Spatially Adaptive Intensity Bounds for Image Restoration

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Spatially adaptive intensity bounds on the image estimate are shown to be an effective means of regularising the ill-posed image restoration problem. For blind restoration, the local intensity constraints also help to further define the solution, thereby reducing the number of multiple solutions and local minima. The bounds are defined in terms of the local statistics of the image estimate and a control parameter which determines the scale of the bounds. Guidelines for choosing this parameter are developed in the context of classical (nonblind) image restoration. The intensity bounds are applied by means of the gradient projection method, and conditions for convergence are derived when the bounds are refined using the current image estimate. Based on this method, a new alternating constrained minimisation approach is proposed for blind image restoration. On the basis of the experimental results provided, it is found that local intensity bounds offer a simple, flexible method of constraining both the nonblind and blind restoration problems.

Keywords and phrases: image resolution, blur identification, blind image restoration, set-theoretic estimation.

1. INTRODUCTION

In many imaging systems, blurring occurs due to factors such as relative motion between the object and camera, defocusing of the lens, and atmospheric turbulence. An image may also contain random noise which originated in the formation process, the transmission medium, and/or the recording process.

The above degradations are adequately modelled by a linear space-invariant blur and additive white Gaussian noise, yielding the following model:

\[ g = h \ast f + v, \tag{1} \]

where the vectors \( g, f, h, \) and \( v \) correspond to the lexicographically ordered degraded and original images, blur, and additive noise, respectively, which are defined over an array of pixels \( (m, n) \). The two-dimensional convolution can be expressed as \( h \ast f = Hf = Fh \), where \( H \) and \( F \) are block-Toeplitz matrices and can be approximated by block-circulant matrices for large images [1, Chapter 1].

The goal of image restoration is to recover the original image \( f \) from the degraded image \( g \). In classical image restoration, the blur is known explicitly prior to restoration. However, in many imaging applications, it is either costly or physically impossible to completely characterise the blur based on a priori knowledge of the system [2]. The recovery of an image when the blur is partially or completely unknown is referred to as blind image restoration. In practice, some information about the blur is needed to restore the image.

There are a number of factors which contribute to the difficulty of image restoration. The problem is ill posed in the sense that if the image formation process is modelled in a continuous, infinite-dimensional space, then a small perturbation in the output, that is, noise, can result in an unbounded perturbation of the least squares solution of (1) for the image or the blur [1]. Although the discretised inverse problem is well posed [3], the ill-posedness of the continuous
The blind image restoration problem is also ill defined, since the available information may not yield a unique solution to the corresponding optimisation problem. Even if a unique solution exists, the cost function is, with the exception of the NAS-RIF algorithm [4], nonconvex, and convergence to local minima often occurs without proper initialisation. Undesirable solutions can be eliminated by incorporating more effective constraints.

In this paper, spatially adaptive intensity bounds are therefore proposed as a means of (1) regularising the ill-posed restoration problem; and (2) limiting the solution space in blind restoration so as to avoid convergence to undesirable solutions. The bounds are implemented in the framework of the gradient projection method proposed in [5, 6].

Prior research on spatially adaptive intensity bounds has been conducted solely in the context of classical image restoration. Local intensity bounds were first introduced in [7] for artifact suppression. These bounds were applied to the Wiener filtered image, that is, they were applied to a solution rather than to the optimisation problem itself. In [8], it was shown that the constraints could be incorporated in the Kaczmarz row action projection (RAP) algorithm [9]. However, optimality in a least squares sense is guaranteed only if the constraints are linear [8]. Alternatively, a quadratic cost function subject to a convex constraint is minimised by projecting each iteration of the steepest descent algorithm onto the constraint provided that the step size lies within a specified range [5]. In [10], space-variant intensity bounds were applied using this gradient projection method. The intensity bounds were updated using information from the current image estimate, but the effect of bound update on the convergence of the gradient projection method was not analysed. Similar methods have been proposed for the update of the regularisation parameter and/or the weight matrix in constrained least squares restoration [11, 12]. In these cases, convergence was proven via the linearisation of the problem.

The work presented in this paper builds on previous research in several respects [13, 14, 15]. In Section 2, a new method of estimating spatially adaptive intensity bounds is proposed. This method is distinguished both in terms of which parameters define the bounds and, as discussed in Section 4, how the bounds are updated from the current image estimate. In Section 3, the effect of the scaling parameter, which plays a similar role to the regularisation parameter in classical image restoration, is examined. In Section 4, convergence of the modified gradient projection method is discussed. The problem definition changes slightly each time the bounds are updated, and it is therefore important to understand how this may affect the convergence of the algorithm. Lastly, in Section 5, these intensity bounds are applied to blind image restoration. A new alternating minimisation algorithm is established for this purpose. Section 6 contains a discussion of the results, conclusions, and directions for further research.

2. DEVELOPMENT AND IMPLEMENTATION OF LOCAL INTENSITY BOUNDS

2.1. Characterisation of the image

It is assumed that the estimated image \( \hat{f} \) belongs to the space \( L^2(\Omega) \) of square-summable, real-valued, two-dimensional sequences defined over a finite subset \( \Omega \subset P^2 \), where \( P^2 \equiv P \times P \) denotes the Cartesian product of nonnegative integers [7]. The associated Hilbert space is

\[
\mathcal{H} \equiv \{ \hat{f} : \hat{f} \in L^2(\Omega) \},
\]

with inner product and norm

\[
\langle \hat{f}_1, \hat{f}_2 \rangle \equiv \sum_{(m,n) \in \Omega} \hat{f}_1(m,n) \hat{f}_2(m,n),
\]

\[
||\hat{f}_1|| = (\langle \hat{f}_1, \hat{f}_1 \rangle)^{1/2},
\]

for \( \hat{f}_1, \hat{f}_2 \in \mathcal{H} \).

Typical constraints on the image estimate include nonnegativity and, in blind image restoration, finite support. In this section, spatially adaptive intensity bounds are combined with these constraints to define the solution space for the restored image more precisely, leading to better estimates of both the original image and the blur. Because these constraints define convex sets, they can be incorporated via projection methods. Additionally, a regularisation term [16] is included in the cost function and can be adjusted to give the image a desired degree of smoothness.

In any image restoration scheme, there is a trade-off between noise suppression and preservation of high-frequency detail, since noise reduction is achieved by constraining the image to be smooth. However, because the human visual system is more sensitive to noise in uniform regions of the image than in areas of high spatial activity [17], space-variant image constraints may be used to emphasise noise reduction in the flat regions, and preservation of detail in edge and texture regions [5, 7, 18, 19]. This is achieved by making the radius of the bounds proportional to the spatial activity, measured by an estimate \( \hat{\sigma}_f^2(m,n) \) of the variance of the original image. The local variance is more robust to noise than gradient-based edge detectors [19].

The local mean estimate \( \hat{M}_f(m,n) \) is used as the centre of the bounds. Consequently, the intensity bounds average out zero-mean noise in regions of low variance.

The local statistics are estimated from the degraded image over a square window centred at pixel \((m,n)\):

\[
\hat{M}_f(m,n) = M_g(m,n) = \frac{1}{\Lambda} \sum_{r=m-N_m+N \atop s=n-N_n+N} g(r,s),
\]

\[
\hat{\sigma}_f^2(m,n) = \frac{1}{\Lambda} \sum_{r=m-N_m+N \atop s=n-N_n+N} [g(r,s) - \hat{M}_f(m,n)]^2,
\]

\[
\hat{\sigma}_f^2(m,n) = \max \left[ 0, \hat{\sigma}_f^2(m,n) - \hat{\sigma}_y^2 \right],
\]

where \( \Lambda = (2N + 1)(2N + 1) \) and \( \hat{\sigma}_y^2 \) is the estimated noise
variance. The window size over which the local statistics are calculated may be fixed or adaptive [20, 21], but the improvement offered by an adaptive window was found to be marginal, and a fixed window of size \(3 \times 3\) or \(5 \times 5\) produced good results.

The proposed intensity bounds are then defined by

\[
|\hat{f}(m, n) - \hat{M}_f(m, n)| \leq \beta \hat{\sigma}^2_f(m, n),
\]

where \(\beta\) is the scaling parameter. Combining the bounds with the support and nonnegativity constraints yields

\[
\mathcal{C}_f \triangleq \left\{ \hat{f} \in \mathcal{H} : l(m, n) \leq \hat{f}(m, n) \leq u(m, n), \quad (m, n) \in \mathcal{F}_f, \quad \hat{f}(m, n) = 0, \quad (m, n) \notin \mathcal{F}_f \right\},
\]

where \(\mathcal{F}_f \subseteq \Omega\) is the support of the image, and

\[
l(m, n) = \max \{ 0, \hat{M}_f(m, n) - \beta \hat{\sigma}^2_f(m, n) \},
\]

\[
u u(m, n) = \hat{M}_f(m, n) + \beta \hat{\sigma}^2_f(m, n).
\]

The convexity of \(\mathcal{C}_f\) is easily proven by observing that for any \(\hat{f}_1, \hat{f}_2 \in \mathcal{C}_f\) and \(0 \leq y \leq 1\),

\[
y \hat{f}_1(m, n) + (1-y) \hat{f}_2(m, n) \geq y l(m, n) + (1-y) l(m, n) = l(m, n),
\]

\[
y \hat{f}_1(m, n) + (1-y) \hat{f}_2(m, n) \leq y u(m, n) + (1-y) u(m, n) = u(m, n).
\]

The closure of \(\mathcal{C}_f\) follows from the openness of the complement \(\overline{\mathcal{C}_f}\).

