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VISIONTRAIN

Stefan Karlsson

Illuminance Flow

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Phd advisor: **Jan Koenderink, Sylvia Pont** (j.j.koenderink@phys.uu.nl, s.c.pont@phys.uu.nl)
Host institution: Utrecht University(partner 10), Netherlands

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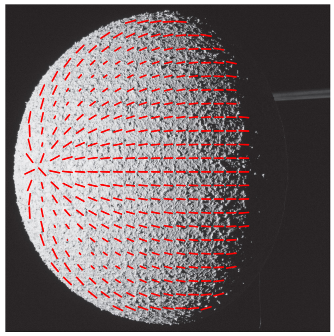

Figure 1: Example illustration of Illuminance Flow. The **local orientation of the illumination** are the individual red lines, considered independently. The **illuminance flow** is the set of all lines, over the smooth surface of an object. There is structure in such a set, in the sense that they form a flow field in the image plane.

1 Introduction: The Phd topic

Patches of roughly uniform 3D texture reveal the local orientation of the illumination(azimuthal angle of the incident beam), which can be used to map the global structure of the so called illuminance flow. The concept of illuminance flow is defined as the set of local illumination orientations that form a flow field in the image of a smooth surface, with constant light field, as illustrated by figure 1. Illuminance flow is a robust indicator of the light field and an important entity for many subsequent inferences from the image such as shape from shading and (3D) texture segmentation. Furthermore, psychophysical experiments (done by Jan Koenderink, Sylvia Pont and Astrid Kappers before the beginning of this ph.d. project [3]) found that human observers are able to estimate the local illumination orientation from 3D texture. The results of these experiments were in many regards similar to estimates on the basis of our computer vision algorithm[4](the basis of the project work), using the squared gradient or Hessian.

This project extends above mentioned studies. The main interest is to investigate the possibility of estimating the illuminance flow over 3D solid rough objects, with systematical variations of the shape, surface roughness and light field, and to use it for concrete vision problems, such as shape/lightfield inference.

2 Brief review of the state of the art

The light field in which objects are situated is important in machine vision. Often slight changes in illumination produce large changes in an object's appearance, especially with regard to finer scale 3D corrugations across the object's surface (so-called 3D or surface texture).

A great deal of work has been done regarding methods for handling image variation due to translation, rotation and scale [9], [7], [2]. Only in the last decade or so has the subject of lighting variation been given serious attention within the machine vision field [5], [6]. The focus has been mainly on arriving at a set of lighting invariant features. The traditional approach has been to vary the light field and gather statistics that are insensitive to light change (often resulting in edges and corners in the albedo map).

Interesting work is being done by modeling the imaging process and deriving object-specific subsets of image space, so-called illuminance cones[5], by which robust lighting-insensitive matching can be carried out (not invariant, since the model does not account for *e.g.* cast shadows).

For recent advances into the topic of illuminance flow and the physics/optics based approach, we refer to [4], [8] and [10]. These are discussed in section 3.

3 Approach and methodology

We are much interested in a related problem to that of invariant object features: from the image of the object and its surroundings, what can be said about the light field? This could be used, for instance, in shape from shading, light invariant texture segmentation or as part of an object recognition algorithm, if assumptions about the light field could be incorporated.

When the light field has a dominant directional component (collimated beams being the extreme case) anisotropy will be imposed in the image of the surface. In some cases this can be used to estimate the illuminance flow. It has been shown[4] that using the structure tensor of either the Hessian or the gradient yields good estimates. However, formally, this only applies under a set of assumptions, namely:

- Isotropic surface
- Lambertian reflectance
- Uniform albedo
- Low relief
- Normal view
- Light field of dominant directional component (*e.g.* collimated beams)

Experimental results have been presented for real world surfaces[4]; the structure tensors yielded promising results, with orientation estimates within a few degrees of the veridical orientation. The illumination elevation was not estimated due to the bas-relief ambiguity [1].

All the assumptions listed above are important in their own right. Some work has been done on extending the theory to account for non-normal views [8] and non-uniform albedo [10].

4 Scientific achievements

The first set of our publications will focus on the isotropy assumption (i.e. to handle more general anisotropic surfaces) and normal viewing (viewing objects surface patches will in general NOT be normal, as evident from figure 1 (on the sphere, only the point in the middle of the image is viewed normally, the rest obliquely) , which, as far as we know, has not been given any attention so far. We have successfully devised a theory that predicts the output for anisotropic surfaces. Both the gradient and Hessian based tensors will yield deviations from the true orientation of the illuminance flow. The theory presented in our first paper (see section 7) predicts these deviations, which are shown to conform well to experiments on rendered surfaces.

As part of the research exchange with VISIONTRAIN partner INRIA (Grenoble, France. Supervisors R. Horaud and E. Prados) the Ph.D student has spent 3 months (January-March 2007) where the theory has been adapted also to non-normal (oblique) viewing, work in progress that is currently being tested. We hope to publish these results at the earliest possible opportunity.

Interesting sidetracks have been explored by the Ph. D student, that include:

- A wavelet approach. Combining complex valued filter banks with simple non-linear operations can be used to approximate the suggested algorithm of the first publication. This constitutes an equivalent algorithm, with improvements to time complexity, and possible benefits in terms of biological motivation of the operations (the algorithm might plausibly be mapped to early stages of the human visual system).

- A theoretical handling of 'glossiness/bumpiness perception' of 3D textures. As lambertian surfaces are made of higher relief (more bumpy), they are perceived as more glossy. Similarly, as they are made more glossy, they are perceived as more bumpy. This might indicate a physical ambiguity from single view images, where bumpiness is indistinguishable from certain transforms of the reflectance property(while still remaining uniform, i.e. the surface geometry may vary, but the surface reflectance is perceived as being not spatially varying).

5 Results

The Ph.D student has developed a rendering environment using Matlab and OpenGL, in which the relevant parameters can be varied. Experimental data, has been successfully gathered using this software, and was used in the first publication. Implementation and development of all relevant algorithms have been performed. The first paper has been written and now under revision, and the contents of the second paper has been worked out, and the relevant software development is underway for generating experimental data.

6 Future work

We plan on extending the research into shape from shading. The surface texture of the objects viewed are assumed not to be part of the 'Geometry', but instead provide cues to the global shape. The estimates of illuminance flow will greatly deteriorate as the surface patch is viewed very obliquely. This happens mostly close to the object contours in the image plane. If the object has been segmented from background, then the information of the contour can be included in both the shape recovery of the object, as well as in a regularization scheme for the illuminance flow. We envision an algorithm that combines bottom-up (the current work into local estimates of illumination orientation) with top-down (where such information as the contour position can be incorporated).

Interesting sidetracks that the Ph.D student would like to follow up on are applications to texture segmentation/classification.

7 List of publications

S. Karlsson, S.C. Pont and J.J. Koenderink, "Illuminance Flow over Anisotropic Surfaces", under review at *Journal of Optical Society A*, 2007

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