EURASIP Journal on Applied Signal Processing 2004:4, 542–558

Handwriting: Feature Correlation Analysis for Biometric Hashes

Claus Vielhauer

Multimedia Communications Lab (KOM), Darmstadt University of Technology, 64283 Darmstadt, Germany

Platanista GmbH, 06846 Dessau, Germany

Faculty of Computer Science, Otto-von-Guericke University, 39106 Magdeburg, Germany
Email: claus.vielhauer@iti.cs.uni-magdeburg.de

Ralf Steinmetz

Multimedia Communications Lab (KOM), Darmstadt University of Technology, 64283 Darmstadt, Germany
Email: ralf.steinmetz@kom.tu-darmstadt.de

Received 17 November 2002; Revised 9 September 2003

In the application domain of electronic commerce, biometric authentication can provide one possible solution for the key management problem. Besides server-based approaches, methods of deriving digital keys directly from biometric measures appear to be advantageous. In this paper, we analyze one of our recently published specific algorithms of this category based on behavioral biometrics of handwriting, the biometric hash. Our interest is to investigate to which degree each of the underlying feature parameters contributes to the overall intrapersonal stability and interpersonal value space. We will briefly discuss related work in feature evaluation and introduce a new methodology based on three components: the intrapersonal scatter (deviation), the interpersonal entropy, and the correlation between both measures. Evaluation of the technique is presented based on two data sets of different size. The method presented will allow determination of effects of parameterization of the biometric system, estimation of value space boundaries, and comparison with other feature selection approaches.

Keywords and phrases: biometrics, signature verification, feature evaluation, feature correlation, cryptographic key management, handwriting, information entropy.

1. MOTIVATION

Today, a wide spectrum of technologies for user identification and verification exists and a great number of the systems that have been published are based on long-term research. The basic concept behind all biometric systems is the idea to make use of machine-measurable traits to distinguish persons. In order to be adequate for this process, a number of requirements must be fulfilled by a human trait feature, see [1]. For our working context, the following four are of main interest:

(i) uniqueness: the feature must vary to a reasonable extent amongst a wide set of individuals (intervariability);
(ii) constancy (permanence): the feature must vary as little as possible for each individual (intravariability);
(iii) distribution (universality): the feature must be available for as many potential users as possible;
(iv) measurability (collectability): the feature must be electronically measurable.

Biometric characteristics, which fulfill the above requirements, can be classified in a number of ways, for example, see [2, 3]. One common approach is to divide into measures, which are either originating from a physiological or a behavioral trait of subjects, although it has been shown that every process of capturing biometric measures includes behavioral components to some extent [2]. In the context of our work based on handwriting, we use the terminology of passive and active biometric schemes to clearly point out the aspects of the user awareness and cooperation.

Active schemes include all schemes taking into account time-relevant information such as voice and online handwriting recognition, keystroke behavior, and gait analysis. Such biometric features require a specific action from the users and thus can only be obtained with their cooperation. An example for this cooperative approach is the signature-based user authentication, where the user actively triggers the verification process by feeding the system with a writing sample. Passive traits like fingerprint and face recognition, hand geometry analysis or iris scan, as well as the offline analysis of handwriting are based on visible physiological characteristics, which are retrieved in a time-invariant manner. These biometric features can be obtained from users without their explicit cooperation, thus allowing identification of persons without their agreement or even knowledge. A straightforward paradigm for such an enforced verification is the forensic identification using fingerprints. For potential applications, this basic difference between active and passive biometric schemes has a significant consequence, as each application will have different requirements with respect to the subject's cooperation. While, for example, in access control applications, one can expect a high degree in user cooperation as the desire of physical or logical access can be anticipated, this is not necessarily the case in forensic applications, for example, for proof of identity.

From the perspective of potential applications, online handwriting as an active biometric scheme appears to be particularly interesting in domains that deal with combined document and user authentication, which today is handled by electronic signatures. Nowadays, legal and design aspects of electronic signature infrastructures are clearly defined, for example, in the European Directive for Electronic Signature [4], and security aspects are handled by cryptographic techniques. However, there still are problems in the area of user authentication because electronic signatures make use of asymmetric cryptographic schemes, requiring management of public and secret (private) keys. Today's practice of storing private keys of users of electronic signatures on chip cards protected by personal identification number (PIN) has a systematic weakness. The underlying access control mechanism is based on possession and knowledge, both of which can be transferred to other individuals with or without the holder's intension. Making use of biometrics for key management can fill this security gap. A straightforward approach is to protect the private key by performing biometric user verification prior to release from the secured environment, for example, a smart card [5]. This approach is based on a biometric verification with a binary result set (verified or not verified) as a decision to control access. A physically secure location is still required for the sensitive data.

In this paper, we will present a feature analysis strategy for examination of a biometric system based on online handwriting analysis with a specific system response category, the biometric hash, which has recently been published [6]. The biometric hash is a mathematical fingerprint based on a set of preselected statistical features of the handwritten sample of an individual, which can directly be used for key generation, avoiding the problem of secure storage. Our evaluation strategy for this system is based on three statistical measures:

(a) *intrapersonal stability* reflecting the degree of scatter within each individual feature;
(b) *interpersonal entropy* of hash value components as a result of the biometric hash algorithm. This value is an indicator for the potential information density of each feature component;
(c) feature *stability and entropy correlation* to analyze the dependency between measure (a) and (b) with respect the contribution of each feature parameter to the entire biometric hash.

These three measures are evaluated to analyze the given biometric hash algorithm at a specific operation point, where the contribution of our work is twofold. Firstly, we aim to conceptually prove the concept of biometric hash generation by analyzing the relevance of information carried by each individual feature. Secondly, we present a new feature analysis based on correlation of deviation and entropy along with evaluation results for this method. While typically in feature selection problems, the aim is to reduce the complexity of a given problem by separating features that carry no or little information, there is no requirement for dimension reduction for the evaluated algorithm due to its low complexity. Our aim is to find quantitative terms for the share of the resulting value space for each of the feature components, which can be used as a basis for an estimation of the achievable value space. We will present a strategy for systematic, quantitative analysis of feature relevance for generating a biometric hash value and briefly discuss a limited set of related work in the area of feature analysis and feature selection with respect to this specific biometric application. Further, we will discuss the problem of correlation and entropy of the feature space within the scope of biometric hashes for several semantic classes for handwriting. We will present results of evaluations of the biometric hash using the method presented, which are based on two different test databases. For the first database with limited size, details will be presented and the discussion will be summarized into a feature significance classification. In order to validate the findings of the initial evaluation, the results are reviewed based on results of a second, extended test containing writing samples from a large database consisting of several thousand signatures.

The paper is structured as follows. In Section 2, we will give an introduction to feature evaluation and a discussion of the selected work in this domain followed by a discussion on the distinction of handwriting in several domains like handwriting recognition, forensic writer identification, or signature verification in Section 3. Section 4 will briefly describe the state of the art of biometric hash systems and introduce our system concept of biometric hashes based on handwriting. In Section 5, we present an analysis scheme towards intrapersonal deviation of feature values, including test results from our experiments. From the same test database, the information entropy as a measure for the achievable hash value space on an interpersonal scope is introduced and the results are presented in Section 6. Based on the findings in Sections 5 and 6, a correlation analysis is performed in Section 7, including a relevance classification of the features examined. As the initial test data set is too small to justify significant conclusions, Section 8 presents findings of applying this feature analysis method based on an extended data set and compares them with results from the initial test. Finally, we will conclude our work in Section 9 and summarize our contribution and future activities.

2. INTRODUCTION AND RELATED WORK

The task of automated biometric user authentication requires the analysis and comparison of individually stored reference measures against features from an actual test input. Storage of reference templates is a machine learning problem, which requires the determination of adequate feature sets for classification. Feature evaluation or selection describing the process of identifying the most relevant features for a classification task is a research area of broad application. Today, we find a great spectrum of activities and publications in this area. From this variety, we have selected those approaches that appear to show the most relevant basics and are most closely related to our work discussed in the paper.[1]

In an early work on feature evaluation techniques, which has been presented almost three decades ago, Kittler has discussed methods of feature selection in two categories: measurement and transformed space [7]. It has been shown that methods of the second category are computationally simple, while theoretically, measurement-based approaches lead to superior selection results, but at the time of publication, these methods were computationally too complex to be practically applied to real-world classification problems. In a more recent work, the hypothesis that feature selection for supervised classification tasks can be accomplished on the basis of correlation-based filter selection (CFS) has been explored [8]. Evaluation on twelve natural and six artificial database domains has shown that this selection method increases the classification accuracy of a reduced feature set in many cases and outperforms comparative feature selection algorithms. However, none of the domains in this test set is based on biometric measures related to natural handwriting data. Principal component analysis (PCA) is one of the common approaches for the selection of features, but it has been observed that, for example, data sets having identical variances in each direction are not well represented [9]. Chi and Yan presented an evaluation approach based on an adopted entropy feature measure which has been applied to a large set of handwritten images of numerals [10]. This work has shown good results in the detection of relevant features compared to other selection methods. With respect to the feature analysis for the biometric hash algorithm, it is required to analyze the trade-off between intrapersonal variability of feature measures and the value space, which can be achieved by the resulting hash vectors over a large set of persons. Therefore, we have chosen to evaluate not only the entropy for each feature, but also the degree of intrapersonal variability of feature values. Our evaluation strategy presented in this work is based on application-specific entropy which is determined from the response of the biometric hash function and intrapersonal deviations of feature parameters as measures for scatter. An overview of the algorithm and the initial feature set as presented in the original publication will be given in Section 4.

[1]An exhaustive discussion of the huge number of approaches that have been published in the subject is beyond the scope of this paper. Therefore the authors have decided to refer to a very limited number of references which appear to be of significant relevance for the purpose of evaluating the specific technique discussed in this paper.

3. DISTINCTION OF HANDWRITING

Three main categories of handwriting-based biometric approaches can be identified: handwriting recognition, forensic verification, and user authentication. Handwriting recognition denotes the process of automatic retrieval of the ground truth of a handwritten document; it can also be considered as a specialization of optical character recognition (OCR). Here, a wide variety of approaches based on offline and online analysis have been suggested. A comprehensive overview of the state of the art in handwriting recognition can be found in [11]. Determination of the identity of the writer is not the primary aim in handwriting recognition, thus in this category, systems make use of individual writing characteristics in order to improve the overall recognition accuracy. In this kind of systems, user-specific templates are generated during a training phase in order to store information about the writing style along with the writing semantic. Based on this information, handwriting systems can be designed in a way that a writer can be identified while writing arbitrary text. This idea was taken over by researches at a very early point in time [12]. While in handwriting recognition, the primary purpose of storing user-specific templates is the improvement of recognition rates, forensic applications use sets of writing samples of known origin in order to compare them with a handwritten document written by an unknown or suspected person. The aim typically is to find evidence on the originator of a handwritten document in court cases. Expert testimonies-based methods to analyze the individuality of handwriting are generally accepted at court since many decades, for example, since 1923 in the United States, and research towards an automated writer verification system is still an actual topic. For example, a quantitative assessment of the discriminatory power of handwriting was performed in [13]. By nature of forensic applications, the verification does not require the approval or even knowledge of writers. In handwriting verification systems however, users enroll to the system with the intention of a later approval of authenticity within a secured scenario. Typically, handwriting-based biometric verification and identification systems use one specific semantic class: signatures. Signature as proof of authenticity is a socially well-accepted transaction, especially for legal document management and financial transactions. The individual signature serves five main functions [14]: not only authenticity and identity functions, which can be provided by any of the biometric schemes, but also finalization, evidence, and warning functions, which are unique to the signature. Furthermore, handwriting allows the use of additional semantic classes to the signature. Publications on the use of writing semantics like pass phrases or symbols in handwriting verification systems can be found in [15, 16]. For the overall security, this combination of knowledge and traits shows advantages compared to the signature. Firstly, the image of a signature is a public feature which is available to everyone holding a hardcopy of a signed document.

This simplifies attacks by a potential forger, especially on time-invariant features. Secondly, additional semantics can be used to register several different references for one user, allowing the design of challenge-response systems. Another aspect is the possibility to change the content of the reference sample, which is important in case a biometric feature gets compromised.

Handwriting verification systems typically operate in two different modes. In the verification mode, the system is fed with a pretended identity and a writing sample and the response is either a positive or negative match. Identification only requires a writing sample input and the system will either output the most likely identity or a mismatch. Besides these two typical modes, biometric hashes denote an additional class of system responses. The following section will introduce this category of biometric systems.