The corresponding projection operator is

\[
P_f \hat{f}(m, n) \begin{cases} l(m, n), & \hat{f}(m, n) < l(m, n), \quad (m, n) \in \mathcal{F}_f, \\ \hat{f}(m, n), & l(m, n) \leq \hat{f}(m, n) \leq u(m, n), \quad (m, n) \in \mathcal{F}_f, \\ u(m, n), & \hat{f}(m, n) > u(m, n), \quad (m, n) \in \mathcal{F}_f, \\ 0, & (m, n) \notin \mathcal{F}_f. \end{cases}
\]

2.2. Constrained minimisation via the gradient projection method

The restored image is given as the solution of the following constrained optimisation problem:

\[
\text{Minimise } ||g - H\hat{f}||^2 + \alpha ||\hat{C}\hat{f}||^2, \quad \hat{f} \in \mathcal{C}_f,
\]

where \(\alpha\) and \(C\) are the regularisation parameter and high-pass regularisation operator, respectively. In the absence of local intensity constraints, a rough estimate of \(\alpha\) is given by \(1/\text{BSNR}\), where BSNR is the signal-to-noise ratio of the blurred image [22]. The regularisation term of (12) is sometimes modified for spatially adaptive noise smoothing by using a weighted norm [5]

\[
||C\hat{f}||^2_w \triangleq \sum_{(m, n) \in \Omega} w(m, n) |c(m, n) \ast \hat{f}(m, n)|^2,
\]

where the weights \(w(m, n)\) are calculated according to [18, 21, 23, 24]:

\[
w(m, n) = \frac{1}{1 + \nu \hat{\sigma}^2_f(m, n)},
\]

and \(\nu = 1000/\sigma_{\max}^2\) is a tuning parameter designed so that \(w(m, n) \to 1\) in the uniform regions and \(w(m, n) \to 0\) near the edges.

The unique solution of (12) is obtained by means of the following iteration [5, 24]:

\[
\hat{f}_{k+1} = P_f \left( (I - \alpha \mu CT^T C) \hat{f}_k + \mu H^T (g - H\hat{f}_k) \right) = P_f G(\hat{f}_k),
\]

where the step size \(\mu\) satisfies

\[
0 < \mu < \frac{2}{\lambda_{\max}}
\]

and \(\lambda_{\max}\) is the maximum eigenvalue of \((H^T H + \alpha C^T C)\). Equation (15) represents the projection of the steepest descent iterate onto the constraint \(\mathcal{C}_f\), and hence is named the gradient projection method.

The iterations are terminated when the following condition is satisfied [1, Chapter 6]:

\[
\frac{||\hat{f}_{k+1} - \hat{f}_k||^2}{||\hat{f}_k||^2} \leq \delta,
\]

where \(\delta\) is typically \(\mathcal{O}(10^{-6})\).

3. Choice of the scaling parameter

The scaling parameter \(\beta\) in (9) plays a similar role to the regularisation parameter \(\alpha\) in the classical constrained least squares approach [16]. If \(\beta\) is too large, then the intensity bounds fail to prevent noise amplification. However, if \(\beta\) is very small, then much detail is lost.

In this section, an optimal value of the bound scaling parameter is chosen by maximising the improvement in signal-to-noise ratio (ISNR) of the restored image in terms of \(\beta\), when \(\alpha\) is constant. The ISNR is defined as

\[
\text{ISNR} = 10 \log \left( \frac{\sum_{(m, n) \in \mathcal{F}_f} (f(m, n) - g(m, n))^2}{\sum_{(m, n) \in \mathcal{F}_f} (f(m, n) - \hat{f}(m, n))^2} \right).
\]

The effects of the noise level, blur type, and image characteristics are used to develop guidelines for choosing \(\beta\) when the original image \(f\) is unavailable for comparison with the restored image \(\hat{f}\).
To illustrate the effect of $\beta$ on the ISNR, the 256 × 256 Cameraman image in Figure 1a was degraded by a $1 \times 9$ point spread function (PSF) with truncated Gaussian weights and 20 dB additive white Gaussian noise, as shown in Figure 1b. The local statistics were estimated over a $3 \times 3$ window from the degraded image. The image was then restored for different $\alpha$ and $\beta$ values. Figure 2a plots the ISNR as a function of $\beta$ for various values of the regularisation parameter $\alpha$ in (12).

It can be seen from Figure 2a that the ISNR varies smoothly as a function of $\beta$, with a well-defined maximum for small $\alpha$. The plot for $\alpha = 0$ shows the ISNR when only the intensity bounds are used to regularise the problem. As $\alpha$ is increased, the optimal value of $\beta$ also increases, most noticeably for large $\alpha (\alpha \gg 1/\text{BSNR} = 0.01)$. This is because the problem is already over-regulised. However, for $\alpha \leq 1/\text{BSNR}$, both the optimal scaling parameter and its corresponding ISNR do not vary significantly with $\alpha$. In all instances, the flattening out of the ISNR for $\beta > 10^4$ indicates that only the bounds for which $\hat{\sigma}^2(m,n) = 0$, as defined by (5), are active.

When the local statistics of the original image are known, the Miller regularisation term does not improve the peak ISNR, as indicated in Figure 2b by comparison of the graphs for $\alpha = 0$ and $\alpha > 0$. In fact, the peak ISNR deteriorates as $\alpha$ becomes very large. Furthermore, the location of the peak does not vary significantly with $\alpha$. Similar results are obtained for weighted regularisation, as shown in Figure 2c.

These results indicate that if good estimates of the local statistics are available, then, with the proper choice of $\beta$, the intensity bounds are more effective than classical least squares methods in constraining the solution. Even when the statistics are estimated from the degraded image, the location and value of the peak ISNR do not change significantly for $\alpha \leq 1/\text{BSNR}$. Therefore, the case $\alpha = 0$ can serve as a guideline for the choice of the scaling parameter.

The question is how to determine the optimal value of $\beta$ without reference to the original image. A possible criterion is the noise level. Figure 3 plots the ISNR as a function of the residual error at the solution, $\|g - \hat{H}(\beta)\|^2$, corresponding to $\alpha = 0$ in Figures 2a and 2b. The squared norm of the noise, $\epsilon^2 \approx N_{\text{pixels}}\hat{\sigma}^2$, where $N_{\text{pixels}}$ is the total number of image pixels, is indicated by the vertical line through the graph. It can be seen that the peak closely corresponds to the point where the residual error is equal to the squared noise norm.

The general validity of this criterion is indicated by an examination of Table 1, which compares the residual error...
Spatially Adaptive Intensity Bounds for Image Restoration

\[ \beta = 0, 0.01, 0.1, 1 \]

\[ ISNR (dB) \]

\[ -2 \quad 0 \quad 2 \quad 4 \]

(a) ISNR as a function of \( \beta \): local statistics estimated from (a) the degraded image with uniform regularisation, (b) the original image with uniform regularisation, and (c) the original image with weighted regularisation.

(b) ISNR as a function of \( \beta \) and the noise norm for various noise levels, blur types, and images (Lena or the Cameraman). The two blur types tested were the horizontal Gaussian PSF described previously and a \( 5 \times 5 \) pill-box blur, that is, a rectangular PSF with equal weights. The results are listed for bounds derived from both the exact image statistics and the degraded-image statistics. It can be observed that in all cases, the value of the residual error approaches the squared noise norm when \( \beta \) maximises the ISNR.

The main drawback of using this criterion to choose \( \beta \) is that the image must be restored in order to compare the residual error with the noise norm. The process of adapting \( \beta \) may require several restorations before the appropriate value is found. In order to reduce the number of computations, Table 1 can provide an initial estimate of \( \beta \). For each refinement, the final image estimate from the previous stage can be used to initialise the next restoration.

It should be mentioned that in the 30 dB case, the reason that the optimal value of \( \beta \) estimated from the degraded image statistics is much larger than that from the exact image statistics is that for low noise levels, the penalty for underestimating the edge variances due to blurring in the degraded image takes precedence over noise amplification. Therefore, when the degraded statistics are used, the optimal value of \( \beta \) is very large so that the bounds are active only in the uniform regions and consequently the edges are retained. However, when the exact image statistics are used, the edges are not affected by underestimation of the edge variance, and so it is possible to suppress more noise by decreasing \( \beta \).

4. INTENSITY-BOUND UPDATE

When the intensity bounds are calculated from the statistics of the degraded image, the edge variances are underestimated because of blurring. Therefore, the restored image

\[ \| g - H \hat{f}(\beta) \|_2 \] for Figure 1b.

Figure 3: ISNR as a function of \( \| g - H \hat{f}(\beta) \|_2 \) for Figure 1b.
tends to be overly smooth in these areas. This is seen, for example, around the pillars of the domed building in Figure 1d. A more sophisticated approach is to use the additional information obtained during the iterative restoration process to reestimate the intensity bounds. In this section, we evaluate several methods of bound update.

