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Video Segmentation Using Fast Marching and Region Growing Algorithms

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The algorithm presented in this paper is comprised of three main stages: (1) classification of the image sequence and, in the case of a moving camera, parametric motion estimation, (2) change detection having as reference a fixed frame, an appropriately selected frame or a displaced frame, and (3) object localization using local colour features. The image sequence classification is based on statistical tests on the frame difference. The change detection module uses a two-label fast marching algorithm. Finally, the object localization uses a region growing algorithm based on the colour similarity. Video object segmentation results are shown using the COST 211 data set.

Keywords and phrases: video object segmentation, change detection, colour-based region growing.

1. INTRODUCTION

Video segmentation is a key step in image sequence analysis and its results are extensively used for determining motion features of scene objects, as well as for coding purposes to reduce storage requirements. The development and widespread use of the international coding standard MPEG-4 [1], which relies on the concept of image/video objects as transmission elements, has raised the importance of these methods. Moving objects could also be used for content description in MPEG-7 applications.

Various approaches have been proposed for video or spatio-temporal segmentation. An overview of segmentation tools, as well as of region-based representations of image and video, are presented in [2]. The video object extraction could be based on change detection and moving object localization, or on motion field segmentation, particularly when the camera is moving. Our approach is based exclusively on change detection. The costly and potentially inaccurate motion estimation process is not needed. We present here some relevant work from the related literature for better situating our contribution.

Spatial Markov Random Fields (MRFs) through the Gibbs distribution have been widely used for modelling the change detection problem [3, 4, 5, 6, 7, 8]. These approaches are based on the construction of a global cost function, where interactions (possibly nonlinear) are specified among different image features (e.g., luminance, region labels). Multiscale approaches have also been investigated in order to reduce the computational overhead of the deterministic cost minimization algorithms [7] and to improve the quality of the field estimates.

In [9], a motion detection method based on an MRF model was proposed, where two zero-mean generalized Gaussian distributions were used to model the interframe difference. For the localization problem, Gaussian distribution functions were used to model the intensities at the same site in two successive frames. In each problem, a cost function was constructed based on the above distributions along with a regularization of the label map. Deterministic relaxation algorithms were used for the minimization of the cost function.

On the other hand, approaches based on contour evolution [10, 11] or on partial differential equations are also proposed in the literature. In [12], a three-step algorithm is proposed, consisting of contour detection, estimation of the velocity field along the detected contours and finally the determination of moving contours. In [13], the contours to be detected and tracked are modelled as geodesic active contours. For the change detection problem a new image is generated, which exhibits large gradient values around the moving area. The problem of object tracking is posed in a unified active contour model including both change detection and object localization.

In the framework of COST 211, an Analysis Model (AM) is proposed for image and video analysis and segmentation [14]. The essential feature of the AM is its ability to fuse information from different sources: colour segmentation, motion segmentation, and change detection. Kim et al. [15] proposed a method using global motion estimation, change detection, temporal and spatial segmentation.

Our algorithm, after the global motion estimation phase, is mainly based on change detection. The change detection problem is formulated as two-label classification. In [16] we introduce a new methodology for pixel labelling called *Bayesian Level Sets*, extending the *level set* method [17] to pixel classification problems. We have also introduced the *Multi-Label Fast Marching* algorithm and applied it at first to the change detection problem [18]. A more recent and detailed presentation is given in [19]. The algorithm presented in this paper differs from previous work in the final stage, where the boundary-based object localization is replaced by a region-based object labelling.

In Section 2, the method for selecting the appropriate frame difference for detecting the moving object is presented. In Section 3, we present the multi-label fast marching algorithm, which uses the frame difference and an initial labelling for segmenting the image into unchanged and changed regions with respect to the camera, that is, changes independent of the camera motion. The last step of the entire algorithm is presented in Section 4 where a region growing technique extends an initial segmentation map. Section 5 concludes the paper, commenting on the obtained results.

2. FRAME DIFFERENCE

In our approach, the main step in video object segmentation is change detection. Therefore, for each frame we must first determine another frame which will be retained as a reference frame and used for the comparison. Three different main situations may occur: (a) a constant reference frame, as in surveillance applications, (b) another frame appropriately selected, in the case of a still camera, and (c) a computed displaced frame, in the case of a moving camera.

The image sequence must be classified according to the above categories. We use a hierarchical categorization based on statistics of frame differences (Figure 1). At first the hypothesis (a) is tested against the other two. We can consider there to exist a unique background reference image if, for a number of frames, the observed frame differences are negligible. A test on the empirical probability distribution is then used.

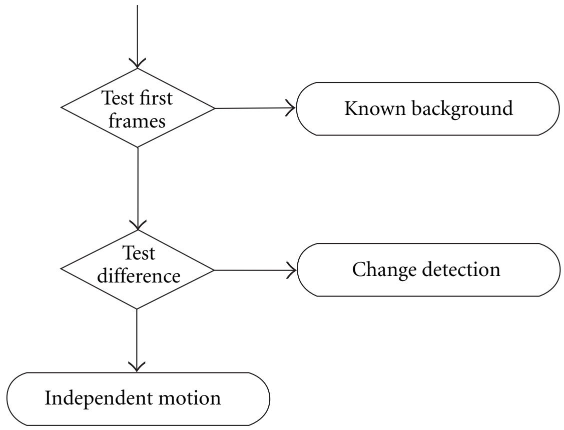


Figure 1: The tests of image sequence classification.

