomorphisms. A diffeomorphism is generically a geometric transformation of structures in kind, e.g., an isosceles triangle to an obtuse triangle, or a sphere into an ovoid. In other words, diffeomorphisms are one-to-one invertible mappings that are

[1] Grenander and Miller, "Computational Anatomy: An Emerging Discipline", *Quarterly of Applied Mathematics*, 1998

smoothly varying, or differentiable. The most basic diffeomorphisms are those taught in Euclidean geometry and include translation, rotation, scale and skew, each with three degrees of freedom. Collectively, these are called the affine group and comprise 12 degrees of freedom, or dimensions. Dr. Miller has discovered (and demonstrated) that, in computer vision, it is possible to work with the infinite dimensional group of diffeomorphisms (ultimately, diffeomorphisms are the "shape" analogue of matrix groups used for rotations and translations through infinite dimensions). In this manner it is possible to mathematically describe and know structures and transformations of tremendous complexity, providing the basis for comparing and generating large deformations and changes in anatomical structure.

Anatomic Diffeomorphic Mapping (ADM)

In the original application of diffeomorphic mapping to the computational study of internal brain structure, 2D "slices" (serial cross-sections of the brain corresponding to a specific depth) generated by CT and MRI scans were analyzed. Using diffeomorphic maps, 3D geometries were created with 1-to-1 correspondence between subject brains, thus providing the basis for computational clinical analysis of neurological conditions and disorders. Beyond advancing medical technology, diffeomorphic mapping technologies provide a viable method for the description and understanding of anatomic structures in general. Animetrics is the first to apply this approach to external anatomic structures with its exclusive Anatomic Diffeomorphic Mapping (ADM) technology. For facial analysis, an arbitrary number of photographic images (1 or more) are analyzed to generate a 3D mesh representation of the face. The diffeomorphic mapping of image-plane data to a 3D mesh results in an accurate representation of the underlying projective geometry using smooth deformations. The resultant geometric representation of a face present in the image is not a condition applied to a flexible grid or generic facial representation but, rather, a fully structured facial geometry. The resultant geometry is combined with texture data from the source image(s) to produce an *Avatar*. The fully defined Avatar, unique to the subject, is a completely structured 3D representation of the face which can be manipulated through affine motion to describe pose, or through small deformations to describe expression. Deformable templates are a leading alternative approach for performing 3D analysis of image data for facial recognition. Although they can effectively compensate for limited motion by adjusting the relative position of the features or nodes to one another, this is essentially a linear mapping on a 2D surface where the underlying geometry is never fixed. This sort of manipulation is therefore only effective over a limited range of motion; as motion forces the relative position of the nodes into an invalid relation, the template is no longer able to provide an accurate representation. In striking contrast, the fully defined Avatar generated through ADM can be manipulated over a full range of potential motion without ever changing the underlying structure.

Infinite Vectorspace Environment Mapping (IVEM)

Environmental lighting conditions have a drastic impact on facial recognition. There are two principal requirements for the accurate and effective estimation of lighting on a surface. First, an accurate 3D representation of the face is needed; it is impossible to analyze lighting effects on a surface without a thorough understanding of that surface. Second, it is necessary to provide a model under which the complete range of photometric variability can be accommodated. Animetrics IVEM is the execution of this model: a complete environmental lighting solution utilizing an infinite vectorspace. The face represented in photographic data is not simply a projected geometry with specific coloration, but the sum total of the interactions of projective geometry, surface coloration, the lighting environment and camera parameters. The analysis of the projective geometry via ADM produces the Avatar. By treating the lighting environment as the *extrinsic* condition of the *intrinsic* properties of the Avatar, IVEM generates a global solution for the external effects that contribute to the specific representation of the face in the image-plane. Although other solutions may prove capable of solving for a primary light source (and possibly secondary, tertiary, etc., light sources) through reverse-projection, a complete solution is not possible with a fixed-source representation of light. Animetrics IVEM treats lighting as an infinitely variable condition of the projective geometry, and provides unmatched flexibility in the accommodation lighting variation in facial recognition applications.

Animetrics ADM and IVEM Provide Unmatched Power for Facial Analysis

By providing a full, unique Avatar of the subject's face, along with a multidimensional mapping of the lighting environment, Animetrics technology allows facial identification systems to correct for an unprecedented range of variation in facial imagery. By providing an accurate 3D representation of the face and generating complete lighting solution, the combination of Animetrics ADM and IVEM makes it possible to return any facial image to a predefined state by discarding variation in pose over a tremendous range of motion and effectively normalizing the lighting environment. Animetrics ADM/IVEM technologies help limit the effect of the transient conditions of pose and lighting in the comparison of subject facial imagery and registered target imagery and provide tremendous improvements in identification and verification accuracy.