# 52. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

**PROCCEDINGS** | **10 - 13 September 2007**

## FACULTY OF COMPUTER SCIENCE AND AUTOMATION

# COMPUTER SCIENCE MEETS AUTOMATION

## VOLUME II

Session 6 - Environmental Systems: Management and Optimisation

Session 7 - New Methods and Technologies for Medicine and Biology

Session 8 - Embedded System Design and Application

Session 9 - Image Processing, Image Analysis and Computer Vision

Session 10 - Mobile Communications

Session 11 - Education in Computer Science and Automation

TECHNISCHE UNIVERSITÄT ILMENAU

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## Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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**R. Blaschek / B. Meffert**

# Feature Point Matching for Stereo Image Processing using Nonlinear Filters

**ABSTRACT**

*For evaluating stereo image pairs of two cameras the calculation of the so-called fundamental matrix is an appropriate method. The matching algorithm requires a large number of proper reference points. If the cameras have an almost parallel alignment, typically very simple and fast correlation algorithms (e.g., sum of absolute differences) estimate the similarity between feature point candidates. But in practice such algorithms will fail because the alignment of the cameras is often less restrictive.*
*This article describes a method that uses nonlinear filters, derived from Gabor wavelet filter sets, to extract information about the texture of the reference points. These filters can help to overcome usual matching problems caused by intensity differences or rotation and scaling of surrounding gray values of the reference point candidates.*

## NONLINEAR FILTERS

Corner detectors, like Harris corner detector or SUSAN, provide a sufficient large number of points of interest. For each point a spectral signature can be calculated using filter sets of modified Gabor wavelets. The modifications are based on an adaptation that satisfies the wavelet theory and the neurophysiological constraints for so-called *simple cells* in the visual cortex [1]:

$$\psi\left(x,y,\omega_0,\theta,\kappa\right) = \frac{\omega_0}{\sqrt{2\pi}\kappa} e^{-\frac{\omega_0^2}{8\kappa^2}\left(4(x\cos\theta+y\sin\theta)^2+(-x\sin\theta+y\cos\theta)^2\right)} \cdot \left[e^{i(\omega_0 x\cos\theta+\omega_0 y\sin\theta)} - e^{-\frac{\kappa^2}{2}}\right] \quad . \tag{1}$$

The modifications of the Gabor wavelets adjust the elliptical Gaussian that envelopes the complex plane wave such that each of the wavelets has the same number of extremal values. Scale and direction of the wavelet can be chosen by $\omega_0$ and $\theta$, whereas $\kappa$ allows to specify the bandwidth of the filter ($\kappa = \pi$ corresponds to one octave). Since $\psi$ provides a complex-valued 2D Gabor function one can obtain an even-symmetric

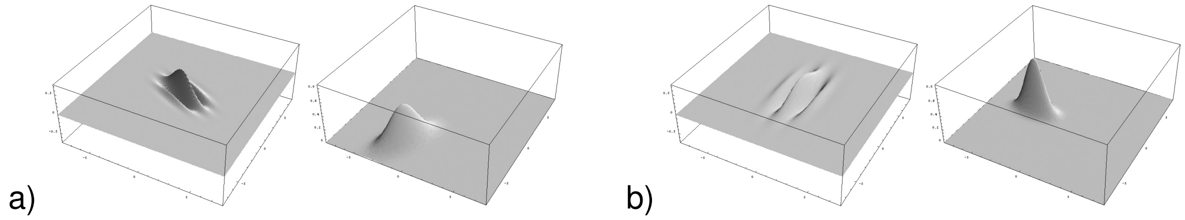


Figure 1: Real part of two Gabor wavelets for orientation angles a) $\theta = 65°$ and b) $\theta = 0°$ and the corresponding power spectra.

cosine and an odd-symmetric sine component by splitting the function into its real and imaginary part. Figure 1 shows an even-symmetric wavelet for two orientations.

The spectral signature for the reference points is calculated by applying an ensemble of Gabor wavelets on these points and their surrounding gray values. Typically the filter set consists of eight to sixteen orientations at four to six scales. Each filter mask is convolved with the actual image in the surrounding window of the reference points, i.e. 16×16 pixel, and the result is accumulated. This leads to a signature with an approximation of the signal energy for certain scale and direction.