When the reference is not constant we have to determine the more appropriate reference in order to identify independently moving objects. In order to determine the reference frame, it must be ascertained whether the camera is moving or not. The test is again based on the empirical probability distribution of the frame differences. More precisely, if the probability that the observed frame difference is less than 3, is less than 0.5, then the camera is considered as possibly moving, and the parametric camera motion is estimated, according to an algorithm presented later.

Before considering the two possible cases we will present the statistical model used for the frame difference, because the determination of the appropriate reference frame is based on this model. Let $D = \{d(x, y), (x, y) \in S\}$ denote the gray level difference image. The change detection problem consists of determining a "binary" label $\Theta(x, y)$ for each pixel on the image grid. We associate the random field $\Theta(x, y)$ with two possible events, $\Theta(x, y) = \text{static}$ (*unchanged pixel*), and $\Theta(x, y) = \text{mobile}$ (*changed pixel*). Let $p_{D|\text{static}}(d \mid \text{static})$ (resp., $p_{D|\text{mobile}}(d \mid \text{mobile})$) be the probability density function of the observed inter-frame difference under the H_0 (resp., H_1) hypothesis. These probability density functions are assumed to be zero-mean Laplacian for both hypotheses ($l = 0, 1$)

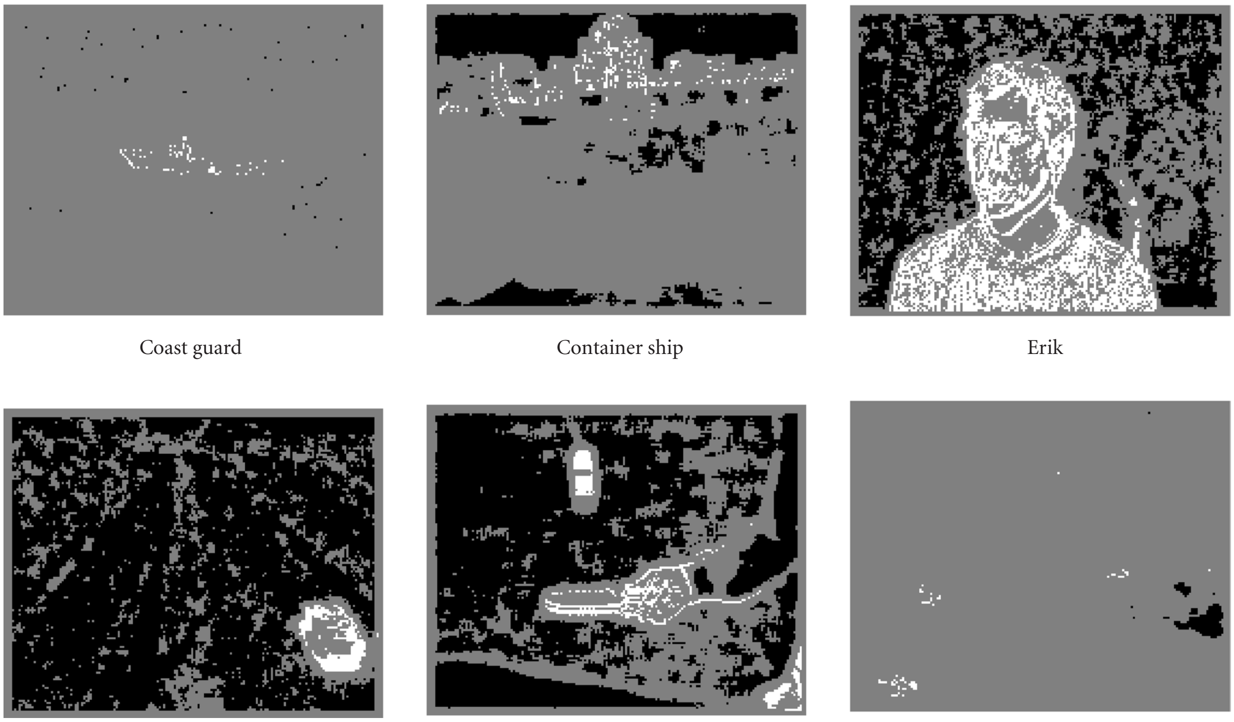
$$p\big(d(x, y) \mid \Theta(x, y) = l\big) = \frac{\lambda_l}{2} e^{-\lambda_l |d(x,y)|}. \qquad (1)$$

Let P_0 (resp., P_1) be the a priori probability of hypothesis H_0 (resp., H_1). Thus the probability density function is given by

$$p_D(d) = P_0 p_{D|0}(d \mid \text{static}) + P_1 p_{D|1}(d \mid \text{mobile}). \qquad (2)$$

In this mixture distribution $\{P_l, \lambda_l; l \in \{0, 1\}\}$ are unknown parameters. The principle of Maximum Likelihood is used to obtain an estimate of these parameters [20].

In the case of a still camera, the current frame must be compared to another frame sufficiently distinct, that is, a frame where the moving object is displaced to be clearly detectable. For that the mixture of Laplacian distributions (2) is first identified. The degree of discrimination of the two distributions is indicated by the ratio of the two corresponding



Coast guard | Container ship | Erik

Road surveillance | Tennis table | Urbicande

Figure 2: Initial labelled sets.

standard deviations, or, equivalently, by the ratio of the two estimated parameters λ_0 and λ_1. Indeed, the Bhattacharya distance between the two distributions is equal to $\ln(\lambda_0 + \lambda_1)/2\sqrt{\lambda_0\lambda_1}$. So we search for the closest frame which is sufficiently discriminated from the current one. Indeed, a value below the threshold means that the objects' movement is small, and therefore it is difficult to detect the object. The threshold (T_λ) on the ratio of standard deviations is supplied by the user, and thus is determined by the frame difference.