4.1. Method 1

The most obvious way to update the intensity bounds is to calculate the local statistics of the image estimate at each iteration and then to use these statistics to generate new bounds \([10, 13, 15]\).

In this case, the local intensity bounds at iteration \(k\) become

\[
\begin{align*}
\ell_k(m, n) &= \max \left[ 0, \hat{M}_{f,k}(m, n) - \beta \hat{\sigma}_{f,k}^2(m, n) \right], \\
\upsilon_k(m, n) &= \hat{M}_{f,k}(m, n) + \beta \hat{\sigma}_{f,k}^2(m, n),
\end{align*}
\]

(19)

where

\[
\hat{M}_{f,k}(m, n) = \frac{1}{(2N + 1)^2} \sum_{r=-N}^{N} \sum_{s=-N}^{N} \hat{f}_k(r, s),
\]

\[
\hat{\sigma}_{f,k}^2(m, n) = \max \left\{ 0, \frac{1}{(2N + 1)^2} \times \sum_{r=-N}^{N} \sum_{s=-N}^{N} \left[ \hat{f}_k(r, s) - \hat{M}_{f,k}(m, n) \right]^2 - \sigma_k^2 \right\},
\]

(20)

and \(\hat{f}_k\) is the current image estimate. If \(\hat{\sigma}_{f,0}^2(m, n) = 0\), then the bounds at \((m, n)\) are not updated, since the local statistics are not expected to change significantly in the uniform regions.

Updating the bounds in this manner has an iterative effect in that the activation of the constraints on neighbouring pixels leads to a decrease in the local activity, and hence the reestimated bound radius \(\beta \hat{\sigma}_{f,k}^2(m, n)\) is also smaller. The continual decrease of the bound radii in the low-variance regions results in loss of detail.

4.2. Method 2

Since the loss of detail occurs where the bounds have been activated over a neighbourhood of pixels, a simple modification of the proposed method is to reestimate only the inactive bounds. While this limits iterative smoothing, the edge sharpness can only improve marginally since the initial underestimation of the edge variances produces relatively tight bounds which, once activated, cannot be further improved.

4.3. Method 3

A third method of bound update monitors the convergence of the local variance estimates in order to determine when the local intensity constraints are applied at a given pixel. In the uniform regions, the original and degraded images differ only by the additive noise, and the variance estimates in these regions converge very quickly. Consequently, the intensity bounds are applied at an early stage of the algorithm, limiting noise amplification in these relatively uniform regions where it is most noticeable. At the edges, the inversion of the blurring process leads to a significant change in the edge variances during the first iterations. Thus, the intensity bounds near the edges are applied at a late stage of the algorithm, thereby increasing the edge sharpness. The additional noise is masked by the edges.

The procedure can be described as follows.

(1) The intensity bounds are initialised to

\[
[l_0(m, n), u_0(m, n)] = \begin{cases} 
[0, 0], & (m, n) \notin F_f, \\
[\hat{M}_{f,0}(m, n), \hat{M}_{f,0}(m, n)], & \hat{\sigma}_{f,0}^2(m, n) = 0, \ (m, n) \in F_f, \\
[0, \infty), & \text{otherwise.}
\end{cases}
\]

(21)
Define $\mathcal{F}_{f,0} \triangleq \{(m,n) : \hat{\sigma}^2_{f,0}(m,n) = 0 \text{ or } (m,n) \not\in \mathcal{F}_f \}$. 

(2) At each iteration, the local variance $\sigma^2_{f,k}(m,n)$ of the current image estimate is calculated. Let $\mathcal{F}_{f,k}$ denote the set of pixels for which the local variance converges at iteration $k$, that is,

$$\mathcal{F}_{f,k} \triangleq \{(m,n) : \frac{|\hat{\sigma}^2_{f,k}(m,n) - \hat{\sigma}^2_{f,k-1}(m,n)|}{\hat{\sigma}^2_{f,k-1}(m,n)} \leq \tau, (m,n) \not\in \mathcal{F}_{f,r}, r < k \}. \quad (22)$$

Define the intensity bounds for $(m,n) \in \mathcal{F}_{f,k}$ as

$$l_k(m,n) = \max \left[0, \hat{M}_{f,k}(m,n) - \beta \hat{\sigma}^2_{f,k}(m,n) \right],$$
$$u_k(m,n) = \hat{M}_{f,k}(m,n) + \beta \hat{\sigma}^2_{f,k}(m,n). \quad (23)$$

(3) Find the next iterate according to

$$\hat{f}_{k+1} = P_{f,k}P_{f,k-1} \cdots P_{f,0}G(\hat{f}_k), \quad (24)$$

where

$$P_{f,0} \hat{f}(m,n) = \begin{cases} \hat{M}_{f,0}(m,n), & \hat{\sigma}^2_{f,0}(m,n) = 0, (m,n) \in \mathcal{F}_f, \\ \hat{f}(m,n), & \hat{f}(m,n) \geq 0, (m,n) \in \mathcal{F}_f, \\ 0, & \text{otherwise}; \end{cases} \quad (25)$$

$$P_{f,k} \hat{f}(m,n) = \begin{cases} l_k(m,n), & \hat{f}(m,n) < l_k(m,n), (m,n) \in \mathcal{F}_{f,k}, \\ u_k(m,n), & \hat{f}(m,n) > u_k(m,n), (m,n) \in \mathcal{F}_{f,k}, \\ \hat{f}(m,n), & \text{otherwise.} \end{cases}$$

4.4. Comparison of the methods

The Lena image in Figure 4a was blurred by a $5 \times 5$ pill-box blur with 20 dB BSNR, as shown in Figure 4b. The degraded image was restored using the various bound update methods and the results are shown in Figure 5, which plots the ISNR as a function of $\beta$ for each method. The Lena image
was chosen because the large amount of blurring, particularly in the texture region of the feathers, emphasised underestimation of the variance. A $5 \times 5$ window was used to calculate the local statistics. In Method 1, iterative smoothing was most noticeable at low $\beta$, as illustrated in Figure 5 by the sharp decrease in the ISNR as $\beta$ becomes very small. Figure 4c shows the loss of detail resulting from this iterative process, combined with severe noise amplification in some regions. In terms of the ISNR, there was no improvement over the fixed bounds. Method 2 produced similar results to the fixed-bound method, as the edge bounds which had already been activated could not be improved. Method 3 gave a significant improvement in terms of the maximum ISNR. The decrease in the optimal $\beta$ indicates that the statistics used in the intensity bounds were closer to those of the original image, as seen by a comparison of the peak location in Figures 2a and 2b. The best restoration is shown in Figure 4d.

4.5. Convergence of the update methods

When the intensity bounds are updated from the current image estimate, the iteration of (15) is no longer guaranteed to converge since the projection operator changes with the iteration $k$. In practice, because the image estimate is initialised to the degraded image, which is a reasonable approximation to the solution, the image estimate changes very little between iterations, and the corresponding adjustment of the bounds is also small.

In the simulations, the iterations converged according to the criterion of (17), for $\delta = 10^{-6}$, albeit at a slower rate than with fixed bounds. The change in convergence rate was the greatest for Method 3 since many areas of the image were initially allowed to converge towards the unconstrained solution and only later were the bounds added. The difference was, of course, dependent on the relative importance of the regularisation parameter $\alpha$ and the scaling parameter $\beta$.

Some insight into how bound update affects convergence can be obtained by adopting the linearisation approach in [11, 12]. To begin, the projection operator at iteration $k$ is divided into three separate operators:

$$\hat{f}_{k+1} = P_{f,\text{pos}}P_{f,\text{fix}}P_{f,\text{update}}[G(\hat{f}_k)],$$

(26)

where $P_{f,\text{pos}}$ is the positivity operator, $P_{f,\text{fix}}$ denotes the projection onto the bounds which are not updated from $\hat{f}_k$, $P_{f,\text{update}}$ denotes the projection onto the updated bounds, and $G(\cdot)$ is the steepest descent operator. The indices of the constraints fixed at iteration $k$ form the set $\mathcal{F}_{\text{fix}}$, and the indices of the updated constraints form $\mathcal{F}_{\text{update}}$, where $\mathcal{F}_{\text{fix}} \cap \mathcal{F}_{\text{update}} = \emptyset$.

Let the combined mapping $P_{f,\text{update}}G$ be denoted by $T$. Then

$$\|\hat{f}_{k+1} - \hat{f}_k\| = \|P_{f,\text{pos}}P_{f,\text{fix}}T(\hat{f}_k) - P_{f,\text{pos}}P_{f,\text{fix}}T(\hat{f}_{k-1})\|$$

$$\leq \|P_{f,\text{fix}}T(\hat{f}_k) - P_{f,\text{fix}}T(\hat{f}_{k-1})\|$$

$$\leq \|T(\hat{f}_k) - T(\hat{f}_{k-1})\|$$

(27)

because the projections $P_{f,\text{pos}}$ and $P_{f,\text{fix}}$ do not change between iterations $k$ and $k-1$, and any projection is, by definition, nonexpansive, that is, for $\hat{f}_1, \hat{f}_2 \in \mathcal{H}$, $\|P\hat{f}_1 - P\hat{f}_2\| \leq \|\hat{f}_1 - \hat{f}_2\|$.
The nonlinear operator $T$ is linearised by means of the Jacobian matrix $J_T$:

$$T(\hat{f}_k) - T(\hat{f}_{k-1}) \approx J_T(\hat{f}_k)(\hat{f}_k - \hat{f}_{k-1}).$$  

The $(m,n)$th element of the Jacobian $J_T$ is given by

$$[J_T]_{mn} = \frac{\partial T_m(\hat{f})}{\partial \hat{f}_n},$$

where $T_m$ is the $m$th element of the vector $T(\hat{f})$ and $\hat{f}_n$ is the $n$th element of the vector $\hat{f}$.