4. BIOMETRIC HASHES

Information exchange over public networks like the Internet implies a wide number of security requirements. Many of these security demands can be satisfied by cryptographic techniques which generally are based on digital keys. Here, we find two constellations of keys: keys for symmetric systems, where all participants of the secret communication share the same secret key, and public keys, which consist of pairs of a secret key (private) and a publicly available key. While systems of the first category are typically designed for efficient cipher systems, the second type is used mainly in digital signatures or protocols to securely exchange secret session keys. In either category, we have the requirement to protect the keys from unauthorized access. As cryptographically strong keys are rather large, and it is certainly not feasible to let users memorize their personal keys. As a consequence of this, in real-world scenarios today, digital keys are typically stored on smart cards protected by a special kind of password, the PIN. However, there are problems with PIN; for example, they may be lost, passed on to other persons accidentally or purposely, or they may be reverse-engineered by brute force attacks.

These difficulties in using passcode-based storage of cryptographic keys motivate the use of biometric authentication for key management which is based on human traits rather than knowledge. Various methods to apply biometrics to solve key management problems have been presented in the past [17]:

(i) *secure server systems* which release the key upon successful verification of the biometric features of the owner;
(ii) *embedding of the digital key* within the biometric reference data by a trusted algorithm, for example, bit-replacement;
(iii) combination of digital key and biometric image into a so-called *Bioscrypt*™ in such a way that neither information can be retrieved independently of the other;
(iv) *derivation of* the digital key directly from a biometric image or feature.

There are problems with all of these approaches. In the first scenario, a secured environment is required for the server and further, all communication channels need to be secured, which is not possible in all application scenarios. Embedding secret information in a publicly available data set like in the second suggestion will allow an attacker to retrieve secret information for all users once the algorithm is known. The idea of linking both digital key and biometric feature into a Bioscrypt™ can result in a good protection of both data sets, but it is rather demanding regarding the infrastructure required. Approaches of the fourth category face problems due to the fact that biometric features typically show a high degree of intrapersonal variability due to natural and physiological reasons. A key that is composed directly from the biometric feature values might not show stability over a large set of verifications. Secondly, if the derivation of the key is based on passive traits like the fingerprint, the key is lost for all times, once compromised.

To overcome the problems of the approaches of the last category, it is desirable to derive a robust key value directly from an active biometric trait, which includes an expression of intention by the user. A voice-based approach for such a system can be found in [18], where cryptographic keys are generated from spoken telephone number sequences. As for all biometric techniques based on voice, there is a security problem in reply attacks, which can easily be performed by audio recording. For key generation based on handwriting, we have presented a new biometric hash function in [6]. By making use of handwriting, an active, behavioral trait, and additional semantic classes like pass phrases and PINs, the system allows to change the biometric reference in case it would get compromised. Instead of providing a positive or a negative verification result, the biometric hash is a vector of ordinal values unique to one individual person within a set of registered users. Originally, the new concept of biometric hash has been presented where the hash vector was calculated by statistical analysis of 24 online and offline features of a handwriting sample. Continuative research has lead to a system implementation based on 50 features, as presented in Section 4.1. A brief description of the algorithm will be given in Sections 4.2 and 4.3.

4.1. System overview

The initial prototype system is implemented on a Palm Vx handheld computer equipped with 8 MB RAM and a MC68EZ328 CPU at a clock rate of 20 MHz. The built-in digitizer has a resolution of 160×160 pixels at 16 gray scales and provides binary pen-up/pen-down pen pressure information. Although it is widely observed that writing features based on pressure can show a great significance for writer verification, we limit our system to one-bit pen-up/pen-down signals. This is due to the fact that our superior work context is aimed towards device-independence, and a wide number of digitizer devices do not support pressure signal resolutions above one bit.

Figure 1 illustrates the process of the biometric hash calculation. In the data acquisition phase, the pen position

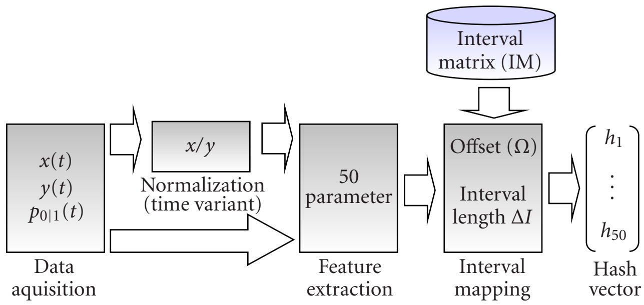


FIGURE 1: Process of the biometric hash calculation.

signals $x(t)/y(t)$ and the binary pressure signal $p_{0|1}(t)$ are recorded from the input device. These signals are then made available for the feature extraction both in a normalized (x/y normalization for determination of time variant features) and an unfiltered signal. After feature extraction of 50 statistical parameters, these are mapped to the biometric hash by the interval mapping process, making use of a user-specific interval matrix (IM). The IM is determined during enrollment, and the algorithm for this will be presented in Section 4.3.

4.2. Feature parameters

The proceeding of obtaining a hash vector by interval mapping requires the utilization of a fixed number of scalar feature values, which are computed by statistical analysis of the sampled physical signals. A comprehensive overview of relevant features used in publications on signature verification can be found in [19, 20]. Due to the resource and hardware limitations on a PDA platform like the one used in our project, we have based our initial research on biometric hash on 24 statistical features, which have been extended for the work presented in this paper to 50 parameters shown in Table 1. To satisfy the need to have a fixed number of components, these features are either based on a global analysis of signals or on partitioning to a fixed number of subsets, which was chosen intuitively.

4.3. Interval matrix determination

The IM is a matrix with a dimension of $K \times 2$, where K denotes the number of feature components that is taken into account, as listed in Table 1. Each of the $i \in [1, \dots, K]$ two-dimensional vector components consists of an interval length ΔI_i and an offset value Ω_i. The interval length and offset values are determined for each user during an enrollment process consisting of $j \in [1, \dots, N]$ writing samples for each of the nonnegative feature parameters $n_{i,j}$ in the following min/max strategy:

$$\text{Initial interval: } [I_{\text{InitLow}}, \dots, I_{\text{InitHigh}}] = [\,\text{MIN}\,(n_{i,j}), \dots, \text{MAX}\,(n_{i,j})]; \tag{1}$$

$$\text{Initial interval length: } \Delta I_{\text{Init}} = I_{\text{InitHigh}} - I_{\text{InitLow}}; \tag{2}$$

$$\text{Interval: } [I_{\text{Low}}, \dots, I_{\text{High}}] = \begin{cases} [I_{\text{InitLow}} - t_i^* \Delta I_{\text{Init}}, \dots, I_{\text{InitHigh}} + t_i^* \Delta I_{\text{Init}}] \\ \quad \text{if } (I_{\text{InitLow}} - t_i^* \Delta I_{\text{Init}}) > 0, \\ [0, \dots, I_{\text{InitHigh}} + t_i^* \Delta I_{\text{Init}}] \\ \quad \text{if } (I_{\text{InitLow}} - t_i^* \Delta I_{\text{Init}}) \leq 0, \end{cases} \tag{3}$$

which is, for each of the j features, an initial interval $[I_{\text{InitLow}}, \dots, I_{\text{InitHigh}}]$ with an initial interval length ΔI_{Init} is determined. Then the effective interval $[I_{\text{Low}}, \dots, I_{\text{High}}]$ is defined by the initial interval, with the left boundary I_{InitLow} reduced by $t_i^* \Delta I_{\text{Init}}$ (or 0, if the term becomes negative) and the right boundary I_{InitHigh} increased by $t_i^* \Delta I_{\text{Init}}$.

The parameter-specific tolerance factor t_i is introduced to compensate for the intravariability of each feature parameter. Factor values for t_i are dependent on the number of samples per enrollment N and have been estimated in separate intrapersonal variability tests as described in Section 5. Table 2 presents values for t_i which have been estimated for each of the parameters n_i based on an enrollment size of $N = 6$.

All feature parameters are of nonnegative integer type and test values will be rounded accordingly. Thus the effective interval length ΔI_i can be written as

$$\Delta I_i = I_{\text{High}} + 0.5 - (I_{\text{Low}} - 0.5) = I_{\text{High}} - I_{\text{Low}} + 1, \tag{4}$$

whereas the interval offset value Ω_i is defined as

$$\Omega_i = I_{\text{Low}}\,\text{MOD}\,\Delta I_I. \tag{5}$$

Thus, the IM can be written as follows:

$$\text{IM} = \begin{pmatrix} \Delta I_1, \Omega_1 \\ \Delta I_2, \Omega_2 \\ \vdots \\ \Delta I_K, \Omega_K \end{pmatrix}. \tag{6}$$

4.4. Hash value computation

The hash value computation is based on a mapping of each of the feature parameters of a test sample to an integer value scale. Due to the nature of the determination of the interval matrix, all possible values v_1 and v_2 within the extended interval $[I_{\text{Low}}, \dots, I_{\text{High}}]$ for each of the $i \in [1, \dots, K]$ features n_i within IM, as defined in the previous Section 4.3, fulfill the following condition:

$$\begin{aligned} \left\lfloor \frac{(v_1 - \Omega_i)}{\Delta I_i} \right\rfloor &= \left\lfloor \frac{(v_2 - \Omega_i)}{\Delta I_i} \right\rfloor \quad \forall v_1, v_2 \in [I_{\text{Low}}, \dots, I_{\text{High}}], \\ \left\lfloor \frac{(v_1 - \Omega_i)}{\Delta I_i} \right\rfloor &\neq \left\lfloor \frac{(v_2 - \Omega_i)}{\Delta I_i} \right\rfloor \quad \forall v_1, v_2 \notin [I_{\text{Low}}, \dots, I_{\text{High}}]. \end{aligned} \tag{7}$$

That is, all given v_1 and v_2 within the extended interval lead to identical integer quotients, whereas values below or above the interval border lead to different integer values. Thus, we

Table 1: Feature parameters for the biometric hash calculation.

Parameter name	Index	Param.	Description
Segment count	1	n_1	Number of pen-down events
Duration	2	n_2	Total writing duration in ms
Sample count	3	n_3	Total number of samples
Maximum count	4	n_4	Sum of local maximum in x- and y-signals
Aspect ratio	5	n_5	x/y ratio of the writing image times 1000
Pen-up pen-down ratio	6	n_6	Ratio of total pen-up and total pen-down times multiplied by 1000
X-integral	7	n_7	Total area covered by the absolute x-signal
Y-integral	8	n_8	Total area covered by the absolute y-signal
X-velocity	9	n_9	Average absolute writing velocity in x-direction
Y-velocity	10	n_{10}	Average absolute writing velocity in y-direction
X-acceleration	11	n_{11}	Average absolute writing acceleration in x-direction
Y-acceleration	12	n_{12}	Average absolute writing acceleration in y-direction
X-distribution velocity	13	n_{13}	Maximum x-distribution $\text{Max}(x) - \text{Min}(x)$ over total writing time
Y-distribution velocity	14	n_{14}	Maximum y-distribution $\text{Max}(y) - \text{Min}(y)$ over total writing time
Segmented x-areas	15–19	n_{15}–n_{19}	x-integral of 5 segments of equal length $T_{\text{Total}}/5$
Segmented y-areas	20–24	n_{20}–n_{24}	y-integral of 5 segments of equal length $T_{\text{Total}}/5$
Path length	25	n_{25}	Total path length of writing trace in pixel
Delta X	26	n_{26}	Total horizontal image expansion
Delta Y	27	n_{27}	Total vertical image expansion
Effective average speed	28	n_{28}	Ratio of total writing path length and total writing time
Pixel count 12-segment	29–40	n_{29}–n_{40}	Number of pixels in each 4 by 3 sector
Cumulated integral error x	41	n_{41}	Sum of absolute x-differences between discrete integration rectangle versus trapeze
Cumulated integral error y	42	n_{42}	Sum of absolute y-differences between discrete integration rectangle versus trapeze
Integral error sign x	43	n_{43}	Effective sign of feature 41
Integral error sign y	44	n_{44}	Effective sign of feature 42
Cumulated radiant	45	n_{45}	Radiant of cumulated x/y from upper left corner of image
Average radiant	46	n_{46}	Average radiant of all x/y sample points from upper left corner of image
Cumulated distance	47	n_{47}	Distance t of cumulated x/y from upper left corner of image
Average distance	48	n_{48}	Average distance of all x/y sample points from upper left corner of image
Average x-position	49	n_{49}	Average of all x-sample values
Average y-position	50	n_{50}	Average of all y-sample values

write the hash function h for each feature parameter f_i of a test sample as follows:

$$h(f_i, \Delta I_i, \Omega_i) = \left\lfloor \frac{(f_i - \Omega_i)}{\Delta I_i} \right\rfloor. \tag{8}$$

Thus, the resulting hash vector consists of K components of integer values.

