Guest Editorial
Introduction to the Special Issue on Recent Advances in Biometric Systems

WE ARE pleased to present 14 papers in this special issue devoted to recent advances in biometric systems. A total of 78 papers were submitted for consideration for the special issue. Those that appear in this special issue result from a careful review process and consideration of timing for the special issue. Other papers, which were originally submitted for consideration for the special issue, may be undergoing major revisions and resubmission and appear at a later time in a regular issue of this journal or possibly in some other journal. In particular, several submissions in the area of iris biometrics could not be considered for this special issue due to their experimental results being based primarily on the CASIA 1 iris image dataset [1].

Papers on a broad variety of topics were submitted to the special issue. The large active areas of biometrics such as face, fingerprint, voice, signature, and iris were naturally well represented in the submissions. Newer and smaller areas such as gait and ear biometrics were also represented. Even more unusual areas such as brain signal recordings and infrared imaging of hand vein patterns were also represented. The diversity of topics in the submitted papers is reflected to some degree in the accepted papers and is an indication of the broad and vibrant current nature of the field.

Security and privacy issues in large biometrics systems have received relatively less attention in the past. We are indeed fortunate to have two excellent papers in this area, dealing with what are called "revocable" or "cancelable" biometrics. The first paper works in the context of face recognition and the second paper models forgery for behavioral biometrics.

The paper "Cancellable Biometrics Realization with Multispace Random Projections" by Teoh and Yuang addresses both revocability and privacy of biometrics templates using a two-factor cancelable formulation. In the first step, the biometric data are distorted by transforming the raw biometric data into a fixed-length feature vector in a nonreversible but revocable manner. In the second step, the feature vector is rojected onto a sequence of random subspaces derived from user-specific pseudorandom numbers (PRNs). This process is invertible, thus making the replacement of biometrics possible by replacement of the PRNs. The proposed method has been verified using the FERET face database [10].

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Ballard *et al.* present a stimulating paper on evaluation methodologies for behavioral biometrics that take into account threat models which have been, thus far, largely ignored. They argue that trained and target-selected forgers (in the framework of a generative attack model) must be considered to accurately assess the true security afforded by a biometric system. While basing the experiments on handwriting modality, they provide a blueprint for carrying out threat assessment of other behavioral biometrics as well.

Often, multibiometrics is viewed as improving security and performance of biometrics systems. We have three interesting papers covering novel research in the area of biometrics fusion. Gait recognition is a novel biometric that received increased visibility in the research community through the "Human ID at a Distance" program [4]. The paper "Integrating Face and Gait for Human Recognition at a Distance in Video" by Zhou and Bhanu represents the latest trend related to this area, which is the multibiometric combination of face and gait. Previous work on this topic has assumed the ideal view for each modality, a side view for gait, and a frontal view for face. Zhou and Bhanu tackle the more practical but also more challenging problem of using the information for both modalities that can be extracted from the same view. They extract both face and gait information from a side view, using an enhanced side face image and a gait energy image, respectively. They report results of experiments involving 100 video sequences from 45 people and compare the performance of the individual biometrics and different fusion methods. This paper should be of interest to all those working on either face recognition or recognition by gait.

Three-dimensional face recognition is an active area of research in recent years [8]. It is touted by many in the biometrics community today as the way to overcome the complaints that 2-D face recognition cannot adequately deal with changes in pose and illumination, and is also vulnerable to spoofing. Lin *et al.* from the University of Wisconsin describe a 3-D face recognition method that considers features from multiple facial regions, in contrast to previous single-region approaches. They use an LDA-based approach to assign weights and perform fusion of features from the different regions. The paper reports significant improvement on the face recognition grand challenge (FRGC) dataset and robustness of the method even in the presence of facial expressions.

The paper "Fusing Face Recognition Algorithms and Humans" by O'Toole *et al.* is another paper that should be of interest to everyone working in the field of face recognition. Comparison of the face recognition abilities of humans and algorithms is a topic of broad interest and importance, one touched on by these same authors in another recent paper [5] and by Adler and Schuckers in this special issue in the paper mentioned below. However, this paper goes beyond comparing the abilities of humans and algorithms to the combination of the abilities of humans and algorithms. This is potentially a very important and useful topic in any system in which there will be a person monitoring or interpreting the results of a biometric algorithm. This paper first looks at fusing the results of algorithms in experiments using data from the FRGC [6] and, then, considers the problem of fusing the results from human and algorithm recognition, with the goal of maximizing face recognition performance through hybrid systems consisting of multiple algorithms and humans.