The matrix $J_T$ is derived by dividing the pixels into three sets which represent the possible outcomes at each iteration.

1. The first set is
   
   $\mathcal{S}_{\text{grad}} = \mathcal{S}_{\text{fix}} \cup \{m \in \mathcal{S}_{\text{update}} : M_j(m) - \beta \sigma_j^2(m) \leq G_m(\hat{f}) \leq M_j(m) + \beta \sigma_j^2(m)\}.
   $\mathcal{S}_{\text{grad}}$

2. The second set is
   
   $\mathcal{S}_{\text{high}} = \{m \in \mathcal{S}_{\text{update}} : G_m(\hat{f}) > M_j(m) + \beta \sigma_j^2(m)\}$.

In this case, $m$ corresponds to a pixel at which the bounds are fixed between iterations $k - 1$ and $k$, or the iterate lies within the updated bounds. Therefore, $T_m$ represents the steepest descent step

$$T_m(\hat{f}) = G_m(\hat{f}) = \hat{f}(m) + \mu [g(m) * h(-m) - \mu [h(m) * h(-m) + c(m) * c(-m)] * \hat{f}(m)],$$

and hence,

$$[J_T]_{mn} = \delta(m-n) - \mu [h(m-n) * h(n-m) + c(m-n) * c(n-m)], \quad m \in \mathcal{S}_{\text{grad}}.$$

In this case, $\Delta_b = 0.15$. 204 image updates in 17 cycles; (c), (d) updated bounds ($\beta = 30, \alpha = 0.05$): 748 image iterations in 20 cycles.

Figure 7: Restoration of Figure 6a with (a), (b) uniform regularisation only ($\alpha = 0.09$): 204 image updates in 17 cycles; (c), (d) updated bounds ($\beta = 30, \alpha = 0.05$): 748 image iterations in 20 cycles.
The steepest descent iterate lies above the upper bound, which has been updated from the previous image estimate. The operator $T_m$ becomes

$$
T_m(\hat{f}) = M^{-1}(m) + \beta \sigma^2_f(m)
$$

$$
= \frac{1}{\Lambda} \sum_{r \in \mathcal{F}_{\text{win}}(m)} \hat{f}(r)
$$

$$
+ \beta \left\{ \frac{1}{\Lambda} \sum_{r \in \mathcal{F}_{\text{win}}(m)} \hat{f}^2(r) - \left[ \frac{1}{\Lambda} \sum_{r \in \mathcal{F}_{\text{win}}(m)} \hat{f}(r) \right]^2 \right\},
$$

(34)

where $\mathcal{F}_{\text{win}}(m)$ denotes the window of $\Lambda$ pixels over which the local statistics at the $m$th pixel are measured. Then, for $m \in \mathcal{F}_{\text{update}}$

$$
[J_T]_{mn} = \begin{cases}
\frac{1}{\Lambda} \{1 + 2\beta [\hat{f}(n) - M_f(m)] \}, & n \in \mathcal{F}_{\text{win}}(m), \\
0, & n \notin \mathcal{F}_{\text{win}}(m).
\end{cases}
$$

(35)

(3) The third set is

$$
\mathcal{F}_{\text{low}} = \{ m \in \mathcal{F}_{\text{update}} : G_m(\hat{f}) < M_f(m) - \beta \sigma^2_f(m) \}. \quad (36)
$$

The steepest descent iterate lies below the lower bound, and therefore, for $m \in \mathcal{F}_{\text{low}}$

$$
[J_T]_{mn} = \begin{cases}
\frac{1}{\Lambda} \{1 - 2\beta [\hat{f}(n) - M_f(m)] \}, & n \in \mathcal{F}_{\text{win}}(m), \\
0, & n \notin \mathcal{F}_{\text{win}}(m).
\end{cases}
$$

(37)
Since
\[ ||T(\hat{f}_k) - T(\hat{f}_{k-1})|| \approx ||J_T(\hat{f}_k)(\hat{f}_k - \hat{f}_{k-1})|| \leq ||J_T(\hat{f}_k)|| \cdot ||\hat{f}_k - \hat{f}_{k-1}||, \]
(38)
a sufficient (but not necessary) condition for convergence is
\[ ||J_T(\hat{f}_k)|| < 1, \ k = 1, 2, \ldots, \infty, \] where \( ||\cdot|| \) represents the \( L_2 \) norm [25]. While this condition cannot be satisfied for all possible \( \hat{f}_k \), some observations can be made about the typical behaviour of the bound update schemes when the degraded behaviour is used to initialise the iteration.

Assuming that most pixels belong to \( S_{\text{grad}} \), that is, the bounds have not been updated from \( \hat{f}_k \) or the iterate falls within the updated bounds, the matrix \( J_T \) will have the predominant form of the block-circulant matrix \( I - \mu(HTH + \alpha C^T C) \). The \( L_2 \) norm of this matrix is \( \max_m |1 - \mu \lambda_m| \), where \( \lambda_m \) denotes an eigenvalue of \( H^T H + \alpha C^T C \). The desired norm \( \theta < 1 \) can be obtained if there exists a \( \mu \) which satisfies
\[ \frac{1 - \theta}{\lambda_{\min}} < \mu < \frac{1 + \theta}{\lambda_{\max}}. \] (39)

The rows belonging to \( S_{\text{high}} \) or \( S_{\text{low}} \) have the structure of the pill-box blur convolution matrix, with additive zero-mean fluctuations. These fluctuations are small because the bounds are activated in the regions of relatively low variance. Therefore, the norm of a matrix formed from a combination of these rows will be approximately 1, closely corresponding to the all-one eigenvector.

The pixels in \( S_{\text{high}}, S_{\text{low}}, \) or \( S_{\text{grad}} \) are usually clustered together in regions whose dimensions greatly exceed those of the window used to calculate the local statistics. Thus, \( J_T \) can be partitioned into nearly block-circulant submatrices corresponding to neighbouring pixels in either sets. Because the nonzero elements of the submatrices correspond to a small window around the current pixel \( m \), they do not overlap significantly column-wise or row-wise, and the norm of \( J_T \) can be approximated by the largest norm of the submatrices. From the previous discussion, this is close to 1 if \( \mu \) satisfies (39). Simulations indicate that small violations of the convergence condition \( ||J_T|| < 1 \) are partially compensated by the operators \( P_{\text{pos}} \) and \( P_{\text{fix}} \).

5. BLIND IMAGE RESTORATION

In the previous sections, spatially adaptive intensity bounds were used in nonblind image restoration to limit noise amplification due to the ill-conditioning of the blur matrix. In this section, the intensity bounds are applied to blind image restoration in order to further define the solution and to reduce noise. An alternating minimisation approach, which switches between constrained optimisation of the image and the blur, is used. This approach has the advantage that the methods described in Section 4 can easily be extended to blind image restoration.

5.1. Characterisation of the blur

The constraints on the blur presented in this section are intended to describe a large class of degradations. It is assumed that the blur estimate \( \hat{h} \) belongs to the Hilbert space \( \mathcal{H} \) defined previously. Like the image, the estimated blur coefficients are constrained to be nonnegative, that is, \( \hat{h}(m, n) \geq 0 \), \( (m, n) \in \Omega \). It is further assumed that the blurring process preserves energy, and therefore, \( \sum_{(m,n)\in\Omega} \hat{h}(m,n) = 1 \) [26, page 69].

Typically, the blur is negligible outside a small region of support \( \mathcal{F}_h \) which is not known precisely. Therefore, a conservatively large support is used to initialise the blur estimate. At the end of each blur optimisation, the estimated support is pruned such that a rectangular support is maintained. In truncating the support, an estimate \( \hat{h}(m, n) \) on a row/column bordering the PSF is assumed to be negligible if it is an order of magnitude smaller than its nearest neighbour in the adjacent row/column [1, Chapter 6].

Within the estimated support, the PSF is assumed to be symmetric [27], that is,
\[ h(m, n) = h(-m, n), \] (40)
where \( h(-m, n) \triangleq h(L_m - m, L_n - n) \), and the image is of dimension \( L_m \times L_n \). In this case, the phase of the discrete Fourier transform of the blur is either 0 or \( \pm \pi \).