5. INTRAPERSONAL SCATTER: FEATURE DEVIATION

One major problem in using biometric features to directly derive hash values is the trade-off between natural intrapersonal variability of feature values between several samples of an individual user and the requirement to have a persistent value in the biometric hash. A trivial example for this dilemma is the total writing time of a signature. This feature is very straightforward to calculate and, therefore, very often used in verification systems with limited resources like digital signal processor chips [21]. Amongst first-order features, it shows a rather stable intrapersonal behavior. If, for example, a natural intrapersonal variance of 5% is observed, the average signature duration of a subject is 5 seconds; all duration values in $[4.75, \dots, 5.25]$ seconds should be acceptable to authenticate this particular feature. Depending on the sampling rate of the digitizer device used for the signature capture, this can lead to a great number of acceptable discrete values, a sampling rate of 10 milliseconds would lead to 51 possible values that would lead to a positive result. Thus in order to achieve stable hash values, all features must be mapped into a value space, using, for example, an interval-mapping algorithm, as described in Section 4. The evaluation of intrapersonal deviations of features was performed by measuring the average deviations between enrollment and test sets of enrollments for a given test database, and details of the test procedure are given below.

Table 2: Tolerance values estimation for $N = 6$.

Parameter name	$t_i(\%)$	n_i
Segment count	565	n_1
Duration	1400	n_2
Sample count	590	n_3
Maximum count	715	n_4
Aspect ratio	635	n_5
Pen-up pen-down ratio	625	n_6
X-integral	645	n_7
Y-integral	505	n_8
X-velocity	625	n_9
Y-velocity	780	n_{10}
X-acceleration	545	n_{11}
Y-acceleration	585	n_{12}
X-distribution velocity	685	n_{13}
Y-distribution velocity	765	n_{14}
Segmented x-area 1	1800	n_{15}
Segmented x-area 2	1085	n_{16}
Segmented x-area 3	595	n_{17}
Segmented x-area 4	860	n_{18}
Segmented x-area 5	1010	n_{19}
Segmented y-area 1	1060	n_{20}
Segmented y-area 2	1030	n_{21}
Segmented y-area 3	820	n_{22}
Segmented y-area 4	760	n_{23}
Segmented y-area 5	635	n_{24}
Path length	655	n_{25}
Delta X	630	n_{26}
Delta Y	710	n_{27}
Effective average speed	750	n_{28}
Pixel count segment 1/12	1065	n_{29}
Pixel count segment 2/12	565	n_{30}
Pixel count segment 3/12	1060	n_{31}
Pixel count segment 4/12	470	n_{32}
Pixel count segment 5/12	460	n_{33}
Pixel count segment 6/12	1070	n_{34}
Pixel count segment 7/12	495	n_{35}
Pixel count segment 8/12	565	n_{36}
Pixel count segment 9/12	320	n_{37}
Pixel count segment 10/12	825	n_{38}
Pixel count segment 11/12	760	n_{39}
Pixel count segment 12/12	690	n_{40}
Cumulated integral error x	615	n_{41}
Cumulated integral error y	340	n_{42}
Integral error sign x	0	n_{43}
Integral error sign y	0	n_{44}
Cumulated radiant	495	n_{45}
Average radiant	395	n_{46}
Cumulated distance	840	n_{47}
Average distance	1010	n_{48}
Average x-position	915	n_{49}
Average y-position	1045	n_{50}

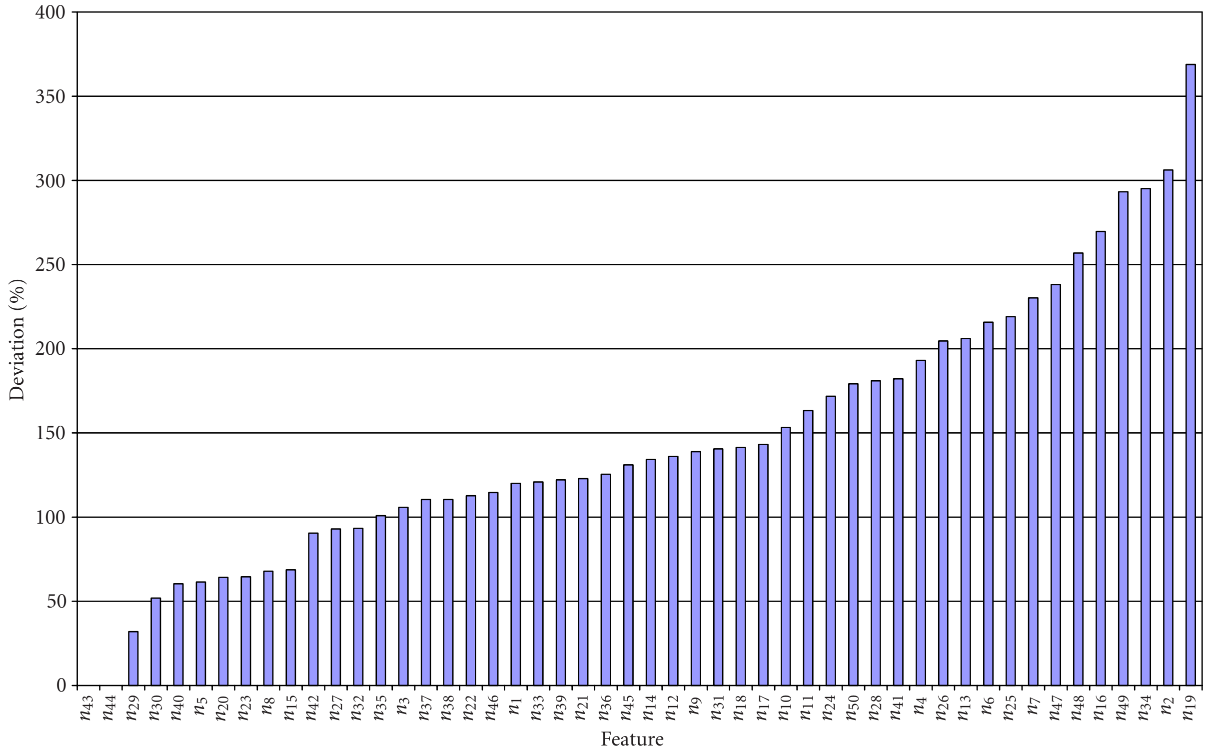


FIGURE 2: Sorted histogram of average deviation d_i in feature values of signatures with $e = 6$ in initial test.

This initial test was based on 10 users with 10 writing samples of 5 semantic classes. All users are familiar with computer devices and the writing samples were collected during 2 enrollment sessions, where the second recording session was at least two weeks after the first. As mentioned in the motivation, additional evaluations based on extended databases are described in Section 8 and will be concluded with a comparison of test results.

Our tests for evaluation of the intravariability have been performed separately for the following 5 different semantic classes:

(i) *signature*;
(ii) fixed *PIN* (all users were asked to write the same PIN 8710);
(iii) arbitrary *pass phrase* (user may choose any combination of words/numbers);
(iv) the German *word* “Sauerstoffgefäß” for all users;
(v) arbitrary specific *symbol* (the user may use a short sketch of his choice).

The tests have been performed based on all 10 users for each feature and each semantic class according to the following instructions:

(1) for *each of the semantic classes* $s \in$ [signature, PIN, pass phrase, fixed word, and user-defined symbol],
  (a) for *each* of the $g \in [1, \ldots, 10]$ *users* u_g and for *each* of the $i \in [1, \ldots, 50]$ *features* n_i,
    (i) *divide* each set of 10 samples into all possible combinations of *e enrollment* samples and $10 - e$ *test samples*;
  (b) for *each of the e enrollments and each of the* $10 - e$ *tests*, calculate the following deviation:
    (i) determine *minimum and maximum enrollment values* ve_{Min} *and* ve_{Max} from all *e* samples;
    (ii) determine *average enrollment value* $\mu_e = ve_{\text{Min}} + (ve_{\text{Max}} - ve_{\text{Min}})/2$;
    (iii) determine *minimum and maximum values* t_{Min} *and* t_{Max} from the actual test sample;
    (iv) calculate *maximum relative deviation* d_e from average enrollment value μ_e:

$$d_e = \text{MAX}\left(\frac{|\mu_e - t_{\text{Min}}|}{|\mu_e - ve_{\text{Min}}|}, \frac{|\mu_e - t_{\text{Max}}|}{|\mu_e - ve_{\text{Max}}|}\right); \tag{9}$$

    (v) *average* d_e of all enrollments of all users and semantic class *s into average feature deviation* $d_{i,s}$.

Figure 2 presents the histogram for the averaged deviations for each of the features numbers *i* of this test for an enrollment size of $e = 6$ samples and the semantic signature.

The two features n_{43} and n_{44} (integration error sign for x and y signals) resulted in a feature value of 0 for all tests, thus the relative deviation cannot be determined. We observe a relatively strong increase in deviations between feature n_{15} and n_{42}. Further, the gradient significantly increases for all features right of n_{17}. In order to determine particularly low and high variance features, we classify features of the first category into low, the second into high, and all remaining into medium intravariance. We get the classification of low intravariance and high intravariance features in Table 3 and Table 4, respectively.

There are two interesting observations. The three features with the lowest intravariability are in the same feature category as n_{34}, being amongst the three features with the highest variability. All these features are calculated by calculating the number of pixels of the writing trace in segmented images, which are obtained by dividing the signature image into 4×3 equal-sized images according to Figure 3.

While the two upper, leftmost areas show a high stability, the pixel count in area 6 is varying strongly. The other interesting observation is the ranking and n_{25} (trace path length) and n_2 (total writing duration). Both features are time- or sequence-variant and are commonly known as rather reliable features for verification. Apparently these features are not significantly stable in the biometric hash generation and furthermore, it is interesting to see that in amongst the 8 parameters of the low-variability class, only one online feature (n_8, Y-Integral) can be found. An explanation for this observation can be the global nature of features, which is a prerequisite for the calculation of the biometric hash as described in Section 4. Furthermore, the observation that segmented features in the upper left areas show a lower intrapersonal variance can be explained by the natural left-to-right writing orientation in Latin handwriting.

Table 3: Features showing a low intravariability for $N = 6$ with the semantic class being signature.

Feature	Description	Deviation (%)
$n29$	Pixel count 12-segment (1/12)	32
$n30$	Pixel count 12-segment (2/12)	51.9
$n40$	Pixel count 12-segment (12/12)	60.4
$n5$	Aspect ratio	61.5
$n20$	Segmented y-area 1/5	64.2
$n23$	Segmented y-area 4/5	64.6
$n8$	Y-integral	67.9
$n15$	Segmented x-area 1/5	68.7

Table 4: Features showing a high intrapersonal variability for $N = 6$ with the semantic class being signature.

Feature	Description	Deviation (%)
$n10$	Y-velocity	153.2
$n11$	X-acceleration	163.3
$n24$	Segmented y-area 5	171.8
$n50$	Average y-position	179.2
$n28$	Effective average speed	180.9
$n41$	Cumulated integral error x	182.1
$n4$	Maximum count	193.1
$n26$	Delta X	204.6
$n13$	X-distribution velocity	206
$n6$	Pen-up pen-down ratio	215.7
$n25$	Path length	219.1
$n7$	X-integral	230.2
$n47$	Cumulated distance	238.2
$n48$	Average distance	256.9
$n16$	Segmented x-area 2/5	269.7
$n49$	Average x-position	293.3
$n34$	Pixel Count 12-segment 6/12	295.2
$n2$	Duration	306.2
$n19$	Segmented x-area 5/5	368.8

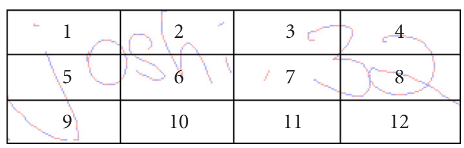


Figure 3: Segmentation of the writing image into 12 equal-sized areas.

6. FEATURE ENTROPY

In Section 5, we have discussed aspects of intrapersonal variability of biometric features based on handwriting. Intrapersonal variability can be interpreted as a measure of instability of a feature parameter. For biometric systems, feature stability is a fundamental requirement; therefore, relevant features should show a low intrapersonal deviation. Besides the stability, the individuality of features needs to be ensured. For the evaluation of individually, we present an entropy analysis in this section. Both characteristics together will then be combined into an indicator for the suitability of a particular feature for the biometric hash in the Section 7.

Information entropy had been introduced by Shannon more than half a century ago [22, 23], and is a measure for the information density within a set of values with known occurrence probabilities. Knowledge of the information entropy is the basis for design of several efficient data coding and compression techniques like the Huffman code [24] as it describes the effective amount of information contained in a finite set. This question of effective information content is directly related to the uniqueness of a biometric feature, which motivated the authors to perform an entropy analysis for each feature of the biometric hash.