The paper "Individual Kernel Tensor-Subspaces for Robust Face Recognition" by Park and Savvides describes a face recognition method that uses tensors (high-order matrices) to extract more information from a single face image than other linear models (such as PCA) by categorizing face images according to each factor, such as people, pose, and illumination, and analyzing the bases of the factor. It proposes an efficient method that does not require tensor factorization for classifying test images. Experimental results are reported on the CMU PIE database.

Everyone with an interest in iris biometrics will want to read the paper "New Methods in Iris Recognition" by John Daugman. The development of the iris biometrics field has been heavily influenced by Daugman's work [2], and this paper presents the latest results in his line of work. The state of the art in iris biometrics algorithms has substantially changed since the beginning of this relatively young field [9]. Whereas circular outlines are assumed to be adequate models of the iris boundary in nearly all of the existing iris biometrics literature, this latest work shows that an improved performance can be gained by going to active contours that allow noncircular boundaries. It also shows how eyelash occlusion of the iris region can be detected using statistical inference, attacks the difficult problem of dealing with off-axis gaze, and discusses score normalization and large-scale databases. Results are presented for the ICE 2005 dataset [3] and the UAE dataset.

The paper "On Techniques for Angle Compensation in Non-Ideal Iris Recognition" by Schuckers *et al.* attacks a problem in making iris biometrics work in a more flexible user interface. Current commercial iris biometric systems require substantial user cooperation in positioning the eye for image acquisition, with the goal of obtaining a good quality image from an approximately frontal view. This paper focuses on techniques for dealing with a particular type of nonideal image, one that is acquired from an off-angle, rather than a frontal view. This is an important topic that will undoubtedly see more activity in the near future.

Despite decades of research in fingerprint recognition, many challenges still exist. The paper "Fingerprint Image Mosaicking by Recursive Ridge Mapping" by Choi *et al.* deals with the issue of obtaining a larger fingerprint image by stitching together smaller images. Their approach matches ridges iteratively in order to overcome the problem of correspondences and compensates for the amount of plastic distortion between two partial images by using a thin plate spline model. By using a three-step process of feature extraction, transform estimation, and mosaicking, the proposed algorithm starts with a transform, which is initially estimated with matched minutiae and the attached ridges. Unpaired ridges in the overlapping area between two images are matched iteratively by minimizing the registration cost, which consists of ridge matching error and inverse consistency error. During the estimation, erroneous correspondences are eliminated by considering the geometric relationship between the correspondences and by minimizing the registration cost. The proposed algorithm has been tested on FVC 2002 database [7], and results are compared with three existing approaches to show the usefulness of the proposed approach.

Another fingerprint analysis paper "Modeling and Analysis of Local Comprehensive Minutiae Relation for Fingerprint Matching" by He *et al.* describes a graph-based method for fingerprint matching. With the comprehensive minutiae points acting as the vertex set and the local binary minutiae relations providing the edge set, a graph representation of the fingerprint is constructed. From the binary relations represented by the edge set, both transformation-invariant and transformation-variant features are extracted. The transformation-invariant features are used in estimating the local matching probability, while the transform-variant features are used in modeling the fingerprint rotation transformation. The final stage of matching is conducted with a variable bounded-box method and iterative strategy. Experiments that are based on FVC 2002 [7] show that the proposed scheme is effective and robust in terms of fingerprint alignment and matching.

Many approaches have been proposed to improve face recognition performance that can tolerate pose variations. The paper "A Mosaicing Scheme for Pose-Invariant Face Recognition" by Singh *et al.* proposes a scheme to generate a composite face image during enrollment based on the evidence provided by frontal and semiprofile face images of an individual, obviating the need to store multiple face templates representing multiple poses. A composite face image is computed using multiresolution splining to blend the side profiles with the frontal image. Experiments conducted on three different databases using a texture-based face recognition engine (a modified version of the C2 algorithm) indicate significant benefits of the proposed face mosaicking scheme in improving recognition performance in the midst of pose variations.