In the case of a moving camera the frame difference is determined by the displaced frame difference of successive frames. The camera movement must be computed for obtaining the displaced frame difference. We use a three-parameter model for describing the camera motion, composed of two translation parameters, (u, v), and a zoom parameter, ϵ. The estimation of the three parameters is based on a frame matching technique with a robust criterion of least median of absolute displaced differences

$$\min \operatorname{median}\left\{\left|I(x, y, t) - I(x - u - \epsilon x, y - v - \epsilon y, t - 1)\right|\right\}. \tag{3}$$

Only a fixed number of possible values for the set of motion parameters (u, v, ϵ) is considered. Assuming convexity, we perform a series of refinements on the parameter space, a three-dimensional "divide-and-conquer" which yields the desired minimum within an acceptable accuracy after only four steps. In our implementation this requires the computation of roughly one hundred values of the median of absolute differences. For reasons of computational complexity the median is determined using the histogram of the absolute displaced frame differences.

3. CHANGE DETECTION USING FAST MARCHING ALGORITHM

3.1. *Initial labelling*

The labelling algorithm requires some initial correctly labelled sets. For that we use statistical tests with high confidence for the initialisation of the label map. The percentage of points labelled by purely statistical tests depends on the ability to discriminate the two classes, which is related to the amount of relative object motion. For the *Coast Guard* sequence (Figure 2), where it is difficult to distinguish the little boat, less than one percent of pixels are initialized. The background is shown in black, the foreground in white and unlabelled points in gray. For the *Erik* sequence (Figure 2), for which the two probability density functions are shown in Figure 3, a large number of pixels are classified in the initialization stage.

The first test detects changed sites with high confidence. The false alarm probability is set to a small value, say P_F. The threshold for labelling a pixel as "changed" is

$$T_1 = \frac{1}{\lambda_0} \ln \frac{1}{P_F}. \tag{4}$$

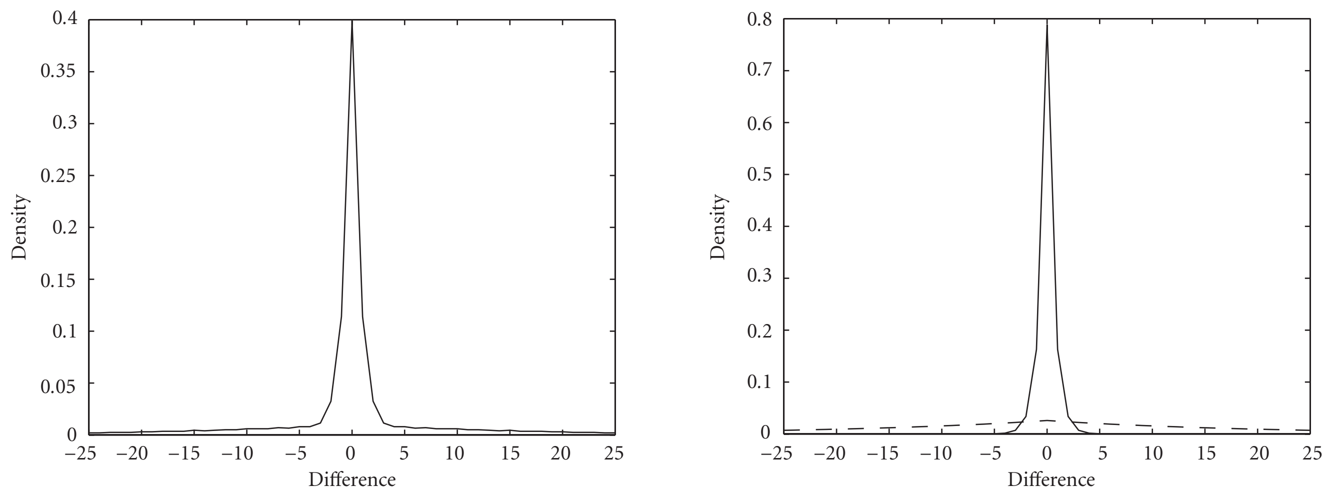


FIGURE 3: Mixture decomposition in Laplacian distributions for the inter-frame difference (*Erik* sequence).

TABLE 1

w	3	4	5	6	7
γ_w^1	1.6	3.6	7.0	12.0	20.0
γ_w^2	0.4	1.0	1.6	4.0	10.0

Subsequently, a series of tests is used for finding unchanged sites with high confidence, that is, with a small probability of non-detection. For these tests a series of six windows of dimension $(2w + 1)^2$, $w = 2, \dots, 7$, is considered and the corresponding thresholds are preset as a function of λ_1. We denote by B_w the set of pixels labelled as unchanged when testing the window indexed by w. We set them as follows:

$$B_w = \left\{ (x, y) : \sum_{k=-w}^{w} \sum_{l=-w}^{w} \left| d(x+k, y+l) \right| < \frac{\gamma_w}{\lambda_1} \right\}, \qquad (5)$$

for $w = 2, \dots, 7$. The probability of non-detection depends on the threshold γ_w, while λ_1 is inversely proportional to the dispersion of $d(x, y)$ under the "changed" hypothesis. As the evaluation of this probability is not straightforward, the numerical value of γ_w is empirically fixed. The parameter γ_2 is chosen such that at least one pixel is labelled as "changed." The other parameters ($w = 3, \dots, 7$) are such that $\gamma_w = \gamma_w^1 + \gamma_w^2 v_m$, where v_m is proportional to the amount of camera motion. In Table 1 we give the values used in our implementation.