In the biometric hash scenario as described in Section 4, the interpersonal variability has a direct impact on the hash value space. For features with a low interpersonal variability, it can be expected that many users will have similar or identical hash values, whereas a high interpersonal variability indicates a large potential value space. Consequently, we consider the feature entropy of responses of the biometric hash function as a measure to which degree the potential value space of the hashing function is actually occupied by real-world hash values. Our aim is to estimate to which extend

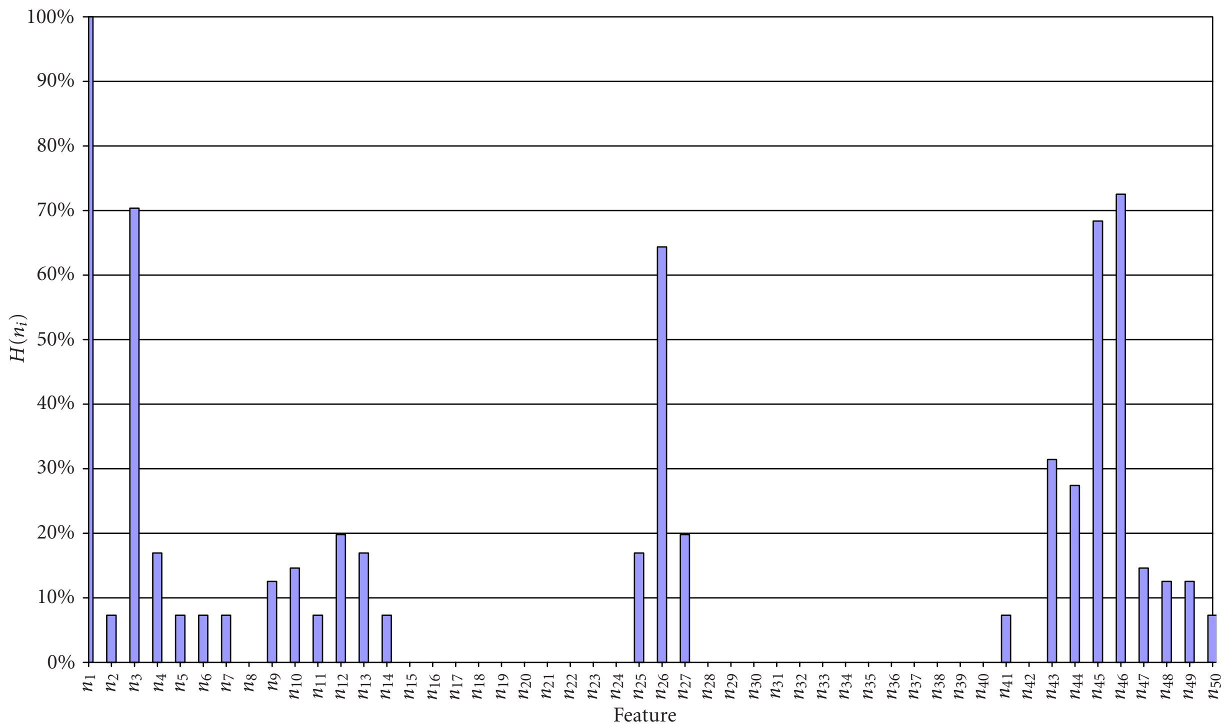


FIGURE 4: Feature entropy of initial test relative to $H(n_1) = 1.93$ with the semantic being signature.

each biometric feature is capable of representing individual values to build the biometric hash. For this estimation, we apply the general formula to determine the entropy H of a system X consisting of $k \in [1, \dots, n]$ states with a respective occurrence probability of p_k, in our context, each of the n states represents the occurrence of value v_k in the response of the biometric hash system, being one of the unique values that have been observed over all T test passes for each feature. Thus the occurrence probability for feature value v_k writes to $p_k = \text{count}(v_k)/T$ and the feature entropy can be written to:

$$H(X) = -\sum_{k=1}^{n} p_k \cdot \log_2 p_k. \tag{10}$$

In this part of our analysis, we are mainly interested in a global quantitative comparison of information capacity of each of the features, as described in Section 4. In order to do so, the interpersonal feature entropy for the same test set as described in Section 5 has been determined. For a classification, all entropy values have been normalized to the highest entropy occurrence, which was found for feature n_1 with an entropy of $H(n_1) = 1.93$.

Figure 4 shows the result of the entropy test, and it visualizes the information content. For a number of features, the hash value was the same for all users in all verification tests. These cases lead to an entropy of zero, thus n_{15} through n_{24}, n_{28} through n_{40}, and n_{42} are zero and do not contribute any user-specific information in the biometric hash scenario. Amongst the remaining nonzero entropy features, five show entropy significantly higher than 50%; these are n_1, n_3, n_{26}, n_{45}, and n_{46}. The remaining features show relatively low entropy in the range between 7% and slightly above 30%. The clear boundary above 50% motivates our classification into high-entropy (greater than 50%), low-entropy (greater than 0%, equal to 50%), and zero-entropy features. Thus in summary, the entropy test resulted in 5 relevant, high-entropy, 20 low-entropy, and 25 zero-entropy features.

7. FEATURE STABILITY AND ENTROPY CORRELATION

In Sections 6 and 7, we have presented two feature evaluation measures for biometric hashes: intrapersonal deviation as a term of instability and intrapersonal entropy as a measurement for information density. In order to have a quantitative measure for the trade-off between deviation and stability, we introduce the feature correlation C_i as the product between the relative feature stability S_i and the feature entropy $H_i = H(n_i)$ for one specific semantic class as per the description of the entropy test in Section 6 as follows:

$$S_i = 1 - \left(d_i / \text{MAX}\left(d_i,\ i \in [1, \dots, K]\right)\right), \tag{11}$$

where d_i denotes average feature deviation (see Section 5),

$$C_i = S_i \cdot H_i \mid i \in [1, \dots, K]. \tag{12}$$

The correlation between feature stability and entropy is a measure for the relevance of individual features in the biometric hash generation because it is a numerical valuation of the uniqueness and constancy that is required for adequate biometric features as pointed out in Section 1. With a total

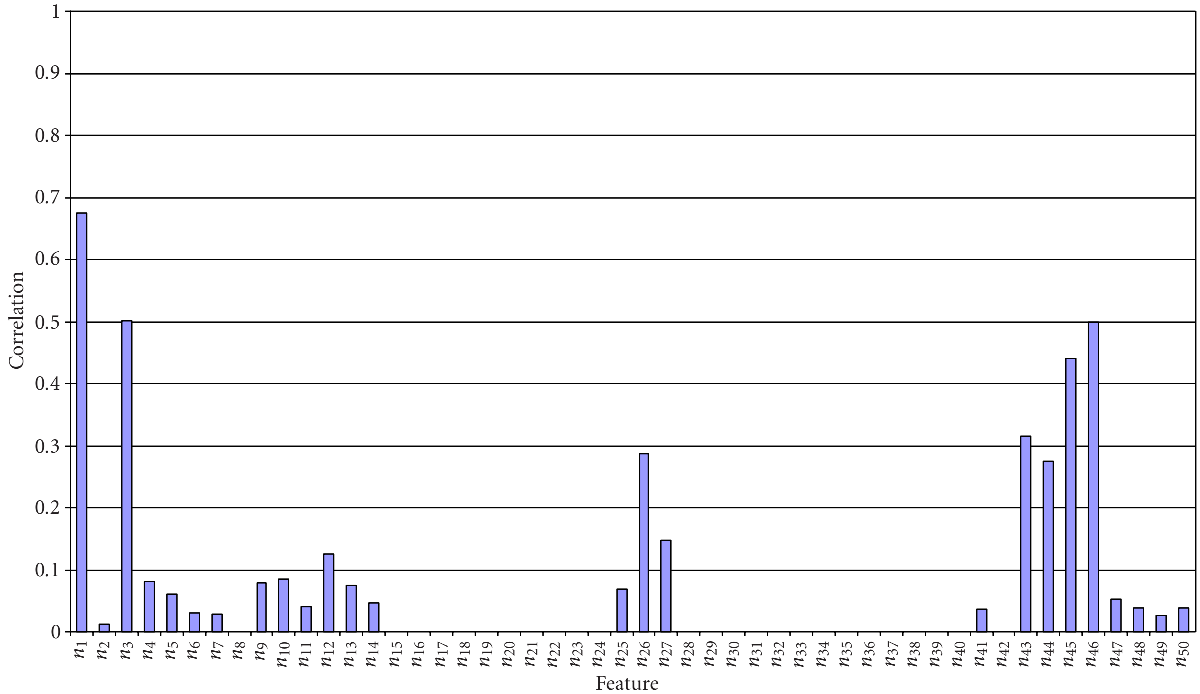


FIGURE 5: Feature stability and entropy correlation.

number of $K = 50$ features for our tests and d_i being the average deviation for feature number i as per the feature variance test in Section 5, S_i is normalized to the maximum feature deviation, thus can have values in the range of $[0, \dots, 1]$, which is also the case for the feature entropy H_i. By calculating the product of both numbers, we receive the feature correlation values C_i as shown in the histogram of Figure 5.

In order to determine suitable features for the biometric hash, we classify features according to their significance according to the following scheme:

(i) no significance: $C_I = 0$,
(ii) low significance: $0 < C_i < 0.25$,
(iii) medium significance: $0.25 \leq C_i < 0.5$,
(iv) high significance: $0.5 = C_I$.

The classification summary in Table 5 displays that there is a clear threshold between the 7 features with high and medium significance ($n_1, n_3, n_{46}, n_{45}, n_{44}, n_{43}, n_{26}$) and the best feature in the low-significance class n_9. This leads us to the conclusion that these features are most suitable amongst the 50 tested for our application of biometric hashes. All 7 features are based on time variant information; however, only $n3$, the sample count, has a linear relation to the writing signal. All other features are second order, based on combined temporal and spatial information.

8. EVALUATION ON EXTENDED DATA SETS

Although the initial evaluation presented in the previous sections confirms the feasibility of feature evaluation in principle, the underlying initial data set is too small to justify significant conclusions. Furthermore, during the initial test, where both signal capturing and data processing were performed on a computationally slow handheld computer, it has turned out that tests on larger data sets could not be performed in reasonable time. Therefore, methods for the biometric hash have been migrated to a PC platform using Object Pascal, and additional tests have been performed on reasonably performant Windows 2000 PC (1.7 GHz, 512 MB RAM).

Data sets used for these extended tests are subsets from a handwriting verification database, which has been collected in an educational environment over a period of three years, containing 5829 signatures from 60 writers obtained from various digitizer tablet devices, as can be seen from Table 6.

The only limitation compared to the initial test set from Section 5 is the number of features that has been implemented on the new platform, which at the time of publication were 36 of the originally 50-dimensional feature set presented in Table 1. The remaining feature set (see Table 7) was considered to be reasonable to evaluate, particularly as for some of the missing features from the original set, it can be assumed that they are highly correlated (e.g., $n26$ and $n27$ with $n5$, $n28$ with $n9$ and $n10$) as they are linearly dependent due to the nature of their determination. Additionally, with the extended database, we have the advantage of a first hardware independent analysis of the algorithm, as sample features originating from various different digitizer devices are included.

Based on this extended data set, samples were taken from all devices shown in Table 7 while the evaluation methodology was chosen identically to the initial approach described in Sections 5, 6, and 7 with the following adoptions:

Table 5: Feature significance classification.

Significance high	Significance medium	Significance low	Significance 0	Feature number	Correlation	Description
X				$n1$	0.67462039	Segment count
X				$n3$	0.501734511	Sample count
	X			$n46$	0.499881971	Average radiant
	X			$n45$	0.440496027	Cumulated radiant
	X			$n44$	0.274043819	Integral error sign y
	X			$n43$	0.314424886	Integral error sign x
	X			$n26$	0.286563794	Delta X
		X		$n9$	0.078190808	X-velocity
		X		$n7$	0.027517839	X-integral
		X		$n6$	0.030396689	Pen-up pen-down ratio
		X		$n50$	0.03764345	Average y-position
		X		$n5$	0.061011774	Aspect ratio
		X		$n49$	0.025678147	Average x-position
		X		$n48$	0.038058075	Average distance
		X		$n47$	0.051751071	Cumulated distance
		X		$n41$	0.03706768	Cumulated integral error x
		X		$n4$	0.080758321	Maximum count
		X		$n27$	0.148098756	Delta Y
		X		$n25$	0.068807745	Path length
		X		$n2$	0.012428692	Duration
		X		$n14$	0.046557959	Y-distribution velocity
		X		$n13$	0.074828997	X-distribution velocity
		X		$n12$	0.125008667	Y-acceleration
		X		$n11$	0.040800259	X-acceleration
		X		$n10$	0.085432856	Y-velocity
			X	$n8$	0	Y-integral
			X	$n15$	0	Segmented x-area 1
			X	$n16$	0	Segmented x-area 2
			X	$n17$	0	Segmented x-area 3
			X	$n18$	0	Segmented x-area 4
			X	$n19$	0	Segmented x-area 5
			X	$n20$	0	Segmented y-area 1
			X	$n21$	0	Segmented y-area 2
			X	$n22$	0	Segmented y-area 3
			X	$n23$	0	Segmented y-area 4
			X	$n24$	0	Segmented y-area 5
			X	$n28$	0	Effective average speed
			X	$n29$	0	Pixel count segment 1/12
			X	$n30$	0	Pixel count segment 2/12
			X	$n31$	0	Pixel count segment 3/12
			X	$n32$	0	Pixel count segment 4/12
			X	$n33$	0	Pixel count segment 5/12
			X	$n34$	0	Pixel count segment 6/12
			X	$n35$	0	Pixel count segment 7/12
			X	$n36$	0	Pixel count segment 8/12
			X	$n37$	0	Pixel count segment 9/12
			X	$n38$	0	Pixel count segment 10/12
			X	$n39$	0	Pixel count segment 11/12
			X	$n40$	0	Pixel count segment 12/12
			X	$n42$	0	Cumulated integral error y

Table 6: Test set size of the extended database by tablet type.