Machine learning researchers will find the face recognition paper by Xu *et al.* extremely interesting. It deals with representation of high-dimensional face data as tensors to reduce the parameters that must be learned. Given the perpetual problem of insufficient training data, dimensionality reduction by tensor representation has recently gained popularity. The authors show that the supervised subspace learning algorithm, rank-one projections and adaptive margins, or RPAM, offers many advantages over other dimensionality reduction methods and reports promising numbers on the CMU PIE dataset.

Signature verification advances are described by Van *et al.* in a comprehensive experimental evaluation on the SVC2004, BIOMET, PHILIPS, and MYCT datasets. They introduce the notion of a "segmentation information" score that is derived by analyzing the Viterbi path, which is then fused with the hidden

Markov model (HMM) likelihood score. This is an interesting and novel approach as both scores are generated by the HMM for each writer. The paper also describes a sophisticated personal normalization scheme that is reported to hold up well across the datasets.

The paper "Comparing Human and Automatic Face Recognition Performance" by Adler and Schuckers contains several elements that will be of broad interest to the face recognition community. Table I of their paper tracks a comparison of human and automatic face recognition performance from 1999 to 2006. It shows a pattern where human face recognition started out performing much better than automatic face recognition, but automatic recognition improved over time to the point where it now outperforms human face recognition. Those who find this result interesting and/or controversial will want to examine, in more detail, the methodology underlying the result. They also present a new methodology to calculate an average detection error tradeoff (DET) curve. The DET curve is related to the receiver operating characteristic curve.

We want to thank the authors, the reviewers, and the Transactions staff for all of the effort that has gone into producing this special issue. We feel confident that the reader will see the fruits of this effort in the many interesting, challenging, and surprising results presented in the papers in this Special Issue.

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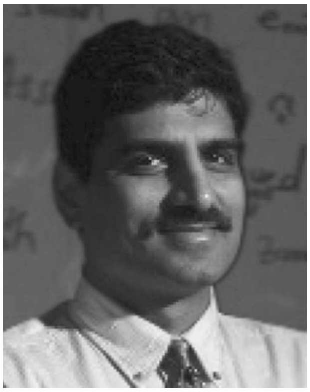
Prof. Bowyer is a Golden Core Member of the IEEE Computer Society. He received the Award of Excellence from the Society for Technical Communication in 2005 for his paper "Face Recognition Technology: Security versus Privacy," which was published in the *IEEE Technology and Society Magazine*. He was the Chair of the IEEE Computer Society Technical Committee on Pattern Analysis and Machine Intelligence. He was the Editor in Chief of the IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE. He was the General Chair of the First IEEE Conference on Biometrics: Theory, Applications and Systems (BTAS 2007).



Venu Govindaraju.

He founded the Center for Unified Biometrics and Sensors, Amherst, NY in 2003, which has received over $5 million in research funding covering over a dozen projects from both the government and the industry. He has supervised the dissertation of ten doctoral students and the theses of over 20 Master's students. He is currently a Professor of computer science and engineering with the Department of Computer Science and Engineering, University at Buffalo, The State University of New York, Amherst. In a research career spanning over 20 years, he has made significant contributions to pattern recognition such as document analysis and biometrics. His seminal work in handwriting recognition was at the core of the first handwritten address interpretation system used by the U.S. Postal Service.

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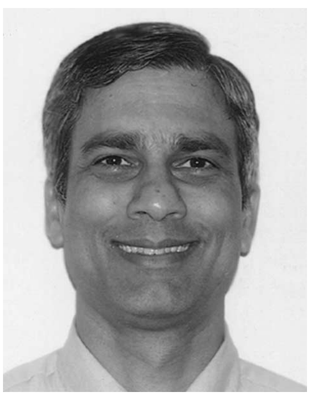

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He is currently a Research Staff Member with the IBM Thomas J. Watson Research Center, Hawthorne, NY, working on biometrics recognition algorithms. He is the holder of 11 awarded patents and several pending patent applications. For the past 20 years, he has published more than 50 peer-reviewed journal papers and conference proceedings on biometrics-related topics. He is a coauthor of *Guide to Biometrics* (Springer) and a coeditor of *Automatic Fingerprint Recognition Systems* (Springer). From 2004 to 2006, he was an Editor of *Pattern Recognition*. His main research interests include computer vision, pattern recognition, image retrieval, and special-purpose architectures for vision-based systems. His current research interests are fingerprint recognition, biometrics fusion, large-scale biometric search/indexing, security and privacy issues related to biometrics, and performance evaluation of biometrics systems.

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