# Bayesian Real-time Optical Flow

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## Abstract

*Optical flow can be used to compute motion detection, time to collision, structure, focus of expansion as well as object segmentation. Unfortunately, most optical flow techniques do not provide accurate and dense measures that are useful for these types of computations. In addition, most techniques are also slow computationally. Albeit, one method proposed by Camus is able to perform optical flow computations in real-time capitalizing on redundancies in the computation and spatial-temporal sampling trade-offs. It is a simple technique based on simulating various motions and computing the SD (sum-difference) of patches. Its problem is that the produced field is not accurate and arbitrary in aperture and blank wall situations. We show that the simulating of various futures can be used as the factored samples that produce the likelihood probabilities that can be used in a particle filtering framework. Maximization/minimization or computing the expectations of the likelihood at a particular location does not necessarily produce the proper flow. We suggest that likelihoods are well behaved when their variance is small and these can be propagated firstly to address aperture problems and secondly to address the extended blank wall problem. We show this propagation with thresholded likelihood values and speculate on how the likelihood distributions can be integrated into an algorithm that has its basis in particle filtering.*

## 1 Introduction

Optical flow is what results from the recovery of the 2-D motion field (i.e., the projection of the 3D velocity profile onto a 2-D plane; or the resulting apparent motion in an image). Most optical flow techniques assume that uniform illumination is present and that all surfaces are Lambertian. Obviously this does not necessarily hold in the real-world, but we assume that these conditions do hold locally. Optical flow describes the direction and speed of feature motion in the 2D image as a result of relative motion between the viewer and the scene. If the camera is fixed, the motion can be attributed to the moving objects in the scene. Optical flow also encodes useful information about scene structure: e.g., distant objects have much slower apparent motion than close objects. The apparent motion of objects on the image plane provides strong cues for interpreting structure and 3-D motion. Some creatures in nature such as birds are chiefly reliant on motion cues for understanding the world.

Optical flow may be used to compute motion detection, time-to-collision, focus of expansion as well as object segmentation; however, most optical flow techniques do not produce an accurate flow map necessary for these calculations [1]. Most motion techniques make the assumption that image irrandiance remains constant during the motion process. The optical flow equation relates temporal ($I_t$) changes in image intensity ($I(x,y,t)$) to the velocity (i.e., disparity) ($(u,v)$).

$$I_x u + I_y v + I_t = 0 \tag{1}$$

This equation is not well posed and many approaches [2] use a smoothness constraint to render the problem well-posed.

$$E^2(x,y) = (I_x u + I_y v + I_t)^2 + \lambda({u_x}^2 + {u_y}^2 + {v_x}^2 + {v_y}^2) \tag{2}$$

Motion field computations are similar to stereo disparity measures albeit for the spatial differences being smaller between temporal images (because of a high sampling rate) and the 3-D displacement between the camera and the scene not necessarily being caused by a single 3D rigid transformation.

Motion recovery techniques have been classified [3] into *intensity-based differential methods*, *frequency-based filtering methods* and *correlation-based methods*. In addition, most of the approaches have usually three steps of processing [3]: (1) *prefiltering* (low or band pass) to enhance signal-to-noise; (2) *measurement extraction* such as spatiotemporal derivatives or local correlation surfaces; and (3) *measurement integration* by regularization, correlation or a least-squares computation. Derivatives can be difficult to compute, especially temporal derivatives where values into the future are not available. Other problems that have been discussed in survey papers [3] include: (1) the validity of equating optical flow with image motion; (2) the problem