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Motion estimation and compensation from noisy image sequences: A new filtering scheme

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Abstract

Motion estimation and compensation are proposed to be used as a filtering scheme. This latter is perceived in the motion compensation stage, when noisy frames are predicted from a clean one in the same sequence. The prediction source frame can be obtained simply by filtering spatially one selected frame in the sequence. The filtering efficiency is under-constrained by the accuracy of the motion vector field estimated between the prediction source and the other noisy frames. A study has been conducted on the motion estimation from noisy image sequences showing the conditions under which the motion vector field accuracy is preserved. Simulation results have shown that a total decrease by about 80% in computation time is achieved compared to the classical motion-compensated filtering.

Keywords: Image sequence; Motion compensation; Motion estimation

1. Introduction

During the last few years, applications utilizing digital video such as multimedia services, teleconferencing, surveillance, object tracking, medical and astronomical imaging, etc., are growing spectacularly. In conjunction with this increased use of digital video, the demand for noise filtering algorithms is also on the rise. The sources of noise that can corrupt an image sequence are numerous. Examples of the more prevalent ones include, the noise introduced by the camera, shot noise that originates in the electronic hardware and the thermal or channel noise [1]. Most noise sources are well modelled by additive white gaussian noise model.

Noise filters for video, which make use of both spatial and time correlations among pixel intensities, are in general called *spatiotemporal* or three-dimensional (3-D) filters. A special class of spatiotemporal filters is that of *temporal* filters where one-dimensional (1-D) filtering techniques in the temporal direction are applied. Approaches that attempt at taking full advantage of the time redundancy incorporate motion detection and compensation [2]. The main distinction between the two is that in the motion-compensated approach the effect of interframe motion is explicitly estimated, whereas in the motion-detection approach the effect of interframe is implicitly accounted for in the design of the filter. In motion-compensated filtering, first a motion estimation algorithm is applied to the noisy image sequence in a first stage to estimate the motion trajectories. The filtering is then performed along the motion trajectory using either FIR filter [3,4] or an IIR filter [5,6]. A systematic overview of 3-D and 1-D motion-compensated and non-motion-compensated filters is given in [1].

In this paper, we propose a novel filtering approach, which is somewhat different from all the existing ones. The basic idea is that noise can be reduced from a noisy frame in a sequence only by performing motion estimation and compensation; that is the approach originality. It is well known that by performing efficient motion estimation between two adjacent frames, one could be predicted (motion-compensated) from the other using the motion vector field estimated between the both. If the frame source is not noisy or less affected by noise, the predicted frame is

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filtered. This filtering scheme is under-constrained by the accuracy of the motion vector field and the quality of the frame source of prediction. Hence, this paper is principally directed toward the study of the motion estimation and compensation process between frames in a noisy context.

The experiments conducted have shown that our filtering scheme so viewed outperforms the classical filtering approach in terms of computation complexity load for a comparable visual quality. This was expected because motion compensation (MC) so viewed performs at once a filtering contrarily to any motion-compensated filter. This alleviates greatly the computation load.

The paper is organised as follows: in Section 2, we first present briefly the block matching motion estimation algorithm and give some background information on the temporal frame prediction using motion compensation. Next, we present in-depth analyses and observations on the motion compensation procedure in a noisy context where we derive our filtering scheme. The experimental evaluation is given in Section 3. Section 4 summarizes the results of the paper and gives a conclusion.

2. Motion estimation and compensation: a new filtering scheme

Estimating motion from two or more consecutive image frames has become an important problem in image sequence processing and for which there are a variety of applications. There are a large number of techniques treating the problem of motion estimation in the literature [7–10]. One popular technique is the Block Matching Algorithm (BMA) [9,10]. In BMA, motion vectors between two frames are estimated by subdividing one frame into blocks of size $T \times T$ and by assuming that all pixels within each nonoverlapping block have the same displacement vector. For each block, the displacement vector is evaluated by searching through a larger block (search window) centred at the same location on the previous frame, for a spatial location, which minimises a matching criterion. One mostly used matching criterion, especially in image sequence analysis framework, is the *Mean Squared Difference* (*MSD*) [10] defined as follows:

$$MSD(d_x, d_y) = \frac{1}{T \times T} \sum_{i=1}^{T} \sum_{j=1}^{T} (f_k(i,j) - f_{k-1}(i + d_x, j + d_y))^2 \quad (1)$$

where $f_k(i,j)$ is the intensity of the pixel of location (i,j) situated in the kth frame in the sequence and $f_{k-1}(i + d_x, j + d_y)$ is the intensity of the pixel of location (i,j) situated in the previous frame shifted by d_x lines and d_y columns. In this measure, the smallest $MSD(d_x, d_y)$ within the search area $-x \leqslant d_x \leqslant x$ and $-y \leqslant d_y \leqslant y$ represents the best match where, x and y are, respectively, the horizontal and the vertical directions of the search. The absolute minimum for the matching criterion can be guaranteed only by performing an exhaustive search (*the Full Search method FS*) [10] of a series of discrete candidate displacements within the search area.

Once the motion field of the image sequence is estimated, motion compensation can be performed as a temporal prediction scheme where a current image frame f_k is estimated $(\hat{f}_k)$ from its previous f_{k-1} in the sequence as follows:

$$\hat{f}_k(i,j) = f_{k-1}(i + d_x, j + d_y) \quad (2)$$

where d_x and d_y represent the motion vector components between frames k and $k - 1$.

Let us consider now that the frames f_k and f_{k-1} are noisy and that f_{k-1} is less contaminated than f_k. In this condition the reconstructed frame $\hat{f}_k$ will be of same level of contamination as f_{k-1}. One can say that a filtering process has been done to the frame f_k. It is clear that the realization of this filtering scheme needs a good quality prediction source and an accurate motion vector field. This latter depends strongly on the noise affecting the sequence and its statistic properties. Hence, in the first part of the study presented in this paper, indepth analyses and discussions are being made on the motion estimation and compensation process from a noisy image sequence. Particularly, two cases are envisaged: (1) the noise is present only in the current frame in the sequence whereas its previous one is not affected; (2) both frames are contaminated by noise. The former case seems to be not real but it is of great interest. Indeed, we will demonstrate next that in case we could get one clean frame in the sequence, even at the price of some 2-D filtering tasks, the whole sequence could be filtered by motion compensation. After exploring the possibilities of getting filtering from motion compensation, we will investigate more (in Section 3) the performance and the limits of the new filtering approach by an experimental evaluation.

2.1. Analyses and observations

2.1.1. Only the current frame is affected by noise whereas its previous one is not

Let us consider the following degradation model:

$$g_k(i,j) = f_k(i,j) + n_k(i,j) \quad (3)$$

where $g_k(i,j)$ is the current noisy frame intensity at spatial location (i,j), $f_k(i,j)$ is its original version and $n_k(i,j)$ denotes the additive white gaussian noise term. Let f_{k-1} be the previous frame in the sequence that is not affected by noise.

According to the motion compensation scheme in (2), the current noisy frame can be reconstructed using its previous neighbour frame and the motion vector field estimated between the both as follows:

$$\hat{g}_k(i,j) = f_{k-1}(i + d_x, j + d_y) \quad (4)$$

where d_x, d_y are the motion vector field components of frames g_k and f_{k-1}.