Finally, the union of the above sets $\cup_{w=2}^{7} B_w$ determines the initial set of "unchanged" pixels.

3.2. Label propagation

A multi-label fast marching level set algorithm is then applied to all sets of points initially labelled. This algorithm is an extension of the well-known fast marching algorithm [17]. The contour of each region is propagated according to a motion field, which depends on the label and on the absolute inter-frame difference. The label-dependent propagation speed is set according to the a posteriori probability principle. As the same principle will be used later for other level set propagations and for their respective velocities, we shall present here the fundamental aspects of the definition of the propagation speed. The candidate label is ideally propagated with a speed in the interval $[0, 1]$, equal in magnitude to the a posteriori probability of the candidate label at the considered point. We define the propagation speed at a site (x, y), for a candidate label l and for a data vector d,

$$v_l(x, y) = \Pr \{ l(x, y) \mid d(x, y) \}. \qquad (6)$$

Then we can write

$$v_l(x, y) = \frac{p(d(x, y) \mid l(x, y)) \Pr \{ l(x, y) \}}{\sum_k p(d(x, y) \mid k(x, y)) \Pr \{ k(x, y) \}}. \qquad (7)$$

Therefore the propagation speed depends on the likelihood ratios and on the a priori probabilities. The likelihood ratios can be evaluated according to assumptions on the data, and the a priori probabilities could be estimated, either globally or locally, or assumed all equal.

In the case of a decision between the "changed" and the "unchanged" labels according to the assumption of Laplacian distributions, the likelihood ratios are exponential functions of the absolute value of the inter-frame difference. In a pixel-based framework the decision process is highly noisy. Moreover, the moving object might be non-rigid, its various components undergoing different movements. In regions of uniform intensity the frame difference could be small, while the object is moving. The memory of the "changed" area of the previous frames should be used in the definition of the local a priori probabilities used in the propagation process. According to (1) and (7) the two propagation velocities could be written as follows:

$$v_0(x,y)=\frac{1}{1+\left(Q_1(x,y;0)\lambda_1/Q_0(x,y;0)\lambda_0\right)e^{(\lambda_0-\lambda_1)|d(x,y)|}},$$
$$v_1(x,y)=\frac{1}{1+\left(Q_0(x,y;1)\lambda_0/Q_1(x,y;1)\lambda_1\right)e^{-(\lambda_0-\lambda_1)|d(x,y)|}}, \tag{8}$$

where the parameters λ_0 and λ_1 have been previously estimated. We distinguish the notation of the a priori probabilities defined here from those given in (2), because they should adapte to the conditions of propagation and to local situations. Indeed, the above velocity definition is extended in order to include the neighbourhood of the considered point

$$v_l(x,y)=\Pr\left\{l(x,y)\mid d(x,y),\hat{k}(x',y'),\ (x',y')\in\mathcal{N}(x,y)\right\}, \tag{9}$$

where the neighbourhood $\mathcal{N}(x,y)$ may depend on the label, and may be defined on the current frame as well as on previous frames. Therefore, in this case the ratio of a priori probabilities is adapted to the local context, as in a Markovian model. A more detailed presentation of the approach for defining and estimating these probabilities follows.

From the statistical analysis of the data's mixture distribution we have an estimation of the a priori probabilities of the two labels (P_0, P_1). This is an estimation and not a priori knowledge. However, the initially labelled points are not necessarily distributed according to the same probabilities, because the initial detection depends on the amount of motion, which could be spatially and temporally variant. We define a parameter β measuring the divergence of the two probability distributions as follows:

$$\beta=\left(\frac{\hat{P}_0P_1}{\hat{P}_1P_0}\right)^{\beta_0(\hat{P}_0+\hat{P}_1)}, \tag{10}$$

where $\hat{P}_0+\hat{P}_1+\hat{P}_u=1$, $\hat{P}_u$ being the percentage of unlabelled pixels. The parameter β_0 is fixed equal to 4 if the camera is not moving, and to 2 if the camera is moving. Then β will be the ratio of the a priori probabilities. In addition, for $v_1(x,y)$ the previous "change" map and local assignements are taken into account, and we define

$$\frac{Q_0(x,y;1)}{Q_1(x,y;1)}=\frac{e^{\theta_1-(\alpha(x,y)+n_1(x,y)-n_0(x,y))\zeta}}{\beta}, \tag{11}$$

where $\alpha(x,y) = \eta(x,y)-1$, with $\eta(x,y)$ the distance of the (interior) point from the border of the "changed" area on the previous pair of frames, and $n_1(x,y)$ (resp., $n_0(x,y)$) the number of pixels in neighbourhood already labelled as "changed" (resp., "unchanged"). The parameter ζ is adopted from the Markovian nature of the label process and it can be interpreted as a potential characterizing the labels of a pair of points. Finally, the exact propagation velocity for the "unchanged" label is

$$v_0(x,y)=\frac{1}{1+\beta(\lambda_1/\lambda_0)e^{\theta_0+(\lambda_0-\lambda_1)|d(x,y)|-n_\Delta(x,y)\zeta}} \tag{12}$$