Experience indicates that it is necessary to impose smoothness constraints on the blur itself. Previously, this was done in the form of a second regularisation term via an extension of either the constrained least squares approach [23] or the total variation method [28]. The disadvantage of this method is that the knowledge of the blur support is implicitly needed to determine the blur regularisation parameter [28]. Therefore, an alternative monotonicity constraint is proposed, which states that the blur should be nonincreasing in the direction of the positive blur axes. This constraint describes many common blurs, such as the pill-box blur and the Gaussian blur, and is expressed mathematically as
\[ \hat{h}(m+1, n) \geq \hat{h}(m, n), \quad m \geq 0, \quad (m+1, n) \in \mathcal{F}_h, \]
\[ \hat{h}(m, n+1) \geq \hat{h}(m, n), \quad n \geq 0, \quad (m, n+1) \in \mathcal{F}_h. \] (41)
The monotonicity constraint is extended to the entire support by means of the symmetry constraint.

5.2. Alternating minimisation approach

The proposed alternating minimisation algorithm follows the general framework of projection-based blind deconvolution [6] but differs in the procedure used to optimise the blur. In contrast to the algorithms proposed in [23, 28], the constraints are incorporated directly in the optimisation rather than applied at the end of each minimisation with respect to either the image or the blur.

Since both \( \hat{f} \) and \( \hat{h} \) are unknown, the cost function becomes
\[ J(\hat{f}, \hat{h}) = ||g - \hat{f} * \hat{h}||^2 + \alpha ||C\hat{f}||^2. \] (42)
Equation (42) is convex with respect to either \( \hat{f} \) or \( \hat{h} \), but not jointly convex. Therefore, the cost function is minimised
most easily by fixing one estimate and optimising with respect to the other. The roles are then reversed and the process is repeated until the algorithm converges to a local minimum.

Since the spatially adaptive intensity bounds have a well-defined projection operator, the image optimisation step is implemented using the constrained steepest descent algorithm (gradient projection method) described in [5]. The advantage of this method is its simplicity and ease of implementation. The introduction of intensity bounds increases the linear convergence rate of the steepest descent algorithm because the bounds impose tight constraints on the solution [29, 30]. Furthermore, the degraded image provides a good initial estimate of the original image.

The intensity bounds are reinitialised according to (21), at the beginning of each image optimisation. During the minimisation cycle, they are applied as the variance estimates converge.

For the blur optimisation, the slow convergence rate of the gradient projection method poses a severe problem since the blur may be initialised far from the actual solution. Furthermore, an explicit expression for the projection operator $P_h$ is not readily available as $\mathcal{C}_h$ is defined by the intersection of several convex sets which are not easily combined.

The structure of the blur optimisation problem is better suited to quadratic programming (QP) because (42) is quadratic with respect to $\hat{\mathbf{h}}$, subject to the linear equality and inequality constraints described in Section 5.1. (A good description of QP can be found in [31].) The assumed support of the blur is usually quite small relative to the image, and so the QP algorithm can easily handle the number of variables.

The resulting blind image restoration algorithm is described below.

1. Choose a conservatively large estimate for the PSF support $-N_m \leq m \leq N_m$ and $-N_n \leq n \leq N_n$. Initialise the image and blur estimates to $(\hat{\mathbf{f}}, \hat{\mathbf{h}}_0) = (P_{\mathbf{f}} \mathbf{g}, \mathbf{e}_1)$, where $\mathbf{e}_1$ denotes the unit vector corresponding to the two-dimensional $\delta$-function. Set the cycle number $k = 1$.

2. Minimise with respect to the blur using the QP algorithm to obtain $\mathbf{h}_k = \arg\{\min_{\mathbf{h} \in \mathcal{F}} J(\mathbf{f}, \mathbf{h})\}$.

3. Truncate the estimated PSF support according to the following conditions.

   (i) If $N_m > 0$ and $\hat{h}(N_m, n) \leq 0.1 \hat{h}(N_m - 1, n), -N_n \leq n \leq N_n$, then $N_m = N_m - 1$.

   (ii) If $N_m > 0$ and $h(m, N_n) \leq 0.1 h(m, N_n - 1), -N_m \leq m \leq N_m$, then $N_n = N_n - 1$.

   (iii) Renormalise the truncated blur.

4. Minimise with respect to the image to obtain $\hat{\mathbf{f}}_k = \arg\{\min_{\mathbf{f} \in \mathcal{F}} J(\mathbf{f}, \mathbf{h}_k)\}$. Set $\mathbf{f}_{k+1} = \mathbf{f}_k$ and initialise the intensity bounds according to (21).

5. Repeat steps (2), (3), and (4) until

   \[
   (\hat{\mathbf{f}}_{k+1}, \mathbf{h}_{k+1}) - (\hat{\mathbf{f}}_k, \mathbf{h}_k) \leq \delta
   \]

   or $k > 20$.

5.3. Experimental results

The Cameraman and Lena images, superimposed on a black background, were degraded by a $5 \times 5$ pill-box blur with 30 dB noise, as shown in Figures 6a and 6b.

A uniform smoothness constraint was used in conjunction with the intensity bounds. A moderate value of $\alpha_1 = 0.05$ was chosen for the regularisation parameter. The scaling parameter $\beta = 30$ was found to give good restorations, but no attempt was made to fine-tune this value. For comparison, the images were restored using uniform regularisation only. In this case, the suggested value of $\alpha = \|\mathbf{g} - H \mathbf{f}\|^2/\|\mathbf{f}\|^2$ was used [22], even though these quantities are not usually known precisely.

The image and blur estimates are shown in Figures 7 and 8. The ISNR was calculated over the image support only. The quality of the blur estimate was measured as follows:

\[
\Delta_k = \sqrt{\frac{\sum_{(m,n) \in \mathcal{F}} [h(m, n) - \hat{h}(m, n)]^2}{\sum_{(m,n) \in \mathcal{F}} [h(m, n)]^2}}.
\]

It can be seen that the addition of intensity constraints significantly improved both estimates. Furthermore, the blur estimate is very precise due to the proper application of constraints such as positivity, energy preservation, circular symmetry, and monotonicity. In particular, the monotonicity constraint, which has not been used in previous blind restoration schemes, significantly improves the blur estimate. The main drawback of the bound update algorithm was the increase in the number of iterations required for the image optimisation. This can be seen by comparing the number of image updates for fixed bounds and updated bounds in Figures 7 and 8.

6. DISCUSSION AND CONCLUSIONS

This paper presented a new method of defining and incorporating spatially adaptive intensity bounds in both blind and nonblind image restoration. The intensity bounds were initially estimated from the local statistics of the degraded image and were updated from the current image estimate to produce more accurate constraints. It was found that if the bound scaling parameter $\beta$ was chosen properly, then the addition of intensity bounds significantly improved the
restoration, with the largest improvement resulting from the proposed bound-update methods. General guidelines for the choice of the scaling parameter were presented.

While the intensity bounds were implemented in the context of the gradient projection method, a number of blind restoration algorithms could be easily modified to incorporate the bounds. Further research needs to be done on the effectiveness of the intensity bounds in these algorithms.

REFERENCES


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Many important applications of multimedia revolve around the detection of humans and the interpretation of human behavior, for example, surveillance and intrusion detection, automatic analysis of sports videos, broadcasts, movies, ambient assisted living applications, video conferencing applications, and so forth. Success in this task requires the integration of various data modalities including video, audio, and associated text, and a host of methods from the field of machine learning. Additionally, the computational efficiency of the resulting algorithms is critical since the amount of data to be processed in videos is typically large and real-time systems are required for practical implementations.

Recently, there have been several special issues on the human detection and human-activity analysis in video. The emphasis has been on the use of video data only. This special issue is concerned with contributions that rely on the use of multimedia information, that is, audio, video, and, if available, the associated text information.

Papers on the following and related topics are solicited:

- Video characterization, classification, and semantic annotation using both audio and video, and text (if available).
- Video indexing and retrieval using multimedia information.
- Segmentation of broadcast and sport videos based on audio and video.
- Detection of speaker turns and speaker clustering in broadcast video.
- Separation of speech and music/jingles in broadcast videos by taking advantage of multimedia information.
- Video conferencing applications taking advantage of both audio and video.
- Human mood detection, and classification of interactivity in duplexed multimedia signals as in conversations.
- Human computer interaction, ubiquitous computing using multimedia.
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Special Issue on

Signal Processing for Location Estimation and Tracking in Wireless Environments

Call for Papers

In recent years, the proliferation of mobile computing devices and wireless technologies has fostered a growing interest in location-aware systems and services. The availability of location information on objects and human beings is critical in many military and civilian applications such as emergency call services, tracking of valuable assets, monitoring individuals with special needs in assisted living facilities, location-assisted gaming (e.g., Geocaching), etc.

Existing positioning systems can be categorized based on whether they are intended for indoor or outdoor applications. Within both of these application areas, there are two major categories of position estimation techniques, as discussed below.

- **Geometric techniques**–Position is estimated by exploiting time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) or other information derived from the relationship between the geometry of an array of receivers and the modeled propagation characteristics of the transmitted signal.

- **Mapping approaches**–Position is estimated based on comparison of local measurements to a “map” of expected distribution of the measured values. For example, in a wireless LAN application, received signal strength (RSS) might be observed either at the location of the client or at a remote reference point. Mapping approaches are also known as location fingerprinting.

Although geometric approaches have the potential to achieve higher precision than mapping approaches, they generally require direct-path signal reception or accurate environmental information at the receiver and often perform poorly in complex multipath environments. On the other hand, estimation accuracy of mapping approaches is limited by both the accuracy of the reference map and the accuracy of observed measurements. Furthermore, frequent and extensive site-survey measurements are often needed to accommodate the time varying nature of wireless channels, structural changes in the environment, and upgrades of wireless infrastructure.