Tablet name	Count (signatures)
Aiptek Hyperpen 8000	9
Palm Vx	447
EIZO Flexscan Touchscreen 18″	1118
Wacom 1 serial	621
Wacom Cintiq 15	1284
Wacom Intuos 2	547
Wacom Intuos 2 Inkpen	31
Wacom 1 USB	971
Wacom Valito	801

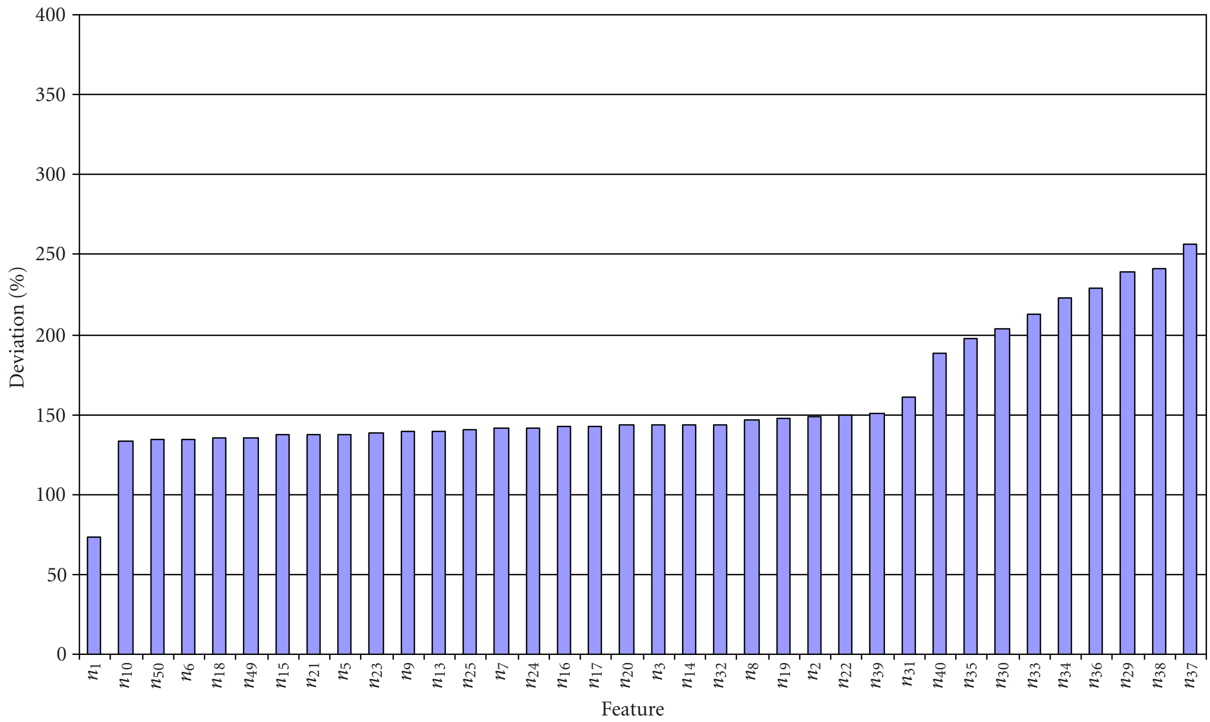
Table 7: Feature parameters evaluated from the extended test set.

Parameter name	Index	Param.	Description
Segment count	1	n_1	Number of pen-down events
Duration	2	n_2	Total writing duration in ms
Sample count	3	n_3	Total number of samples
Aspect ratio	5	n_5	x/y ratio of the writing image times 1000
Pen-up pen-down ratio	6	n_6	Ratio of total pen-up and total pen-down times multiplied by 1000
X-integral	7	n_7	Total area covered by the absolute x signal
Y-integral	8	n_8	Total area covered by the absolute y signal
X-velocity	9	n_9	Average absolute writing velocity in x direction
Y-velocity	10	n_{10}	Average absolute writing velocity in y direction
X-distribution velocity	13	n_{13}	Maximum x-distribution $\mathrm{Max}(x) - \mathrm{Min}(x)$ over total writing time
Y-distribution velocity	14	n_{14}	Maximum y-distribution $\mathrm{Max}(y) - \mathrm{Min}(y)$ over total writing time
Segmented x-areas	15–19	n_{15}–n_{19}	x-integral of 5 segments of equal length $T_{\mathrm{Total}}/5$
Segmented y-areas	20–24	n_{20}–n_{24}	y-integral of 5 segments of equal length $T_{\mathrm{Total}}/5$
Path length	25	n_{25}	Total path length of writing trace in pixel
Pixel count 12-segment	29–40	n_{29}–n_{40}	Number of pixels in each 4 by 3 sector
Average x position	49	n_{49}	Average of all x sample values
Average y position	50	n_{50}	Average of all y sample values

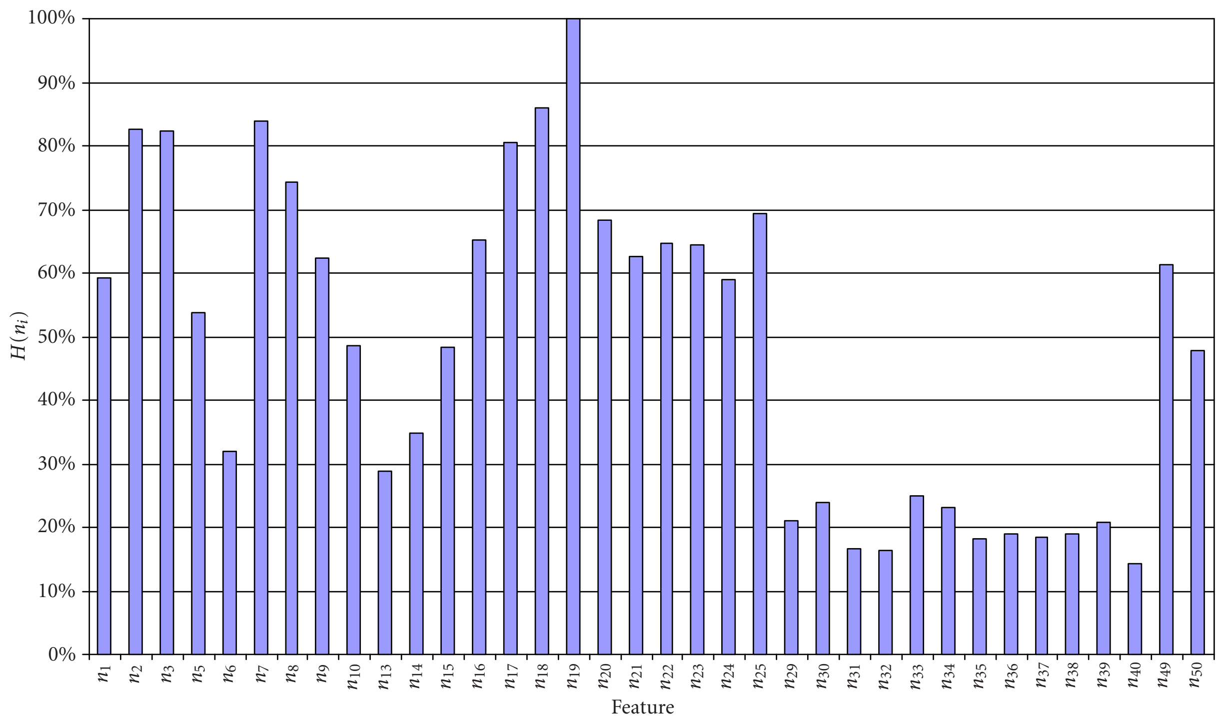
(i) semantic class ($s \in$ [signature]);
(ii) number of users is $g \in [1, \ldots, 54]$;
(iii) the selection of samples was implemented by drawing 10 *sets* of $e = 6$ *enrollment* samples and $10 - e = 4$ *test* samples minus for each user u_g and each tablet type from the database in a pseudorandom manner.

Due to the large number of samples for some users in the extended database, disallowing an exhaustive evaluation of all enrollment/test set pairs, the approach of pseudorandom selection was chosen to reasonably limit the number of trials. Results of deviation and entropy analysis of the extended test are presented in Figures 6a, 6b. Furthermore, Figure 7 visualizes the comparison of correlation between feature entropy and deviation between the initial tests as per Figure 5 and the results of the extended database in ascending order for the later factors.

Correlation factors from the extended test show a statistical characteristics with a means value of $\mu_{\mathrm{Extended}} = 0.175$ and standard deviation of $s_{\mathrm{Extended}} = 0.133$ as compared to the initial correlation factor distribution with $\mu_{\mathrm{Initial}} = 0.048$ and $s_{\mathrm{Extended}} = 0.137$ for the feature set evaluated in the extended test. This indicates an overall increase of significance of the values (note that the standard deviation has changed insignificantly) over a set of several digitizer devices and using signature as writing semantics. Furthermore, it can be observed that amongst the five features showing the highest correlation in the extended data set ($n_{43}, n_3, n_5, n_{32}, n_1$), all except n_5 have been classified as high or medium significant in Section 7. A plausible explanation for n_5 (representing the aspect ratio) being more stable in the extended tests is that as compared to the initial test, only signature samples were taken into account, showing a higher stability in image layout as compared to semantics written with a lower degree of routine. Another interesting observation is the ranking of the correlation of segmented pixel count features $n31 = 0.32$ and $n32 = 0.44$, which are both well noticeable above the standard deviation in the distribution of the extended test, while both features resulted in a correlation value of 0 in the initial test.



(a)



(b)

Figure 6: Sorted feature deviation histogram and relative entropy determined from extended test database. (a) Feature value deviations extended test. (b) Relative feature entropy of initial test based on $H(n19) = 3,61$.

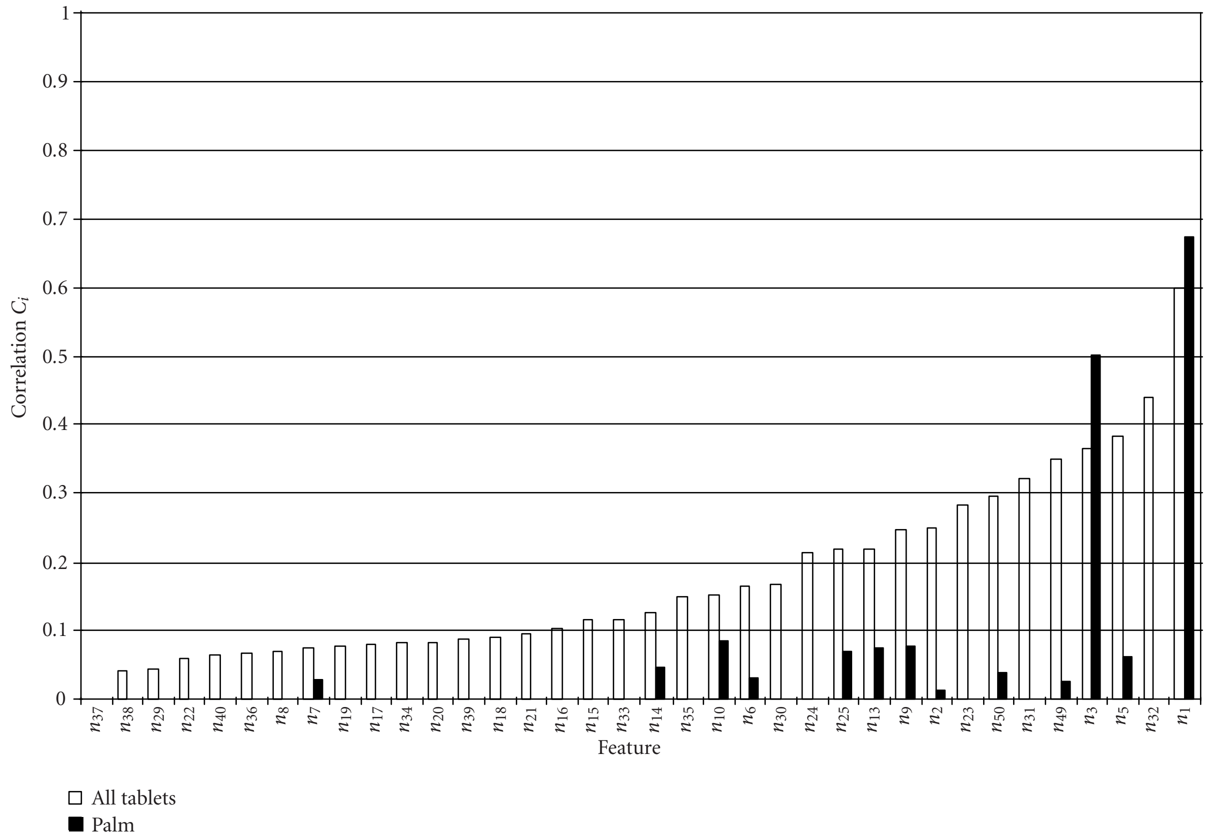


Figure 7: Comparison between stability-entropy correlation of initial and extended databases.