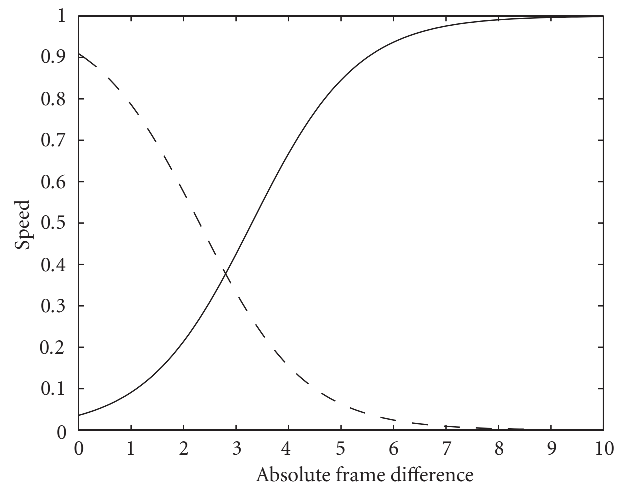


Figure 4: The propagation speeds of the two labels; solid line: "changed" label, dashed line: "unchanged" label.

and for the "changed" label

$$v_1(x,y)=\frac{1}{1+(1/\beta)(\lambda_0/\lambda_1)e^{\theta_1-(\lambda_0-\lambda_1)|d(x,y)|-(\alpha(x,y)-n_\Delta(x,y))\zeta}}, \tag{13}$$

where $n_\Delta(x,y) = n_0(x,y)-n_1(x,y)$. In the tested implementation the parameters are set as follows: $\theta_0 = 4\zeta$ and $\theta_1 = 5\zeta+4$. In Figure 4, the two speeds are mapped as functions of the absolute inter-frame difference for typical parameter values near the boundary.

We use the fast marching algorithm for advancing the contours towards the unlabelled space. Often in level set approaches constraints on the boundary points are introduced in order to obtain a smooth and regularised contour and so that an automatic stopping criterion for the evolution is available. Our approach differs in that the propagation speed depends on competitive region properties, which both stabilises the contour and provides automatic stopping for the advancing contours. Only the smoothness of the boundary is not guaranteed. Therefore, the dependence of the propagation speed on the pixel properties alone, and not on contour curvature measures, is not a strong disadvantage here. The main advantage is the computational efficiency of the fast marching algorithm.

The proposed algorithm is a variant of the fast marching algorithm which, while retaining the properties of the original, is able to cope with multiple classes (or labels). The execution time of the new algorithm is effectively made independent of the number of existing classes by handling all the propagations in parallel and dynamically limiting the range of action for each label to the continually shrinking set of pixels for which a final decision has not yet been reached. The propagation speed may also have a different definition for each class and the speed could take into account the statistical description of the considered class.

Hall monitor Mother and daughter Erik

FIGURE 5: Change detection results.

The high-level description of the algorithm is as follows:

```
InitTValueMap()
InitTrialLists()
while (ExistTrialPixels())
 {
  pxl = FindLeastTValue()
  MarkPixelAlive(pxl)
  UpdateLabelMap(pxl)
  AddNeighborsToTrialLists(pxl)
  UpdateNeighborTValues(pxl)
 }
```

The algorithm is supplied with a label map partially filled with decisions. A map with pointers to linked lists of trial pixel candidacies is also maintained. These lists are initially empty except for sites neighbouring initial decisions. For those sites a trial pixel candidacy is added to the corresponding list for each different label of neighbouring decisions and an initial arrival time is assigned. The arrival time for the initially labelled sites is set to zero, while for all others it is set to infinity. Apart from their participation in trial lists, all trial candidacies are maintained in a common priority queue, in order to facilitate the selection of the candidacy with the smallest arrival time.

While there are still unresolved trial candidacies, the trial candidacy with the smallest arrival time is selected and turned alive. If no other alive candidacy exists for this site, its label is copied to the final label map. For each neighbour of this site a trial candidacy of the same label is added, if it does not already possess one, to its corresponding trial list. Finally, all neighbouring trial pixels of the same label update their arrival times according to the stationary level set equation

$$\left\| \nabla T(x, y) \right\| = \frac{1}{v(x, y)}, \tag{14}$$

where $v(x, y)$ corresponds to the propagation speed at point (x, y) of the evolving front, while $T(x, y)$ is a map of crossing times.

While it may seem that for a given site trial pixels can exist for all different labels, in fact there can be at most four, since a trial candidacy is only introduced by a finalised decision of a neighbouring pixel. In practice, trial pixels of different labels coexist only in region boundaries; therefore, the average number of label candidacies per pixel is at most two. Even in the worst case, it is evident that the time and space complexity of the algorithm is independent of the number of different labels. Experiments indicate a running time no more than twice that of the single contour fast marching algorithm.