In addition to snapshots of AOA, TOA, TDOA or RSS measurements, motion models or prior knowledge of structural constraints can often be used to enhance location estimation accuracy for mobile objects by “tracking” location estimates over time. Trackers that integrate such information into the computation of location estimates are generally implemented using techniques such as Kalman filters, particle filters, Markov chain Monte Carlo methods, etc.

The purpose of the proposed special issue is to present a comprehensive picture of both the current state of the art and emerging technologies in signal processing for location estimation and tracking in wireless environments. Papers are solicited on all related aspects from the point of view of both theory and practice. Submitted articles must be previously unpublished and not concurrently submitted for publication on other journals.

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

- Received signal strength (RSS), angle-of-arrival (AOA), and time-based location estimation
- Ultrawideband (UWB) location estimation
- Bayesian location estimation and tracking
- Pattern recognition and learning theory approaches to location estimation
- Applications of expectation-maximization (EM) and Markov chain Monte Carlo (MCMC) techniques
- Applications of electromagnetic propagation modeling to location estimation
- Mitigation of errors due to non-line-of-sight propagation
- System design and configuration
- Performance evaluation, performance bounds, and statistical analysis
• Computational complexity and distributed computation
• Distributed location estimation
• Synchronization issues
• Testbed implementation, real-world deployment, and measurement

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Special Issue on
Track Before Detect Algorithms

Call for Papers

Seamless detection and tracking schemes are able to integrate unthresholded (or below target detection threshold) multiple sensor responses over time to detect and track targets in low signal-to-noise ratio (SNR) and high clutter scenarios. These schemes, also called "track-before-detect (TBD)" algorithms are especially suitable for tracking weak targets that would only very rarely cross a standard detection threshold as applied at the sensor level.

Thresholding sensor responses result in a loss of information. Keeping this information allows some TBD approaches to deal with the classical data association problem effectively in high clutter and low SNR situations. For example, in detection scenarios with simultaneous activation/illumination from different signal sources this feature allows the application of triangulation techniques, where in the case of contact tracking approaches essential information about weak targets would often be lost because these targets did not produce signals that cross the normal detection threshold. Extending this example to a multi-sensor network scenario, a TBD algorithm that can use unthresholded (or below threshold) data has the potential to show improved performance compared to an algorithm that relies on thresholded data. In low SNR situations, this can substantially increase performance particularly in the case of a dense multi-target scenario.

Naturally, TBD algorithms consume high computational processing power: An efficient realization and coding of the TBD scheme is mandatory.

Another issue that arises when using the TBD scheme is the quality of the sensor model: Practical experience with thresholded data shows that a coarser modelling of the likelihood function might be sufficient and often leads to robust algorithms. How much have these sensor models to be improved in order to allow the TBD algorithms to exploit the information provided with the unthresholded data?

TBD algorithms that are well known to the tracking community are the likelihood ratio detection and tracking (LRDT), maximum likelihood probabilistic data association (MLPDA), maximum likelihood probabilistic multi-hypothesis tracking (MLPMHT), Hough transform based methods and dynamic programming techniques; also related are the probability hypothesis density (PHD), the histogram probabilistic multi- hypothesis tracking (H-PMHT) algorithms, and, of course, various particle filter approaches. Some of these algorithms are capable of tracking extended targets and performing signal estimation in multi-sensor measurements.

The aim of this special issue is to focus on recent developments in this expanding research area. The special issue will focus on one hand on the development and comparison of algorithmic approaches, and on the other hand on their currently ever-widening range of applications such as in active or passive surveillance scenarios (e.g. for object tracking and classification with image and video based sensors, or scenarios involving chemical, electromagnetic and acoustic sensors). Special interest lies in multi-sensor data fusion and/or multi-target tracking applications.

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Special Issue on
Advanced Signal Processing and Pattern Recognition Methods for Biometrics

Call for Papers

Biometric identification has established itself as a very important research area primarily due to the pronounced need for more reliable and secure authentication architectures in several civilian and commercial applications. The recent integration of biometrics in large-scale authentication systems such as border control operations has further underscored the importance of conducting systematic research in biometrics. Despite the tremendous progress made over the past few years, biometric systems still have to reckon with a number of problems, which illustrate the importance of developing new biometric processing algorithms as well as the consideration of novel data acquisition techniques. Undoubtedly, the simultaneous use of several biometrics would improve the accuracy of an identification system. For example the use of palmprints can boost the performance of hand geometry systems. Therefore, the development of biometric fusion schemes is an important area of study. Topics related to the correlation between biometric traits, diversity measures for comparing multiple algorithms, incorporation of multiple quality measures, and so forth need to be studied in more detail in the context of multibiometrics systems. Issues related to the individuality of traits and the scalability of biometric systems also require further research. The possibility of using biometric information to generate cryptographic keys is also an emerging area of study. Thus, there is a definite need for advanced signal processing, computer vision, and pattern recognition techniques to bring the current biometric systems to maturity and allow for their large-scale deployment.

This special issue aims to focus on emerging biometric technologies and comprehensively cover their system, processing, and application aspects. Submitted articles must not have been previously published and must not be currently submitted for publication elsewhere. Topics of interest include, but are not limited to, the following:

- Fusion of biometrics
- Analysis of facial/iris/palm/fingerprint/hand images
- Unobtrusive capturing and extraction of biometric information from images/video
- Biometric identification systems based on face/iris/palm/fingerprint/voice/gait/signature
- Emerging biometrics: ear, teeth, ground reaction force, ECG, retina, skin, DNA
- Biometric systems based on 3D information
- User-specific parameterization
- Biometric individuality
- Biometric cryptosystems
- Quality measure of biometrics data
- Sensor interoperability
- Performance evaluation and statistical analysis

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<th>May 1, 2007</th>
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<td>September 1, 2007</td>
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<td>Final Manuscript Due</td>
<td>December 1, 2007</td>
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<td>1st Quarter, 2008</td>
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Special Issue on
Signal Processing for Data Converters

Call for Papers
Data converters (ADCs and DACs) ultimately limit the performance of today’s communication systems. New concepts for high-speed, high-resolution, and power-aware converters are therefore required, which also lead to an increased demand for high-speed and high-resolution sampling systems in the measurement industry. Present converter technologies operate on their limits, since the downscaling of IC technologies to deep submicron technologies makes their design increasingly difficult. Fortunately, downscaling of IC technologies allows for using additional chip area for digital signal processing algorithms with hardly any additional costs. Therefore, one can use more elaborate signal processing algorithms to improve the conversion quality, to realize new converter architectures and technologies, or to relax the requirements on the analog design. Pipelined ADCs constitute just one example of converter technology where signal processing algorithms are already extensively used. However, time-interleaved converters and their generalizations, including hybrid filter bank-based converters and parallel sigma-delta-based converters, are the next candidates for digitally enhanced converter technologies, where advanced signal processing is essential. Accurate models constitute one foundation of digital corrected data converters. Generating and verifying such models is a complex and time-consuming process that demands high-performance instrumentation in conjunction with sophisticated software defined measurements.

The aim of this special issue is to bring forward recent developments on signal processing methods for data converters. It includes design, analysis, and implementation of enhancement algorithms as well as signal processing aspects of new converter topologies and sampling strategies. Further, it includes design, analysis, and implementation of software defined measurements for characterization and modeling of data converters.

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

- Analysis, design, and implementation of digital algorithms for data converters
- Analysis and modeling of novel converter topologies and their signal processing aspects
- Digital calibration of data converters
- Error identification and correction in time-interleaved ADCs and their generalizations
- Signal processing for application-specific data converters (communication systems, measurement systems, etc.)
- New sampling strategies
- Sampling theory for data converters
- Signal processing algorithms for data converter testing
- Influence of technology scaling on data converters and their design
- Behavioral models for converter characterization
- Instrumentation and software defined measurements for converter characterization

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Special Issue on
Distributed Space-Time Systems

Call for Papers

Diversity is a powerful technique to mitigate channel fading and to improve robustness to cochannel interference in a wireless network. Space-time wireless systems traditionally use multiple colocated antennas at the transmitter and receiver along with appropriate signal design (also known as space-time coding) to realize spatial diversity in the link. Typically this diversity can augment any frequency and time diversity available to the receiver. Multiple antennas also offer the ability to use spatial multiplexing to dramatically increase the data rate.

A recent development in this area aims at dispensing with the need for colocated antennas. Popularly known as the cooperative diversity technique, this uses the antennas at multiple user terminals in a network in the form of a virtual antenna array to realize spatial diversity in a distributed fashion. Such techniques create new challenges in the design of wireless systems.

The purpose of this call for papers is to address some of these challenges such as new protocols for cooperative diversity, cross-layer design, cooperative multiplexing, space-time coding for distributed antennas, cooperative channel estimation and equalization, selecting the right users for participating in a cooperative network, modulation specific issues like OFDMA and CDMA, and distributed space-time processing for sensor networks.