9. CONCLUSION AND FUTURE WORK

In this article, we have presented a new method to evaluate a given biometric authentication algorithm, the biometric hash, by analyzing the features taken into account. We have presented test results from two different data sets of quite different size and origin and introduced three measures for feature evaluation: intrapersonal feature deviation, interpersonal entropy of hash value components, and the correlation between both. Based on this basic idea, we resulted in an initial perception that on a very specific device, a PDA, 7 out of 50 investigated features can be classified as high or medium significant.

As the first results indicated the suitability of our approach, we have performed tests on a significantly extended database in order to get more general and statistically more relevant conclusions. Three main conclusions can be derived from the second test:

(i) with a few exceptions, all of the features showing high significance in the initial test have been reconfirmed;

(ii) entropy of hash values increases over a large set of different tablets as compared to the PDA device; all features have shown nonzero entropy in the extended test;

(iii) feature scattering appears to be rather high on PDA devices as compared to the average over the set of various tablets.

The evaluation data set presented in this work is the largest data set used for a feature analysis of dynamic handwriting based on signature and other semantic classes that could be found in the literature. In [16], a number of 10 different semantic classes for writer verification has been suggested and tested with 20 different users; however, this work limits observations on results in terms of false acceptance rate (FAR) and false rejection rate (FRR) and does not analyze variability within feature classes. Due to the total size of our tests, we consider our findings as statistically significant, opening many areas for future work, where we plan to concentrate on three main aspects: algorithm optimization, additional tests including feature benchmarking, and applications.

Our main working direction will aim to optimize the biometric hashing technique under operational conditions for specific applications, including boundary estimates for the theoretically achievable key space and the extension of feature candidate sets. Also, it will be necessary to perform detailed quantitative analysis of additional semantic classes. Especially the classes of pass phrases and numeric codes are of great interest, as they will allow design of applications including user authentication based on knowledge and being. There is also room for improvement in the interval-matching algorithm. The tolerance value introduced in (3) is estimated based on statistical tests over all users and all semantic classes. Here, we are working on adoptive, user-specific tolerance value determination rather than a global estimation. Although there is no security threat the IM, as it does not allow reverse-engineering of the full biometric template, there still is the problem of enrollment and storing this information for each user individually. To overcome this potential objective for real-world applications, we are working towards mechanisms to determine a biometric hash without any a priori parameters based on the individual.

Based on the introduced three statistical measures, it is also interesting from the discipline of feature selection research to perform feature selection benchmarks by comparing FAR and FRR, based on different feature sets. Here, it will be necessary to determine competing feature sets based on the method presented in this paper and a selection of other published feature evaluation approaches of different nature. A comparison of verification and recognition results for the biometric hash algorithm, parameterized with these different feature sets, will allow conclusions in regard to the impact of feature selection on recognition accuracy.

REFERENCES

[1] A. Jain, R. Bolle, and S. Pankanti, "Introduction to biometrics," in *Biometrics: Personal Identification in Networked Society*, A. Jain, R. Bolle, and S. Pankanti, Eds., vol. 479 of *The Kluwer International Series in Engineering and Computer Science*, pp. 1–41, Kluwer Academic Publishers, Boston, Mass, USA, January 1999.

[2] J. L. Wayman, "Fundamentals of biometric authentication technologies," *International Journal of Image and Graphics*, vol. 1, no. 1, pp. 93–113, 2001.

[3] D. D. Zhang, *Automated Biometrics: Technologies and Systems*, vol. 7 of *The Kluwer International Series on Asian Studies in Computer and Information Science*, Kluwer Academic Publishers, Boston, Mass, USA, 2000.

[4] Directive 1999/93/EC of the European parliament and of the council of 13 December 1999, http://www.signatur.rtr.at/en/repository/legal-directive-20000119.html.

[5] B. Struif, "Use of biometrics for user verification in electronic signature smartcards," in *Smart Card Programming and Security (Proc. International Conference on Research in Smart Cards (e-smart '01))*, I. Attali and T. Jensen, Eds., vol. 2140 of *Lecture Notes in Computer Science*, pp. 220–227, Cannes, France, September 2001.

[6] C. Vielhauer, R. Steinmetz, and A. Mayerhöfer, "Biometric hash based on statistical features of online signatures," in *Proc. 16th International Conference on Pattern Recognition (ICPR '02)*, vol. 1, pp. 123–126, Quebec City, Quebec, Canada, August 2002.

[7] J. Kittler, "Mathematical methods of feature selection in pattern recognition," *International Journal of Man-Machine Studies*, vol. 7, no. 5, pp. 609–637, 1975.

[8] M. A. Hall, *Correlation-based feature selection for machine learning*, Ph.D. thesis, Department of Computer Science, University of Waikato, Hamilton, New Zealand, 1999.

[9] D. A. Forsyth and J. Ponce, *Computer Vision: A Modern Approach*, Prentice-Hall, Englewood Cliffs, NJ, USA, 2003.

[10] Z. Chi and H. Yan, "Feature evaluation and selection based on an entropy measurement with data clustering," *Optical Engineering*, vol. 34, no. 12, pp. 3514–3519, 1995.

[11] R. Plamondon and S. N. Srihari, "On-line and off-line handwriting recognition: a comprehensive survey," *IEEE Trans. on Pattern Analysis and Machine Intelligence*, vol. 22, no. 1, pp. 63–84, 2000.

[12] F. Maarse, L. Schomaker, and H.-L. Teulings, "Automatic identification of writers," in *Human-Computer Interaction: Psychonomic Aspects*, G. van der Veer and G. Mulder, Eds., pp. 353–360, Springer-Verlag, New York, NY, USA, October 1988.

[13] S. Lee, S.-H. Cha, and S. N. Srihari, "Combining macro and micro features for writer identification," in *Document Recognition and Retrieval IX*, P. B. Koutor, T. Kanungo, and J. Zhou, Eds., vol. 4670 of *Proceedings of SPIE*, pp. 155–166, Proceedings SPIE, San Jose, Calif, USA, December 2001.

[14] J. Kaiser, "Vertrauensmerkmal unterschrift—gestaltungskriterien für sichere signierwerkzeuge," in *Informatik 2001—Tagungsband der GI/OCC-Jahrestagung*, pp. 500–504, Vienna, Austria, September 2001.

[15] C. Vielhauer, "Handschriftliche authentifikation für digitale wasserzeichenverfahren," in *Sicherheit in Netzen und Medienströmen*, M. Schumacher and R. Steinmetz, Eds., pp. 134–148, Springer-Verlag, Berlin, Germany, September 2000.

[16] Y. Kato, T. Hamanoto, and S. Hangai, "A proposal of writer verification of hand written objects," in *IEEE International Conference on Multimedia and Expo (ICME '02)*, pp. 585–588, Lausanne, Switzerland, August 2002.

[17] R. K. Nichols, *ICSA Guide to Cryptography*, McGraw-Hill, New York, NY, USA, 1999.

[18] F. Monrose, M. K. Reiter, Q. Li, and S. Wetzel, "Using voice to generate cryptographic keys," in *Proc. Odyssey, The Speaker Verification Workshop*, Crete, Greece, June 2001.

[19] R. Plamondon and G. Lorette, "Automatic signature verification and writer identification—the state of the art," *Pattern Recognition*, vol. 22, no. 2, pp. 107–131, 1989.

[20] F. Leclerc and R. Plamondon, "Automatic signature verification: the state of the art 1989–1993," *International Journal of Pattern Recognition and Artificial Intelligence*, vol. 8, no. 3, pp. 643–660, 1994.

[21] H. Dullink, B. van Daalen, J. Nijhuis, L. Spaanenburg, and H. Zuidhof, "Implementing a DSP kernel for online dynamic handwritten signature verification using the TMS320 DSP family," Tech. Rep. SPRA304, Texas Instruments, EFRIE, France, 1995.

[22] C. E. Shannon, "A mathematical theory of communication," *Bell System Technical Journal*, vol. 27, no. 3, pp. 379–423, 1948.

[23] C. E. Shannon, "A mathematical theory of communication," *Bell System Technical Journal*, vol. 27, no. 4, pp. 623–656, 1948.

[24] M. Nelson and J.-L. Gailly, *The Data Compression Book*, M&T Books, New York, NY, USA, 1995.

Claus Vielhauer is an Assistant Researcher at Otto-von-Guericke University of Magdeburg, Germany, where he has joined the department of Computer Science in 2003 as the Leader of the biometrics research group as part of the Advanced Multimedia and Security Lab (AMSL). In addition, he is working for the Multimedia Communications Lab (KOM) of Technical University Darmstadt, Germany, since 1999, where he also received his M.S. degree in electrical engineering. His research interests are in biometrics with specialization in handwriting recognition and quality evaluation. His main activities are concentrated on the algorithm design for hardware-independent signature verification systems and key management for PKI using biometrics. He has a great number of international publications in the area of

signature verification and biometric test criteria. Furthermore, he is a member of technical program committees of international conferences of great importance to biometrics (ICME, ICBA) and has been organizing and cochairing a number of special sessions on biometrics (ICME, SPIE). Additionally, since 2000, he is the Managing Director of Platanista GmbH, a spinoff company focusing on IT security.

Ralf Steinmetz worked for over nine years in industrial research and development of distributed multimedia systems and applications. Since 1996, he has been the head of the Multimedia Communications Lab at Darmstadt University of Technology, Germany. From 1997 to 2001, he directed the Fraunhofer (former GMD) Integrated Publishing Systems Institute (IPSI) in Darmstadt. In 1999, he founded the Hessian Telemedia Technology Competence Center (httc e.V.). His thematic focus in research and teaching is on multimedia communications with his vision of real "seamless multimedia communications." With over 200 refereed publications he has become ICCC Governor in 1999 and he was awarded the ranking of Fellow of both the IEEE in 1999 and ACM in 2002.

EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

Special Issue on Multirate Systems and Applications

Call for Papers

Filter banks for the application of subband coding of speech were introduced in the 1970s. Since then, filter banks and multirate systems have been studied extensively. There has been great success in applying multirate systems to many applications. The most notable of these applications include subband coding for audio, image, and video, signal analysis and representation using wavelets, subband denoising, and so forth. Different applications also call for different filter bank designs and the topic of designing one-dimensional and multidimentional filter banks for specific applications has been of great interest.

Recently there has been growing interest in applying multirate theories to the area of communication systems such as, transmultiplexers, filter bank transceivers, blind deconvolution, and precoded systems. There are strikingly many dualities and similarities between multirate systems and multicarrier communication systems. Many problems in multicarrier transmission can be solved by extending results from multirate systems and filter banks. This exciting research area is one that is of increasing importance.

The aim of this special issue is to bring forward recent developments on filter banks and the ever-expanding area of applications of multirate systems.