4. MOVING OBJECT LOCALIZATION USING REGION GROWING ALGORITHM

4.1. *Initialisation*

The change detection stage could be used for initialisation of the moving object tracker. The objective now is to localize the boundary of the moving object. The ideal change area is the union of sites which are occupied by the object in two successive time instants

$$C(t, t+1) = O(t) \cup O(t+1), \tag{15}$$

where $O(t)$ is the set of points belonging to the moving object at time t. We also consider the change area

$$C(t-1, t) = O(t) \cup O(t-1). \tag{16}$$

It can easily be shown that the intersection of two successive change maps $C(t-1, t) \cap C(t, t+1)$ is equal to

$$O(t) \cup \big(O(t+1) \cap O(t-1)\big). \tag{17}$$

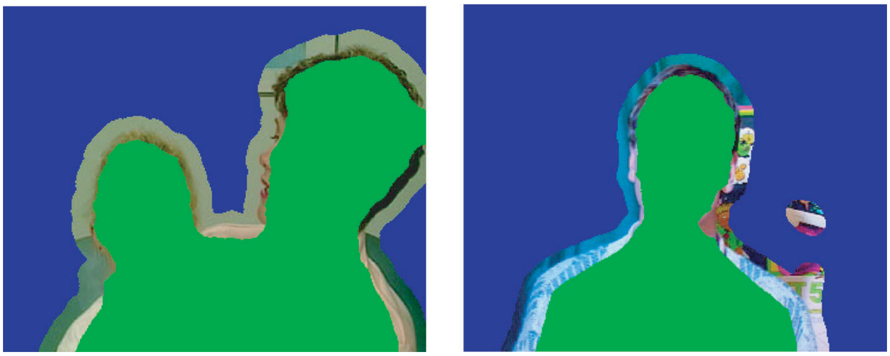
This means that the intersection of two successive change maps is a better initialisation for moving object localization than either one of them alone. In addition, sometimes

$$\big(O(t+1) \cap O(t-1)\big) \subset O(t). \tag{18}$$

If this is true, then

$$C(t, t+1) \cap C(t, t-1) = O(t). \tag{19}$$

Of course, the above described situation is an ideal one, and is a good approximation only in the case of a still camera. When the camera is moving, the camera motion is compensated, and the intersection is suitably adapted. Results of the change detection algorithm are shown in Figure 5.



Mother and daughter Erik

FIGURE 6: Results on the uncertainty area.

Knowing also that there are some errors in change detection and that sometimes, under certain assumptions, the intersection of the two change maps gives the object approximate location, we propose to initialize a region growing algorithm by this map, that is, the intersection of two successive change maps. This search will be performed in two stages: first, an area containing the object's boundary is extracted, and second, the boundary is detected. The description of these stages follows.

4.2. Extraction of the uncertainty area

The objective now is to determine the area that contains the object's boundary with extremely high confidence. Because of errors arising in the change detection stage, and also because of the fact that the initial boundary is, in principle, placed outside the object, as shown in the previous subsection, it is necessary to find an area large enough to contain the object's boundary. This task is simplified if some knowledge about the background is available. In the absence of knowledge concerning the background, the initial boundary could be relaxed in both directions, inside and outside, with a constant speed, which may be different for the two directions. Within this area then we search for the photometric boundary.

The objective is to place the inner border on the moving object and the outer border on the background. We emphasise here that *inner* means inside the object and *outer* means outside the object. Therefore, if an object contains holes the inner border corresponding to the hole includes the respective outer border, in which case the inner border is expanding and the outer border is shrinking. In any case, the object contour is expected to be situated between them at every point and under this assumption it will be possible to determine its location by the region-growing module described in Section 4.3. Therefore, the inner border should advance rapidly for points on the background and slowly for points on the object, whereas the opposite should be happen for the outer border.

For cases in which the background can be easily described, a level set approach extracts the zone of the object's boundary. Suppose that the image intensity of the background could be described by a Gaussian random variable with mean μ and variance σ^2. This model could be adapted to local measurements.

The propagation speeds will be also determined by the a posteriori probability principle. If, as assumed, the intensity on the background points is distributed according to the Gaussian distribution, the local average value of the intensity should also follow the Gaussian distribution with the same mean value and variance proportional to σ^2. The likelihood test on the validity of this hypothesis is based on the normalised difference between the average and the mean value

$$\frac{(\bar{I}-\mu)^2}{\sigma^2}, \tag{20}$$

where $\bar{I}$ is the average value of the intensity in a window of size 3×3 centered at the examined point. A low value means a good fit with the background. Therefore, the inner border should advance more rapidly for low values of the above statistics, while the outer border should be decelerated for the same values.