Papers on the following and related topics are solicited for this special issue:

- New protocols for cooperative diversity systems
- Cross-layer protocol design
- Signal design for distributed space-time systems
- Cooperative channel estimation and equalization
- Cooperative MIMO systems
- Distributed space-time processing for sensor networks
- Power allocation in distributed space-time systems
- Fast algorithms and efficient architectures for virtual MIMO receivers
- Energy efficient relay network architectures

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<td>December 1, 2007</td>
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<td>Publication Date</td>
<td>1st Quarter, 2008</td>
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Special Issue on
Cooperative Localization in Wireless Ad Hoc and Sensor Networks

Call for Papers
One of the major requirements for most applications based on wireless ad hoc and sensor networks is accurate node localization. In fact, sensed data without position information is often less useful.

Due to several factors (e.g., cost, size, power), only a small fraction of nodes obtain the position information of the anchor nodes. In this case, a node has to estimate its position without a direct interaction with anchor nodes and a cooperation between nodes is needed in a multihop fashion. In some applications, none of the nodes are aware of their absolute position (anchor-free) and only relative coordinates are estimated instead.

Most works reported in the literature have studied cooperative localization with the emphasis on algorithms. However, very few works give emphasis on the localization as estimation or on the investigation of fundamental performance limits as well as on experimental activities. In particular, the fundamental performance limits of multihop and anchor-free positioning in the presence of unreliable measurements are not yet well established. The knowledge of such limits can also help in the design and comparison of new low-complexity and distributed localization algorithms. Thus, measurement campaigns in the context of cooperative localization to validate the algorithms as well as to derive statistical models are very valuable.

The goal of this special issue is to bring together contributions from signal processing, communications and related communities, with particular focus on signal processing, new algorithm design methodologies, and fundamental limitations of cooperative localization systems. Papers on the following and related topics are solicited:

- anchor-based and anchor-free distributed and cooperative localization algorithms that can cope with unreliable range measurements
- derivation of fundamental limits in multihop and anchor-free localization scenarios
- new localization algorithms design methodologies based, for example, on statistical inference and factor graphs
- low-complexity and energy-efficient distributed localization algorithms
- distributed ranging and time synchronization techniques
- measurement campaigns and statistical channel modeling
- algorithm convergence issues
- UWB systems
- localization through multiple-antenna systems
- experimental results

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<td>Manuscript Due</td>
<td>August 1, 2007</td>
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<td>Acceptance Notification</td>
<td>December 1, 2007</td>
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<td>Final Manuscript Due</td>
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<td>Publication Date</td>
<td>2nd Quarter 2008</td>
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Special Issue on
Information Theoretic Methods for Bioinformatics

Call for Papers

Information theoretic methods for modeling are at the center of the current efforts to interpret bioinformatics data. The high pace at which new technologies are developed for collecting genomic and proteomic data requires a sustained effort to provide powerful methods for modeling the data acquired. Recent advances in universal modeling and minimum description length techniques have been shown to be well suited for modeling and analyzing such data. This special issue calls for contributions to modeling of data arising in bioinformatics and systems biology by information theoretic means. Submissions should address theoretical developments, computational aspects, or specific applications. Suitable topics for this special issue include but are not limited to:

- Normalized maximum-likelihood (NML) universal models
- Minimum description length (MDL) techniques
- Microarray data modeling
- Denoising of genomic data
- Pattern recognition
- Data compression-based modeling

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<th>Manuscript Due</th>
<th>February 1, 2007</th>
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<tr>
<td>Acceptance Notification</td>
<td>May 1, 2007</td>
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<tr>
<td>Final Manuscript Due</td>
<td>July 1, 2007</td>
</tr>
<tr>
<td>Publication Date</td>
<td>3rd Quarter, 2007</td>
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Special Issue on
Multimedia over Wireless Networks

Call for Papers

Scope
In recent years there has been a tremendous increase in demand for multimedia delivered over wireless networks. The design and capabilities of the mobile devices and the services being offered reflect the increase in multimedia usage in the wireless setting. Applications that are in the process of becoming essential to users include video telephony, gaming, or TV broadcasting. This trend creates great opportunities for identifying new wireless multimedia applications, and for developing advanced systems and algorithms to support these applications. Given the nature of the channel and of the mobile devices, issues such as scalability, error resiliency, and energy efficiency are of great importance in applications involving multimedia transmission over wireless networks.

The papers in this issue will focus on state-of-the-art research on all aspects of wireless multimedia communications. Papers showing significant contributions are solicited on topics including but are not limited to:

- Error resilience and error concealment algorithms
- Rate control for wireless multimedia coding
- Scalable coding and transmission
- Joint source-channel coding
- Joint optimization of power consumption and rate-distortion performance
- Wireless multimedia traffic modeling
- Wireless multimedia streaming
- Wireless multimedia coding
- QoS for wireless multimedia applications
- Distributed multimedia coding

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<th>Manuscript Due</th>
<th>March 1, 2007</th>
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<td>Acceptance Notification</td>
<td>July 1, 2007</td>
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<td>Final Manuscript Due</td>
<td>October 1, 2007</td>
</tr>
<tr>
<td>Publication Date</td>
<td>4th Quarter, 2007</td>
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</table>

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Special Issue on
Image and Video Processing for Disability

Call for Papers

New technologies represent a great opportunity for the improvement of life and independent living of the disabled and elder people. Over the last decade, active researches have produced novel algorithms for blind, deaf, mute people or for people with severe motor disabilities. These researches are strongly related with the development of new dedicated systems for human-computer interactions.

Whatever the kind of handicap, image processing can provide a significant help for disability compensation to avoid the gap increasing between disabled and nondisabled people with respect to the new technologies.

Researches for new systems for disabled people are multidisciplinary research from engineering sciences (computer science, HCI, automatic, electronics, etc.) and human sciences (psychology, cognition, etc.). Here we are focusing on researches involving image and video processing for disability. However, multimodal signals-based systems can be considered.

The goal of this special issue is to provide original contributions in the field of image and video processing for disability.

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

- Eye-gaze analysis and interpretation
- Head motion analysis
- Human behavior modeling
- HCI for disabled people
- Hand-gesture analysis and interpretation
- Sign language recognition
- Modality replacement
- Multimodal systems for disabled
- Facial expressions interpretation

In each case, works should be related to an application dedicated to disabled or elder people’s help.

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<td>Manuscript Due</td>
<td>January 1, 2007</td>
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<td>Acceptance Notification</td>
<td>April 1, 2007</td>
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<td>Final Manuscript Due</td>
<td>June 1, 2007</td>
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<tr>
<td>Publication Date</td>
<td>3rd Quarter, 2007</td>
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Call for Papers

Humans are a basic entity in most videos. Lately, there has been increased interest in devising automated video analysis algorithms that aim to extract, efficiently describe, and organize information regarding the state or state transition of individuals (identity, emotional state, activity, position and pose, etc), interactions between individuals (dialogue, gestures, engagement into collaborative or competitive activities like sports), physical characteristics of humans (anthropometric characteristics, 3D head/body models), and so forth. Such information can be utilized in a multitude of important applications that include, but are not limited to:

- Human computer interaction, ubiquitous computing
- Video characterization, classification, and semantic annotation
- Video indexing and retrieval
- Temporal video segmentation (shot and scene boundary detection) and summarization
- Intelligent video surveillance, access control, and other security related applications

High quality and original contributions on the following (nonexhaustive) list of topics related to anthropocentric video analysis and its applications are solicited:

- Detection and tracking of humans or human body parts
- Action recognition and human behavior analysis
- Emotional state recognition
- Anthropocentric video characterization, semantic annotation, indexing, retrieval, temporal segmentation and summarization
- Efficient description schemes for anthropocentric video information
- Dialogue detection, LiP activity detection, visual speech recognition
- Hand gesture recognition
- 3D modeling of humans
- Person verification and recognition

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IEEE ICME 2007 Call for Papers
2007 International Conference on Multimedia & Expo (ICME)
July 2-5, 2007
Beijing International Convention Center, Beijing, China

IEEE International Conference on Multimedia & Expo is a major annual international conference with the objective of bringing together researchers, developers, and practitioners from academia and industry working in all areas of multimedia. ICME serves as a forum for the dissemination of state-of-the-art research, development, and implementations of multimedia systems, technologies and applications. ICME is co-sponsored by four IEEE societies including the Circuits and Systems Society, the Communications Society, the Computer Society, and the Signal Processing Society. The conference will feature world-class plenary speakers, exhibits, special sessions, tutorials, and paper presentations.

Prospective authors are invited to submit a four-page paper in double-column format including authors’ names, affiliations, and a short abstract. Only electronic submissions will be accepted. Topics include but are not limited to:

- Audio, image, video processing
- Virtual reality and 3-D imaging
- Signal processing for media integration
- Multimedia communications and networking
- Multimedia security and content protection
- Multimedia human-machine interface and interaction
- Multimedia databases
- Multimedia computing systems and appliances
- Hardware and software for multimedia systems
- Multimedia standards and related issues
- Multimedia applications
- Multimedia and social media on the Internet

A number of awards will be presented to the Best Papers and Best Student Papers at the conference. Participation for special sessions and tutorial proposals are encouraged.