Topics of interest include (but are not limited to):

- Multirate signal processing for communications
- Filter bank transceivers
- One-dimensional and multidimensional filter bank designs for specific applications
- Denoising
- Adaptive filtering
- Subband coding
- Audio, image, and video compression
- Signal analysis and representation
- Feature extraction and classification
- Other applications

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	January 1, 2006
Acceptance Notification	May 1, 2006
Final Manuscript Due	August 1, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Yuan-Pei Lin, Department of Electrical and Control Engineering, National Chiao Tung University, Hsinchu, Taiwan; ypl@mail.nctu.edu.tw

See-May Phoong, Department of Electrical Engineering and Graduate Institute of Communication Engineering, National Taiwan University, Taipei, Taiwan; smp@cc.ee.ntu.edu.tw

Ivan Selesnick, Department of Electrical and Computer Engineering, Polytechnic University, Brooklyn, NY 11201, USA; selesi@poly.edu

Soontorn Oraintara, Department of Electrical Engineering, The University of Texas at Arlington, Arlington, TX 76010, USA; oraintar@uta.edu

Gerald Schuller, Fraunhofer Institute for Digital Media Technology (IDMT), Langewiesener Strasse 22, 98693 Ilmenau, Germany; shl@idmt.fraunhofer.de

Special Issue on

Multisensor Processing for Signal Extraction and Applications

Call for Papers

Source signal extraction from heterogeneous measurements has a wide range of applications in many scientific and technological fields, for example, telecommunications, speech and acoustic signal processing, and biomedical pattern analysis. Multiple signal reception through multisensor systems has become an effective means for signal extraction due to its superior performance over the monosensor mode. Despite the rapid progress made in multisensor-based techniques in the past few decades, they continue to evolve as key technologies in modern wireless communications and biomedical signal processing. This has led to an increased focus by the signal processing community on the advanced multisensor-based techniques which can offer robust high-quality signal extraction under realistic assumptions and with minimal computational complexity. However, many challenging tasks remain unresolved and merit further rigorous studies. Major efforts in developing advanced multisensor-based techniques may include high-quality signal extraction, realistic theoretical modeling of real-world problems, algorithm complexity reduction, and efficient real-time implementation.

The purpose of this special issue aims to present state-of-the-art multisensor signal extraction techniques and applications. Contributions in theoretical study, performance analysis, complexity reduction, computational advances, and real-world applications are strongly encouraged.

Topics of interest include (but are not limited to):

- Multiantenna processing for radio signal extraction
- Multimicrophone speech recognition and enhancement
- Multisensor radar, sonar, navigation, and biomedical signal processing
- Blind techniques for multisensor signal extraction
- Computational advances in multisensor processing

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	January 1, 2006
Acceptance Notification	May 1, 2006
Final Manuscript Due	August 1, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Chong-Yung Chi, National Tsing Hua University, Taiwan; cychi@ee.nthu.edu.tw

Ta-Sung Lee, National Chiao Tung University, Taiwan; tslee@cc.nctu.edu.tw

Zhi-Quan Luo, University of Minnesota, USA; luozq@ece.umn.edu

Kung Yao, University of California, Los Angeles, USA; yao@ee.ucla.edu

Yue Wang, Virginia Polytechnic Institute and State University, USA; yuewang@vt.edu

Special Issue on

Search and Retrieval of 3D Content and Associated Knowledge Extraction and Propagation

Call for Papers

With the general availability of 3D digitizers, scanners, and the technology innovation in 3D graphics and computational equipment, large collections of 3D graphical models can be readily built up for different applications (e.g., in CAD/CAM, games design, computer animations, manufacturing and molecular biology). For such large databases, the method whereby 3D models are sought merits careful consideration. The simple and efficient query-by-content approach has, up to now, been almost universally adopted in the literature. Any such method, however, must first deal with the proper positioning of the 3D models. The two prevalent-in-the-literature methods for the solution to this problem seek either

- Pose Normalization: Models are first placed into a canonical coordinate frame (normalizing for translation, scaling, and rotation). Then, the best measure of similarity is found by comparing the extracted feature vectors, or
- Descriptor Invariance: Models are described in a transformation invariant manner, so that any transformation of a model will be described in the same way, and the best measure of similarity is obtained at any transformation.

The existing 3D retrieval systems allow the user to perform queries by example. The queried 3D model is then processed, low-level geometrical features are extracted, and similar objects are retrieved from a local database. A shortcoming of the methods that have been proposed so far regarding the 3D object retrieval, is that neither is the semantic information (high-level features) attached to the (low-level) geometric features of the 3D content, nor are the personalization options taken into account, which would significantly improve the retrieved results. Moreover, few systems exist so far to take into account *annotation* and *relevance feedback* techniques, which are very popular among the corresponding content-based image retrieval systems (CBIR).

Most existing CBIR systems using knowledge either annotate all the objects in the database (full annotation) or annotate a subset of the database manually selected (partial annotation). As the database becomes larger, full annotation is increasingly difficult because of the manual effort needed. Partial annotation is relatively affordable and trims down the heavy manual labor. Once the database is partially annotated, traditional image analysis methods are used to derive semantics of the objects not yet annotated. However, it is not clear "how much" annotation is sufficient for a specific database and what the best subset of objects to annotate is. In other words how the knowledge *will be propagated*. Such techniques have not been presented so far regarding the 3D case.

Relevance feedback was first proposed as an interactive tool in text-based retrieval. Since then it has been proven to be a powerful tool and has become a major focus of research in the area of content-based search and retrieval. In the traditional computer centric approaches, which have been proposed so far, the "best" representations and weights are fixed and they cannot effectively model high-level concepts and user's perception subjectivity. In order to overcome these limitations of the computer centric approach, techniques based on *relevant feedback*, in which the human and computer interact to refine high-level queries to representations based on low-level features, should be developed.

The aim of this special issue is to focus on recent developments in this expanding research area. The special issue will focus on novel approaches in 3D object retrieval, transforms and methods for efficient geometric feature extraction, annotation and relevance feedback techniques, knowledge propagation (e.g., using Bayesian networks), and their combinations so as to produce a single, powerful, and dominant solution.

Topics of interest include (but are not limited to):

- 3D content-based search and retrieval methods (volume/surface-based)
- Partial matching of 3D objects
- Rotation invariant feature extraction methods for 3D objects

- Graph-based and topology-based methods
- 3D data and knowledge representation
- Semantic and knowledge propagation over heterogeneous metadata types
- Annotation and relevance feedback techniques for 3D objects

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	February 1, 2006
Acceptance Notification	June 1, 2006
Final Manuscript Due	September 1, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Tsuhan Chen, Carnegie Mellon University, Pittsburgh, PA 15213, USA; tsuhan@cmu.edu

Ming Ouhyoung, National Taiwan University, Taipei 106, Taiwan; ming@csie.ntu.edu.tw

Petros Daras, Informatics and Telematics Institute, Centre for Research and Technology Hellas, 57001 Thermi, Thessaloniki, Greece; daras@iti.gr

Special Issue on Robust Speech Recognition

Call for Papers

Robustness can be defined as the ability of a system to maintain performance or degrade gracefully when exposed to conditions not well represented in the data used to develop the system. In automatic speech recognition (ASR), systems must be robust to many forms of signal degradation, including speaker characteristics (e.g., dialect and accent), ambient environment (e.g., cellular telephony), transmission channel (e.g., voice over IP), and language (e.g., new words, dialect switching). Robust ASR systems, which have been under development for the past 35 years, have made great progress over the years closing the gap between performance on pristine research tasks and noisy operational data.

However, in recent years, demand is emerging for a new class of systems that tolerate extreme and unpredictable variations in operating conditions. For example, in a cellular telephony environment, there are many nonstationary forms of noise (e.g., multiple speakers) and significant variations in microphone type, position, and placement. Harsh ambient conditions typical in automotive and mobile applications pose similar challenges. Development of systems in a language or dialect for which there is limited or no training data in a target language has become a critical issue for a new generation of voice mining applications. The existence of multiple conditions in a single stream, a situation common to broadcast news applications, and that often involves unpredictable changes in speaker, topic, dialect, or language, is another form of robustness that has gained attention in recent years.

Statistical methods have dominated the field since the early 1980s. Such systems tend to excel at learning the characteristics of large databases that represent good models of the operational conditions and do not generalize well to new environments.

This special issue will focus on recent developments in this key research area. Topics of interest include (but are not limited to):

- Channel and microphone normalization
- Stationary and nonstationary noise modeling, compensation, and/or rejection
- Localization and separation of sound sources (including speaker segregation)
- Signal processing and feature extraction for applications involving hands-free microphones
- Noise robust speech modeling
- Adaptive training techniques
- Rapid adaptation and learning
- Integration of confidence scoring, metadata, and other alternative information sources
- Audio-visual fusion
- Assessment relative to human performance
- Machine learning algorithms for robustness
- Transmission robustness
- Pronunciation modeling

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	February 1, 2006
Acceptance Notification	June 1, 2006
Final Manuscript Due	September 1, 2006
Publication Date	4th Quarter, 2006

GUEST EDITORS:

Herve Bourlard, IDIAP Research Institute, Swiss Federal Institute of Technology at Lausanne (EPFL), 1920 Martigny, Switzerland; herve.bourlard@idiap.ch

Mark Gales, Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, UK; mjfg@eng.cam.ac.uk

Maurizio Omologo, ITC-IRST, 38050 Trento, Italy; omologo@itc.it

S. Parthasarathy, AT&T Labs - Research, NJ 07748, USA; sps@research.att.com

Joe Picone, Department of Electrical and Computer Engineering, Mississippi State University, MS 39762-9571, USA; picone@cavs.msstate.edu

Special Issue on

Signal Processing Technologies for Ambient Intelligence in Home-Care Applications

Call for Papers

The possibility of allowing elderly people with different kinds of disabilities to conduct a normal life at home and achieve a more effective inclusion in the society is attracting more and more interest from both industrial and governmental bodies (hospitals, healthcare institutions, and social institutions). Ambient intelligence technologies, supported by adequate networks of sensors and actuators, as well as by suitable processing and communication technologies, could enable such an ambitious objective.

Recent researches demonstrated the possibility of providing constant monitoring of environmental and biomedical parameters, and the possibility to autonomously originate alarms, provide primary healthcare services, activate emergency calls, and rescue operations through distributed assistance infrastructures. Nevertheless, several technological challenges are still connected with these applications, ranging from the development of enabling technologies (hardware and software), to the standardization of interfaces, the development of intuitive and ergonomic human-machine interfaces, and the integration of complex systems in a highly multidisciplinary environment.

The objective of this special issue is to collect the most significant contributions and visions coming from both academic and applied research bodies working in this stimulating research field. This is a highly interdisciplinary field comprising many areas, such as signal processing, image processing, computer vision, sensor fusion, machine learning, pattern recognition, biomedical signal processing, multimedia, human-computer interfaces, and networking.

The focus will be primarily on the presentation of original and unpublished works dealing with ambient intelligence and domotic technologies that can enable the provision of advanced homecare services.

This special issue will focus on recent developments in this key research area. Topics of interest include (but are not limited to):

- Video-based monitoring of domestic environments and users
- Continuous versus event-driven monitoring
- Distributed information processing
- Data fusion techniques for event association and automatic alarm generation
- Modeling, detection, and learning of user habits for automatic detection of anomalous behaviors
- Integration of biomedical and behavioral data
- Posture and gait recognition and classification
- Interactive multimedia communications for remote assistance
- Content-based encoding of medical and behavioral data
- Networking support for remote healthcare
- Intelligent/natural man-machine interaction, personalization, and user acceptance

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	March 1, 2006
Acceptance Notification	July 1, 2006
Final Manuscript Due	October 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Francesco G. B. De Natale, Department of Information and Communication Technology, University of Trento, Via Sommarive 14, 38050 Trento, Italy; denatale@ing.unitn.it

Aggelos K. Katsaggelos, Department of Electrical and Computer Engineering, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208-3118, USA; aggk@ece.northwestern.edu

Oscar Mayora, Create-Net Association, Via Solteri 38, 38100 Trento, Italy; oscar.mayora@create-net.it

Ying Wu, Department of Electrical and Computer Engineering, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208-3118, USA; yingwu@ece.northwestern.edu

Special Issue on Spatial Sound and Virtual Acoustics

Call for Papers

Spatial sound reproduction has become widespread in the form of multichannel audio, particularly through home theater systems. Reproduction systems from binaural (by headphones) to hundreds of loudspeaker channels (such as wave field synthesis) are entering practical use. The application potential of spatial sound is much wider than multichannel sound, however, and research in the field is active. Spatial sound covers for example the capturing, analysis, coding, synthesis, reproduction, and perception of spatial aspects in audio and acoustics.

In addition to the topics mentioned above, research in virtual acoustics broadens the field. Virtual acoustics includes techniques and methods to create realistic percepts of sound sources and acoustic environments that do not exist naturally but are rendered by advanced reproduction systems using loudspeakers or headphones. Augmented acoustic and audio environments contain both real and virtual acoustic components.

Spatial sound and virtual acoustics are among the major research and application areas in audio signal processing. Topics of active study range from new basic research ideas to improvement of existing applications. Understanding of spatial sound perception by humans is also an important area, in fact a prerequisite to advanced forms of spatial sound and virtual acoustics technology.