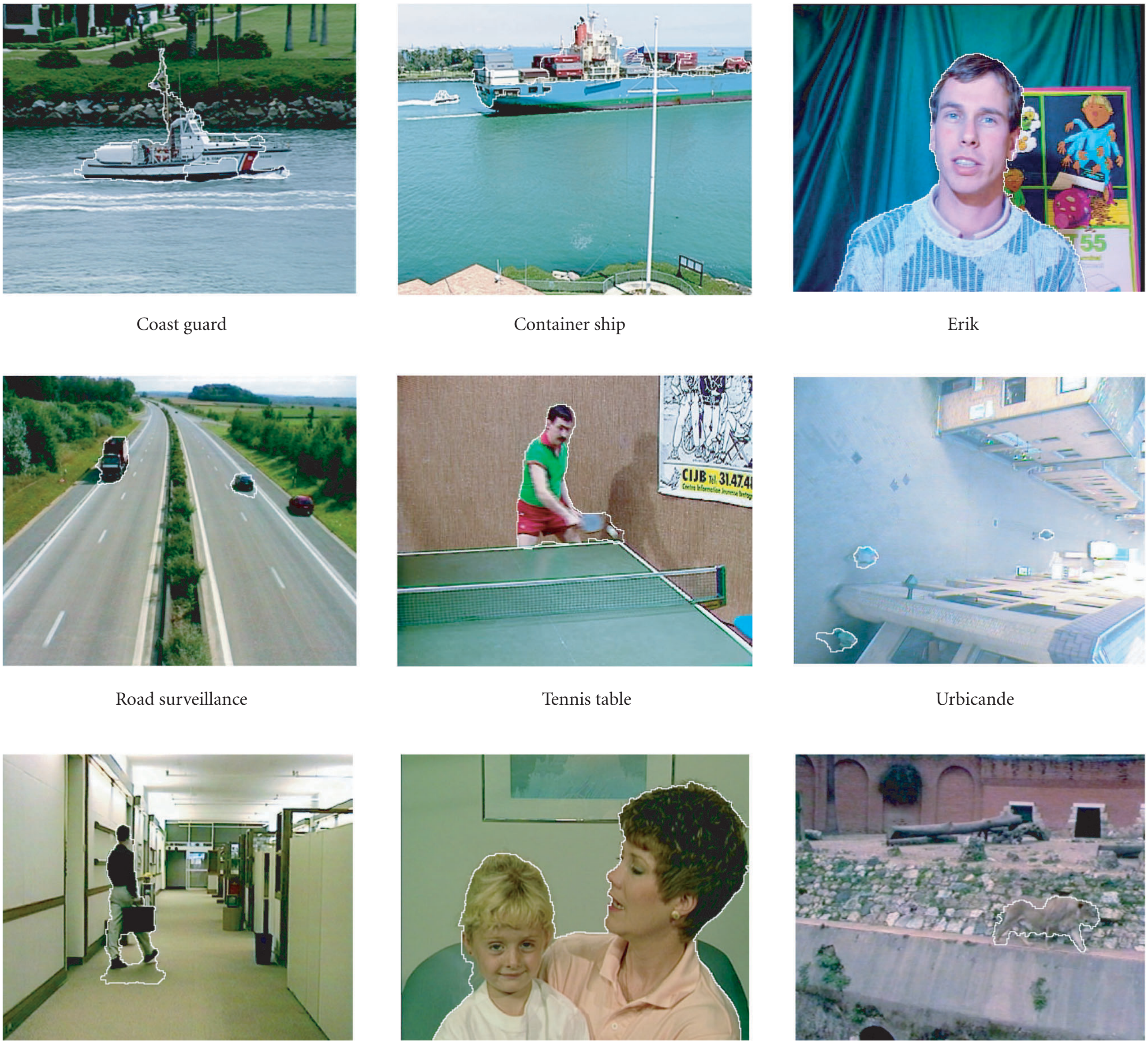
On the other hand, it is almost certain that the border resulting from the previous stages is located on the background. Thus the probability of being on the background is much higher than the probability of being on the object. For the outer border the speed is defined as

$$v_b = \frac{1}{1 + c_b e^{-4(\bar{I}-\mu)^2/\sigma^2}}, \tag{21}$$

where it is considered that the variance of $\bar{I}$ is equal to $\sigma^2/8$. According to (7) the constant c_b is

$$c_b = \frac{P_b}{P_o}\frac{\Delta}{\sigma\sqrt{2\pi}}, \tag{22}$$

where P_b and P_o are the a priori probabilities of being on the background or on the moving object, respectively. We have assumed that in the absence of knowledge the intensity of the object is uniformly distributed in an interval whose width is Δ (possibly equal to 255). As the initial contour is more likely located on the background, P_o is given a smaller value than P_b (typically $P_b/P_o = 3$). The outer border advances with the complementary speed



Coast guard — Container ship — Erik

Road surveillance — Tennis table — Urbicande

Hall monitor — Mother and daughter — Lion

FIGURE 7: Results of video object extraction.

$$v_o = 1 - v_b, \tag{23}$$

using the same local variance computation.

For cases in which the background is inhomogeneous, the uncertainty area is a fixed zone, where the two propagation velocities are constant. They may be different in order to achieve the objective of placing the inner border on the moving object and the outer border on the background. Result on the *Erik* and *Mother and daughter* sequences are shown in Figure 6.

The width of the uncertainty zone is determined by a threshold on the arrival times, which depends on the size of the detected objects and on the amount of motion and which provides the stopping criterion. At each point along the boundary, the distance from a corresponding "center" point of the object is determined using a heuristic technique for fast computation. The uncertainty zone is a fixed percentage of this radius modified in order to be adapted to the motion magnitude. However, motion is not estimated, and only a global motion indicator is extracted from the comparison of the consecutive changed areas. The motion indicator is equal to the ratio of the number of pixels with different labels on two consecutive "change" maps to the number of the detected object points.

4.3. *Region growing-based object localization*

The last stage of object segmentation is carried out by a Seeded Region Growing (SRG) algorithm which was initially proposed for static image segmentation using a homogeneity measure on the intensity function [21]. It is a sequential labelling technique, in which each step of the algorithm labels exactly one pixel, that with the lowest dissimilarity. In [22], the SRG algorithm was used for semi-automatic motion segmentation.