SCHEDULE

- Special Session Proposals Due: December 1, 2006
- Tutorial Proposals Due: December 1, 2006
- Regular Paper Submissions Due: January 5, 2007
- Notification of Acceptance: March 19, 2007
- Camera-Ready Papers Due: April 16, 2007


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Creating exact 3D moving images as ghost-like replicas of 3D objects has been an ultimate goal in video science. Capturing 3D scenery, processing the captured data for transmission, and displaying the result for 3D viewing are the main functional components. These components encompass a wide range of disciplines: imaging and computer graphics, signal processing, telecommunications, electronics, optics and physics are needed.

The objective of the 3DTV-Conference is to bring together researchers and developers from academia and industry with diverse experience and activity in distinct, yet complementary, areas so that full scale 3D video capabilities are seamlessly integrated.

First Call For Papers

Creating exact 3D moving images as ghost-like replicas of 3D objects has been an ultimate goal in video science. Capturing 3D scenery, processing the captured data for transmission, and displaying the result for 3D viewing are the main functional components. These components encompass a wide range of disciplines: imaging and computer graphics, signal processing, telecommunications, electronics, optics and physics are needed.

The objective of the 3DTV-Conference is to bring together researchers and developers from academia and industry with diverse experience and activity in distinct, yet complementary, areas so that full scale 3D video capabilities are seamlessly integrated.

Topics of Interest

3D Capture and Processing
- 3D time-varying scene capture technology
- Multi-camera recording
- 3D photography algorithms
- Synchronization and calibration of camera arrays
- 3D view registration
- Multi-view geometry and calibration
- Holographic camera techniques
- 3D motion analysis and tracking
- Surface modeling for 3-D scenes
- Multi-view image and 3D data processing

3D Transmission
- Systems, architecture and transmission aspects of 3D
- 3D streaming
- Error-related issues and handling of 3D video
- Hologram compression
- Multi-view video coding
- 3D mesh compression
- Multiple description coding for 3D
- Signal processing for diffraction and holographic 3DTV

3D Visualization
- 3D mesh representation
- Texture and point representation
- Object-based representation and segmentation
- Volume representation
- 3D motion animation
- Dense stereo and 3D reconstruction
- Stereoscopic display techniques
- Holographic display technology
- Reduced parallax systems and integral imaging
- Underlying optics and VLSI technology
- Projection and display technology for 3D videos
- Human factors

3D Applications
- 3D imaging in virtual heritage and virtual archaeology
- 3D Teleimmersion and remote collaboration
- Augmented reality and virtual environments
- 3D television, cinema, games and entertainment
- Medical and biomedical applications
- 3D Content-based retrieval and recognition
- 3D Watermarking

Paper Submission

Prospective contributors are invited to submit full papers electronically using the on-line submission interface, following the instructions available at http://www.3dtv-con.org. Papers should be in Adobe PDF format, written in English, with no more than four pages including figures, using a font size of 11. Conference proceedings will be published online by the IEEE.

Important Dates

1 December 2006 Special sessions and tutorials proposals
15 December 2006 Regular Paper submission
9 February 2007 Notification of acceptance
2 March 2007 Submission of camera-ready papers
Call for Papers

The International ITG / IEEE Workshop on Smart Antennas WSA 2007 provides a forum for presentation of the most recent research on smart antennas. The objective is to continue, accelerate, and broaden the momentum already gained with a series of ITG Workshops held since 1996: Munich and Zurich’96, Vienna and Kaiserslautern’97, Karlsruhe’98, Stuttgart’99, Ilmenau’01, Munich’04, Duisburg’05, and Ulm’06. This call for papers intends to solicit contributions on latest research of this key technology for wireless communication systems.

Workshop topics include, but are not limited to:

- Antennas for beamforming and diversity
- Channel measurements
- Spatial channel modeling
- Beamforming
- Diversity concepts
- Space-time processing
- Space-time codes
- MIMO Systems
- Multicarrier MIMO
- Multiuser MIMO
- Cooperative and sensor networks
- Crosslayer optimisation
- Radio resource management
- Cellular systems
- Link, system and network level simulations
- Hard- and software implementation issues

There will be oral as well as poster presentations.

The workshop will be jointly organized by the Institute of Communications and Radio Frequency at Vienna University of Technology and the ftw. Telecommunications Research Center Vienna in cooperation with the VDE, ÖVE, and the IEEE on February 26-27, 2007 in Vienna, Austria.

Organizers and Workshop Chairs

Markus Rupp,
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Information about the workshop can soon be found at: http://www.ftw.at/

Technical program committee

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Call for Papers

The 5th International Symposium on Image and Signal Processing and Analysis (ISPA 2007) will take place in Istanbul, Turkey, from September 27-29, 2007. The scientific program of the symposium consists of invited lectures, regular papers, and posters. The aim of the symposium is to foster interaction of researchers and exchange of new ideas. Prospective authors are invited to submit their manuscripts reporting original work, as well as proposals for special sessions.

Co-Operations and Co-Sponsorships

- European Association for Signal Processing (EURASIP)
- IEEE Region 8*

Symposium Topics

A. Image and Video Processing
B. Image and Video Analysis
C. Image Formation and Reproduction
D. Signal Processing
E. Signal Analysis
F. Applications

For a detailed list of subtopics please visit ISPA 2007 web site.

Important Dates

Submission of full paper: February 15, 2007
Notification of acceptance/rejection: April 15, 2007
Submission of camera-ready papers and registration: May 15, 2007

Symposium Venue

Located in the center of the Old World, Istanbul is one of the world's great cities famous for its historical monuments and scenic beauties. It is the only city in the world which spreads over two continents: it lies at a point where Asia and Europe are separated by a narrow strait - the Bosphorus. Istanbul has been the cradle for many civilizations for over 2500 years and has a very rich history. It has been the capital of three great empires, the Roman, Byzantine and Ottoman empires, and for more than 1,600 years over 120 emperors and sultans ruled the world from here. Istanbul is the heart of Turkey with respect to entertainment, culture, education, shopping, imports and exports, tourism and the arts. The symposium will be organized in the congress center of the Bogazici University.

Paper Submission Procedure

Papers including title, author list and affiliations, figures, results, and references should not exceed six A4 pages. Detailed instructions for electronic submission are available on the ISPA web site. All papers will be subject to a peer-review process with at least two reviewers. All accepted papers will be published in the symposium proceedings in book form and on CD-ROM, which will be available through IEEE Publications Center and in IEEExplore digital library.

Call for Special Session Proposals

Prospective organizers of special sessions are invited to send proposals to Special Session Co-Chairs, according to instructions provided on the ISPA web site. The aim of a special session is to provide an overview of the state-of-the-art and current research directions in specific fields of image and signal processing and analysis.

Best Student Paper Award

Best Student Paper Award in the amount of 300 EUR will be given to a student author. The student’s name must appear first on the paper and the paper must be presented at the symposium to be eligible for the award.

* request pending
ISSPA 2007
International Symposium on Signal Processing and its Applications
in conjunction with the International Conference on Information Sciences, Signal Processing and their Applications
12 – 15 February 2007, Millennium Hotel, Sharjah, U.A.E.

Call For Participation

ISSPA 2007 marks the 20th anniversary of launching the first ISSPA in 1987 in Brisbane, Australia. Since its inception, ISSPA has provided, through a series of 8 symposia, a high-quality forum for engineers and scientists engaged in research and development of Signal and Image Processing theory and applications. Effective 2007, ISSPA will extend its scope to add the new track of Information Sciences. Hence, the intention that the previous full name of ISSPA is replaced after 2007 by the following new full name: International Conference on Information Sciences, Signal Processing and their Applications. ISSPA is an IEEE-indexed conference.

ISSPA 2007 is organized by the University of Sharjah, College of Engineering, Etisalat University College and the American University of Sharjah.

The regular technical program will run for three days along with an exhibition of signal processing and information sciences products. In addition, tutorial sessions will be held on the first day of the symposium. Presentations will be given in the following topics:

1. Filter Design Theory and Methods
2. Multirate Filtering & Wavelets
3. Adaptive Signal Processing
4. Time-Frequency/Time-Scale Analysis
5. Statistical Signal & Array Processing
6. Radar & Sonar Processing
7. Speech Processing & Recognition
8. Fractals and Chaos Signal Processing
9. Signal Processing in Communications
10. Signal processing in Networking
11. Multimedia Signal Processing
12. Nonlinear signal processing
13. Biomedical Signal and Image Processing
14. Image and Video Processing
15. Image Segmentation and Scene Analysis
16. VLSI for Signal and Image Processing
17. Cryptology, Steganography, and Digital Watermarking
18. Image indexing & retrieval
19. Soft Computing & Pattern Recognition
20. Natural Language Processing
21. Signal Processing for Bioinformatics
22. Signal Processing for Geoinformatics
23. Biometric Systems and Security
24. Machine Vision
25. Data visualization
26. Data mining
27. Sensor Networks and Sensor Fusion
28. Signal Processing and Information Sciences Education
29. Others
30. Special Sessions

Prospective authors were invited to submit full length (four pages) papers via the conference website for presentation in any of the areas listed above (showing area in submission). Submission of proposals for student session, tutorials and sessions on special topics were sent to the conference secretary. All articles submitted to ISSPA 2007 are peer-reviewed using a blind review process by at least two independent reviewers.

For more details see www.isspa2007.org/