This special issue will focus on recent developments in this key research area. Topics of interest include (but are not limited to):

- Multichannel reproduction
- Wave field synthesis
- Binaural reproduction
- Format conversion and enhancement of spatial sound
- Spatial sound recording
- Analysis, synthesis, and coding of spatial sound
- Spatial sound perception and auditory modeling
- Simulation and modeling of room acoustics
- Auralization techniques
- Beamforming and sound source localization
- Acoustic and auditory scene analysis
- Augmented reality audio
- Virtual acoustics (sound environments and sources)
- Intelligent audio environments
- Loudspeaker-room interaction and equalization
- Applications

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	May 1, 2006
Acceptance Notification	September 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

Ville Pulkki, Helsinki University of Technology, Espoo, Finland; ville@acoustics.hut.fi

Christof Faller, EPFL, Lausanne, Switzerland; christof.faller@epfl.ch

Aki Harma, Philips Research Labs, Eindhoven, The Netherlands; aki.harma@philips.com

Tapio Lokki, Helsinki University of Technology, Espoo, Finland; ktlokki@cc.hut.fi

Werner de Bruijn, Philips Research Labs, Eindhoven, The Netherlands; werner.de.bruijn@philips.com

EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

Special Issue on

Advances in Electrocardiogram Signal Processing and Analysis

Call for Papers

Since its invention in the 19th century when it was little more than a scientific curiosity, the electrocardiogram (ECG) has developed into one of the most important and widely used quantitative diagnostic tools in medicine. It is essential for the identification of disorders of the cardiac rhythm, extremely useful for the diagnosis and management of heart abnormalities such as myocardial infarction (heart attack), and offers helpful clues to the presence of generalised disorders that affect the rest of the body, such as electrolyte disturbances and drug intoxication.

Recording and analysis of the ECG now involves a considerable amount of signal processing for S/N enhancement, beat detection, automated classification, and compression. These involve a whole variety of innovative signal processing methods, including adaptive techniques, time-frequency and time-scale procedures, artificial neural networks and fuzzy logic, higher-order statistics and nonlinear schemes, fractals, hierarchical trees, Bayesian approaches, and parametric models, amongst others.

This special issue will review the current status of ECG signal processing and analysis, with particular regard to recent innovations. It will report major achievements of academic and commercial research institutions and individuals, and provide an insight into future developments within this exciting and challenging area.

This special issue will focus on recent developments in this key research area. Topics of interest include (but are not limited to):

- Beat (QRS complex) detection
- ECG compression
- Denoising of ECG signals
- Morphological studies and classification
- ECG modeling techniques
- Expert systems and automated diagnosis
- QT interval measurement and heart-rate variability
- Arrhythmia and ischemia detection and analysis
- Interaction between cardiovascular signals (ECG, blood pressure, respiration, etc.)
- Intracardiac ECG analysis (implantable cardiovascular devices, and pacemakers)
- ECGs and sleep apnoea
- Real-time processing and instrumentation
- ECG telemedicine and e-medicine
- Fetal ECG detection and analysis
- Computational tools and databases for ECG education and research

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	May 1, 2006
Acceptance Notification	September 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	1st Quarter, 2007

GUEST EDITORS:

William Sandham, Scotsig, Glasgow G12 9pf, UK; w.sandham@scotsig.co.uk

David Hamilton, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow G1 1XW, UK; d.hamilton@eee.strath.ac.uk

Pablo Laguna Lasaosa, Departmento de Ingeniería Electrónica y Communicaciones, Universidad de Zaragoza, 50015 Zaragoza, Spain; laguna@unizar.es

Maurice Cohen, University of California, San Francisco, USA; mcohen@fresno.ucsf.edu

Hindawi Publishing Corporation
http://www.hindawi.com

EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

Special Issue on

Emerging Signal Processing Techniques for Power Quality Applications

Call for Papers

Recently, end users and utility companies are increasingly concerned with perturbations originated from electrical power quality variations. Investigations are being carried out to completely characterize not only the old traditional type of problems, but also new ones that have arisen as a result of massive use of nonlinear loads and electronics-based equipment in residences, commercial centers, and industrial plants. These nonlinear load effects are aggravated by massive power system interconnections, increasing number of different power sources, and climatic changes.

In order to improve the capability of equipments applied to monitoring the power quality of transmission and distribution power lines, power systems have been facing new analysis and synthesis paradigms, mostly supported by signal processing techniques. The analysis and synthesis of emerging power quality and power system problems led to new research frontiers for the signal processing community, focused on the development and combination of computational intelligence, source coding, pattern recognition, multirate systems, statistical estimation, adaptive signal processing, and other digital processing techniques, implemented in either DSP-based, PC-based, or FPGA-based solutions.

The goal of this proposal is to introduce powerful and efficient real-time or almost-real-time signal processing tools for dealing with the emerging power quality problems. These techniques take into account power-line signals and complementary information, such as climatic changes.

This special issue will focus on recent developments in this key research area. Topics of interest include (but are not limited to):

- Detection of transients
- Classification of multiple events
- Identification of isolated and multiple disturbance sources
- Compression of voltage and current data signals
- Location of disturbance sources
- Prediction of transmission and distribution systems failures
- Demand forecasting
- Parameters estimation for fundamental, harmonics, and interharmonics

Digital signal processing techniques applied to power quality applications are a very attractive and stimulating area of research. Its results will provide, in the near future, new standards for the decentralized and real-time monitoring of transmission and distribution systems, allowing to closely follow and predict power system performance. As a result, the power systems will be more easily planned, expanded, controlled, managed, and supervised.

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscripts through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	May 1, 2006
Acceptance Notification	September 1, 2006
Final Manuscript Due	December 1, 2006
Publication Date	2nd Quarter, 2007

GUEST EDITORS:

Moisés Vidal Ribeiro, Department of Electrical Circuit, Federal University of Juiz de Fora, CEP 36036-330, Juiz de Fora, Brazil; mribeiro@ieee.org

Jacques Szczupack, Department of Electrical Engineering, Pontifical Catholic University of Rio de Janeiro, CEP 22453-900, Rio de Janeiro, Brazil; jacques@ele.puc-rio.br

M. Reza Iravani, The Edward S. Rogers SR., Department of Electrical and Computer Engineering, University of Toronto, Toronto, ON, Canada M5S 3G4; aki.iravani@ecf.utoronto.ca

Irene Yu-Hua Gu, Department of Signals and Systems, Chalmers University of Technology, SE-412 96, Gothenburg, Sweden; irenegu@s2.chalmers.se

Pradipta Kishore Dash, C. V. Raman, College of Engineering Bhubaneswar, Khurda-752054, Orissa, India; pkdash_india@yahoo.com

Alexander Mamishev, Department of Electrical Engineering, University of Washington, WA 98195-2500, Seattle, USA; mamishev@ee.washington.edu

EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

Special Issue on Super-resolution Enhancement of Digital Video

Call for Papers

When designing a system for image acquisition, there is generally a desire for high spatial resolution and a wide field-of-view. To achieve this, a camera system must typically employ small f-number optics. This produces an image with very high spatial-frequency bandwidth at the focal plane. To avoid aliasing caused by undersampling, the corresponding focal plane array (FPA) must be sufficiently dense. However, cost and fabrication complexities may make this impractical. More fundamentally, smaller detectors capture fewer photons, which can lead to potentially severe noise levels in the acquired imagery. Considering these factors, one may choose to accept a certain level of undersampling or to sacrifice some optical resolution and/or field-of-view.

In image super-resolution (SR), postprocessing is used to obtain images with resolutions that go beyond the conventional limits of the uncompensated imaging system. In some systems, the primary limiting factor is the optical resolution of the image in the focal plane as defined by the cut-off frequency of the optics. We use the term "optical SR" to refer to SR methods that aim to create an image with valid spatial-frequency content that goes beyond the cut-off frequency of the optics. Such techniques typically must rely on extensive a priori information. In other image acquisition systems, the limiting factor may be the density of the FPA, subsequent postprocessing requirements, or transmission bitrate constraints that require data compression. We refer to the process of overcoming the limitations of the FPA in order to obtain the full resolution afforded by the selected optics as "detector SR." Note that some methods may seek to perform both optical and detector SR.

Detector SR algorithms generally process a set of low-resolution aliased frames from a video sequence to produce a high-resolution frame. When subpixel relative motion is present between the objects in the scene and the detector array, a unique set of scene samples are acquired for each frame. This provides the mechanism for effectively increasing the spatial sampling rate of the imaging system without reducing the physical size of the detectors.

With increasing interest in surveillance and the proliferation of digital imaging and video, SR has become a rapidly growing field. Recent advances in SR include innovative algorithms, generalized methods, real-time implementations, and novel applications. The purpose of this special issue is to present leading research and development in the area of super-resolution for digital video. Topics of interest for this special issue include but are not limited to:

- Detector and optical SR algorithms for video
- Real-time or near-real-time SR implementations
- Innovative color SR processing
- Novel SR applications such as improved object detection, recognition, and tracking
- Super-resolution from compressed video
- Subpixel image registration and optical flow

Authors should follow the EURASIP JASP manuscript format described at http://www.hindawi.com/journals/asp/. Prospective authors should submit an electronic copy of their complete manuscript through the EURASIP JASP manuscript tracking system at http://www.mstracking.com/asp/, according to the following timetable:

Manuscript Due	September 1, 2006
Acceptance Notification	February 1, 2006
Final Manuscript Due	April 15, 2007
Publication Date	3rd Quarter, 2007

GUEST EDITORS:

Russell C. Hardie, Department of Electrical and Computer Engineering, University of Dayton, 300 College Park, Dayton, OH 45469-0026, USA; rhardie@udayton.edu

Richard R. Schultz, Department of Electrical Engineering, University of North Dakota, Upson II Room 160, P.O. Box 7165, Grand Forks, ND 58202-7165, USA; RichardSchultz@mail.und.nodak.edu

Kenneth E. Barner, Department of Electrical and Computer Engineering, University of Delaware, 140 Evans Hall, Newark, DE 19716-3130, USA; barner@ee.udel.edu

NEWS RELEASE

Nominations Invited for the Institute of Acoustics 2006 A B Wood Medal

The Institute of Acoustics, the UK's leading professional body for those working in acoustics, noise and vibration, is inviting nominations for its prestigious A B Wood Medal for the year 2006.

The A B Wood Medal and prize is presented to an individual, usually under the age of 35, for distinguished contributions to the application of underwater acoustics. The award is made annually, in even numbered years to a person from Europe and in odd numbered years to someone from the USA/Canada. The 2005 Medal was awarded to Dr A Thode from the USA for his innovative, interdisciplinary research in ocean and marine mammal acoustics.

Nominations should consist of the candidate's CV, clearly identifying peer reviewed publications, and a letter of endorsement from the nominator identifying the contribution the candidate has made to underwater acoustics. In addition, there should be a further reference from a person involved in underwater acoustics and not closely associated with the candidate. Nominees should be citizens of a European Union country for the 2006 Medal. Nominations should be marked confidential and addressed to the President of the Institute of Acoustics at 77A St Peter's Street, St. Albans, Herts, AL1 3BN. The deadline for receipt of nominations is **15 October 2005**.

Dr Tony Jones, President of the Institute of Acoustics, comments, "A B Wood was a modest man who took delight in helping his younger colleagues. It is therefore appropriate that this prestigious award should be designed to recognise the contributions of young acousticians."

Further information and an nomination form can be found on the Institute's website at www.ioa.org.uk.

A B Wood

Albert Beaumont Wood was born in Yorkshire in 1890 and graduated from Manchester University in 1912. He became one of the first two research scientists at the Admiralty to work on antisubmarine defence. He designed the first directional hydrophone and was well known for the many contributions he made to the science of underwater acoustics and for the help he gave to younger colleagues. The medal was instituted after his death by his many friends on both sides of the Atlantic and was administered by the Institute of Physics until the formation of the Institute of Acoustics in 1974.

PRESS CONTACT

Judy Edrich
Publicity & Information Manager, Institute of Acoustics
Tel: 01727 848195; E-mail: judy.edrich@ioa.org.uk

EDITORS NOTES

The Institute of Acoustics is the UK's professional body for those working in acoustics, noise and vibration. It was formed in 1974 from the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society (a daughter society of the Institution of Mechanical Engineers). The Institute of Acoustics is a nominated body of the Engineering Council, offering registration at Chartered and Incorporated Engineer levels.

The Institute has some 2500 members from a rich diversity of backgrounds, with engineers, scientists, educators, lawyers, occupational hygienists, architects and environmental health officers among their number. This multidisciplinary culture provides a productive environment for cross-fertilisation of ideas and initiatives. The range of interests of members within the world of acoustics is equally wide, embracing such aspects as aerodynamics, architectural acoustics, building acoustics, electroacoustics, engineering dynamics, noise and vibration, hearing, speech, underwater acoustics, together with a variety of environmental aspects. The lively nature of the Institute is demonstrated by the breadth of its learned society programmes.

For more information please visit our site at www.ioa.org.uk.