BAYESIAN ESTIMATION OF DISCONTINUOUS MOTION IN IMAGES USING SIMULATED ANNEALING

Janusz Konrad† *and Eric Dubois*

INRS-Télécommunications
3 Place du Commerce, Verdun
Québec, Canada, H3E 1H6

Abstract

In this paper we study the Bayesian estimation of motion in image sequences based on stochastic relaxation algorithms. Unlike previous work, where motion smoothness over the complete image was assumed, here we reformulate the Bayesian approach by allowing motion discontinuities. The motion-image relationship is based on the widely used assumption of constant image intensity along motion trajectories. For the image acquisition process we use white Gaussian noise and we conclude that the displaced pel differences can be modeled by independent Gaussian random variables. The displacement field is modeled by a 2D vector Markov random field such that it encourages smooth motion but allows occasional discontinuities at motion boundaries. These discontinuities, called *line elements*, are modeled by a coupled 2D Markov random field favouring absence of line elements, slightly penalizing straight lines and corners, and severely penalizing line ends, intersections and double lines. The maximum *a posteriori* probability estimation criterion is derived from the above models. The optimization problem involves several thousands of unknowns, and is solved by simulated annealing based on the Gibbs sampler. Results of the estimation algorithm applied to television sequences with natural motion are presented. The motion fields obtained by application of the above model are compared with the fields estimated using the model disregarding discontinuities.

1. INTRODUCTION

Estimation of motion (optical flow) in 2D time-varying images has been proved, like many other early vision tasks, to be an ill-posed problem [1]. Since usually the unknown motion field is related to the observed image sequence through a *structural model*, such as the assumption of constant image intensity along motion trajectories, there are infinitely many motion fields consistent with the observed images. In order to resolve this ambiguity and find a unique solution, various *regularization* methods have been proposed. These methods impose constraints, such as smoothness of the motion field, in the form of a stabilizing functional. Motion estimation techniques developed by Horn and Schunck [2], Hildreth [3], and Nagel [4] are examples of regularization.

A different approach to solving this non-uniqueness problem is through Bayesian estimation. Such a Bayesian formulation has been developed by Konrad and Dubois for 2D motion estimation at single resolution level [5] and also via a hierarchical approach [6]. They used the maximum *a posteriori* probability (MAP) estimation criterion, which resulted in minimization of a certain cost functional. This cost functional had the same form as in the regularization approach, and in fact regularization methods can be considered as special cases of Bayesian estimation, with particular choice of the random field model for the motion.

If the cost functional derived from the *structural model* and the displacement field model is quadratic with respect to the motion vectors, the necessary conditions for optimality can be easily established, resulting in a large system of linear equations. Such a system is usually solved using either deterministic relaxation methods (Gauss-Seidel, Jacobi) [2], [4] or the Chebyshev method [7]. There is no guarantee, however, that the global optimum will be attained. For this reason, *stochastic relaxation* algorithms, such as the Metropolis algorithm [8] or Gibbs sampler [9], have been proposed. Incorporated into *simulated annealing* [10], these methods provide convergence (under certain conditions) to the global minimum, and have been used to solve various ill-posed problems e.g., image reconstruction [9], [11], segmentation of moving planar surfaces [12], stereo matching [11], [13].

In this paper we extend the stochastic approach to motion estimation by incorporating motion discontinuities into the model. As in [5] we use a 2D vector Markov random field to model a displacement field, but we also introduce a coupled Markov random field called a *line process* (proposed in [9] to model intensity discontinuities for image restoration) to model motion discontinuities. These two models result in a piecewise-smooth description of motion with occasional discontinuities at the motion boundaries, which is expected to improve estimates in the occlusion areas. We derive the cost functional for MAP estimation of motion fields based on the above models, and minimize it using inhomogeneous simulated annealing implemented via the Gibbs sampler. We present some results of this algorithm applied to television sequences with natural motion, and compare them with motion fields obtained from the model disregarding discontinuities.

This work was supported by the Natural Sciences and Engineering Research Council of Canada under Strategic Grant G-1357

† Also with McGill University, Montreal, on leave from the Technical University of Szczecin, Poland