Intrinsic Filtering of Range Images Using a Physically Based Noise Model

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Abstract

This paper presents a new multi-scales range data filtering technique which produces a scale-space filtering analogous to Gaussian filtering but has several interesting properties such as viewpoint invariance and automatic edge preservation. One of the main contribution of this paper is that it takes into account a physical model of the sensor to ensure optimum filtering of the signal. Using this filter, new algorithms can be developed to detect at multi-scale depth and orientation discontinuities or segment robustly range data based on the sign of Gaussian and mean curvatures.

1 Introduction

More often than not, the computer vision community has processed range images with techniques developed in the context of intensity images, in spite of the fact that range data and images are a sampled set of measurements corresponding to a 3–D surface, observed from a particular viewpoint. In that sense, they are fundamentally different from intensity images. Haralick et al. [13] and later Besl and Jain [4, 5] were among the first to consider range images as true geometric information, using differential geometry to compute intrinsic properties of surfaces such as the Gaussian and mean curvatures.

To properly detect geometric features in range images one must be able to represent them at various scales in order to compute variation of surface properties of increasing globality. In the past, several authors have proposed different methods to solve this problem. One of these methods consists of convolving the image signal with Gaussian kernels of increasing size (scale) and then analyzing the evolution of signal features along the scale dimension. These stack of images as a function of increasing inner scale was coined as a linear "Scale Space" by Witkin [Witkin 1983] and Koenderink [Koenderink 1984]

Instead of using a few discrete scales, Witkin [31] has proposed the use of a continuum of scales and has studied the properties of this scale space for 1-D signals. In the case of more complex signals, the discretization of the formulation led to nontrivial heuristics to establish the correspondence between scales.

Koenderink [15] realized that the generating equation of linear scale-space can be expressed by a linear diffusion equation:

$$\frac{\partial L}{\partial s} = \vec{\nabla} \cdot \vec{\nabla} L = \triangle L = L_{xx} + L_{yy} \qquad (1)$$

for the 2–D case. This equation states that the derivative to scale s equals the divergence of the gradient of the luminance function L, which is the Lapacian, the sum of the second derivatives. The blurring is considered as a diffusion of the intensity over time where time is the scale parameter. The standard Gaussian kernel is the Green's function of the diffusion equation. The derivation of the diffusion equation for scale-space by many other researchers among which we mention:

- Analysis of Causality [15]: coarser scales can only be the causal result of what happened in the finer scales;
- Maximum principle [14]: any increase of the inner scale the maximum luminance of the coarser scale