The segmentation result depends on the dissimilarity criterion, say $\delta(\cdot,\cdot)$. The colour features of both background and foreground are unknown in our case. In addition, local inhomogeneity is possible. For these reasons, we first determine the connected components already labelled, with two possible labels: background and foreground. On the boundary of all connected components we place representative points, for which we compute the locally average colour vector in the *Lab* system. The dissimilarity of the candidate point from the already labelled regions during region growing process is determined using this feature as well as the Euclidean distance. After every pixel labelling, the corresponding feature is updated. Therefore, we search for sequential spatial segmentation based on colour homogeneity, knowing that both background and foreground objects may be globally inhomogeneous, but presenting local colour similarities sufficient for their discrimination.

For the implementation of the SRG algorithm, a list that keeps its members (pixels) ordered according to the dissimilarity criterion is used, traditionally referred to as Sequentially Sorted List (SSL). With this data structure available, the complete SRG algorithm is as follows:

- S1 Label the points of the initial sets.
- S2 Insert all neighbours of the initial sets into the SSL.
- S3 Compute the average local colour vector for a predetermined subset of the boundary points of the initial sets.
- S4 While the SSL is not empty:
  - S4.1 Remove the first point y from the SSL and label it.
  - S4.2 Update the colour features of the representative to which the point y was associated.
  - S4.3 Test the neighbours of y and update the SSL:
    - S4.3.1 Add neighbours of y which are neither already labelled nor already in the SSL, according to their value of $\delta(\cdot,\cdot)$.
    - S4.3.2 Test for neighbours which are already in the SSL and now border on an additional set because of y's classification. These are flagged as boundary points. Furthermore, if their $\delta(\cdot,\cdot)$ is reduced, they are promoted accordingly in the SSL.

When SRG is completed, every pixel is assigned one of the two possible labels: foreground or background.

5. RESULTS AND CONCLUSION

We applied the above described algorithm to the entire COST data set. The results are given in our web page http://www.csd.uoc.gr/tziritas/cost.html

We obtained results ranging from good to very good, depending on the image sequence. Some segmented frames are shown in Figure 7. For comparison the spatial quality measures [23] on the *Erik* (resp., *Hall Monitor*) sequence for the COST AM algorithm [14] and that of our algorithm are shown together in Figure 8 (resp., Figure 9). Our algorithm gives results of quality either similar to or better than the COST AM algorithm. The COST AM results, the reference segmented sequences, and the evaluation tool are taken from the web site http://www.tele.ucl.ac.be/EXCHANGE/

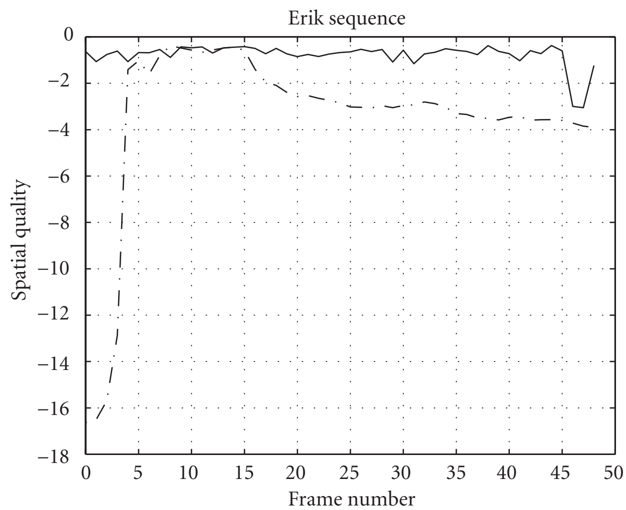


Figure 8: Comparison based on the spatial quality measure for the *Erik* sequence.

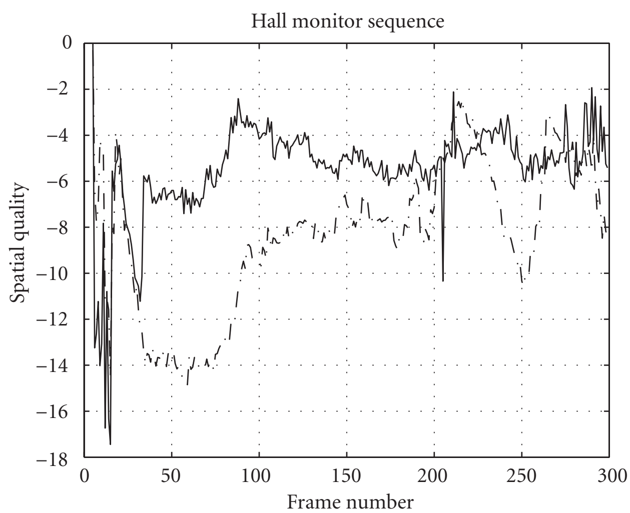


Figure 9: Comparison based on the spatial quality measure for the *Hall monitor* sequence.

For the algorithm proposed the image sequence classification was always correct. The parametric motion model was estimated with sufficient accuracy. The independent motion detection was confident in the case of camera motion. The mixture of Laplacians was accurately estimated, and the initialization of the label map was correct, except for some problems caused by shadows, reflexions, and homogeneous intensity on the moving objects. The fast marching algorithm was very efficient and performant. The last stage of moving object localization can be further improved. The modelization of local colour and texture content could be possible, leading to a more adaptive region growing, or eventually a pixel labelling procedure.

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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

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EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

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

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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

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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

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EURASIP JOURNAL ON APPLIED SIGNAL PROCESSING

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

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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

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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

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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.

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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

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Institute of Acoustics

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.

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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.