Because of the high computational complexity of the convolution operation, this way of calculating the spectral signature is quite ineffective for large numbers of reference points. Heintz and Schäfer [3] calculate the filtering in the frequency domain. To do this the Gabor wavelets have to be converted by Fourier transform (Figure 2):

$$\begin{aligned}\Psi\left(\omega,\phi,\omega_0,\theta,\kappa\right) &= -\sqrt{\frac{2}{\pi}}\frac{\kappa}{\omega_0}e^{-\frac{\kappa^2\left((\omega_0+\omega\cos\theta+\phi\sin\theta)^2+4(\phi\cos\theta-\omega\sin\theta)^2\right)}{2\omega_0^2}} \\ &\cdot\left[-1+e^{\frac{\kappa^2(\omega\cos\theta+\phi\sin\theta)}{\omega_0}}\right] \quad . \qquad (2)\end{aligned}$$

Now the windows around the reference points have to be transformed too, but the computational expense is noticeable lower, because there are fast algorithms available for the Fourier transform. Because the signatures require just an approximation of the

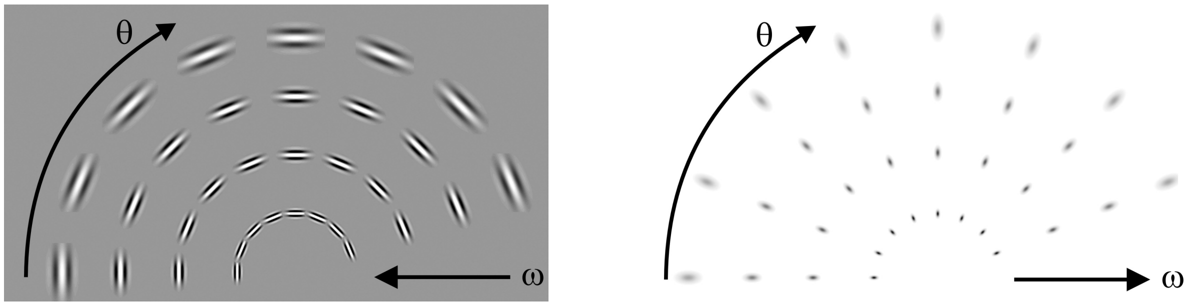


Figure 2: Ensemble of Gabor wavelets and Gabor filters to create a signature with eight orientations in four scales.

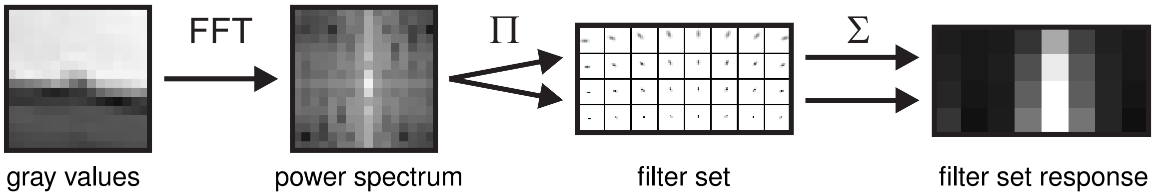


Figure 3: Processing chain for calculating the spectral signature of a reference point.

signal energy, the complex-valued result of the Fourier transform can be substituted by the real-valued power spectrum. Since $\Psi$ provides a small Gaussian in the scale space, most parts of these Gabor filters will be zero and thus the multiplication and accumulation with the power spectra of the reference points is reduced to just a few elements (Figure 3).

## DESCRIPTORS FOR MATCHING

To accomplish the stereo matching successfully, the matching algorithms need meaningful descriptors that characterise the reference point candidates. The spectral signature described above is such a descriptor:

- It is invariant to changes in scene lighting because the constant component of the Fourier spectrum is never used by the Gabor filter.
- It provides the ability to a rotation invariant comparison because circular shifting the signature along the $\theta$-axis is equivalent to rotating the pattern in the image.
- It provides the ability to a scale invariant comparison because shifting the signature along the $\omega$-axis is equivalent to scaling the pattern in the image.

First tests with the signatures have shown, that small windows around the reference points – which are typically 16 or 32 pixel wide – interfere with the theoretical rotation invariance. The closer the angular steps $\Delta\theta$ the less structure is in the signature. This is not surprising, because a 16$\times$16-spectrum has only 137 different spectral coefficients. Using an angular step of e.g. $\Delta\theta = 10^\circ$ leads to an unwanted oversampling at which some coefficients are used up to 7 times. This is a displeasing property, because little changes in the image as well as noise will be fairly distributed over the signature. One can decide to use larger angular steps, but this is contrary to the ability to compare stereo image pairs with small camera rotations.

Another problem arises from the Fourier transform itself. Because of the discrete transformation and the small window size, there is (nearly always) a noticeable strong concentration of the spectrum along the both axis. Regarding the rotation invariance this part of the signal doesn't behave like expected – it is stationary, but still signal

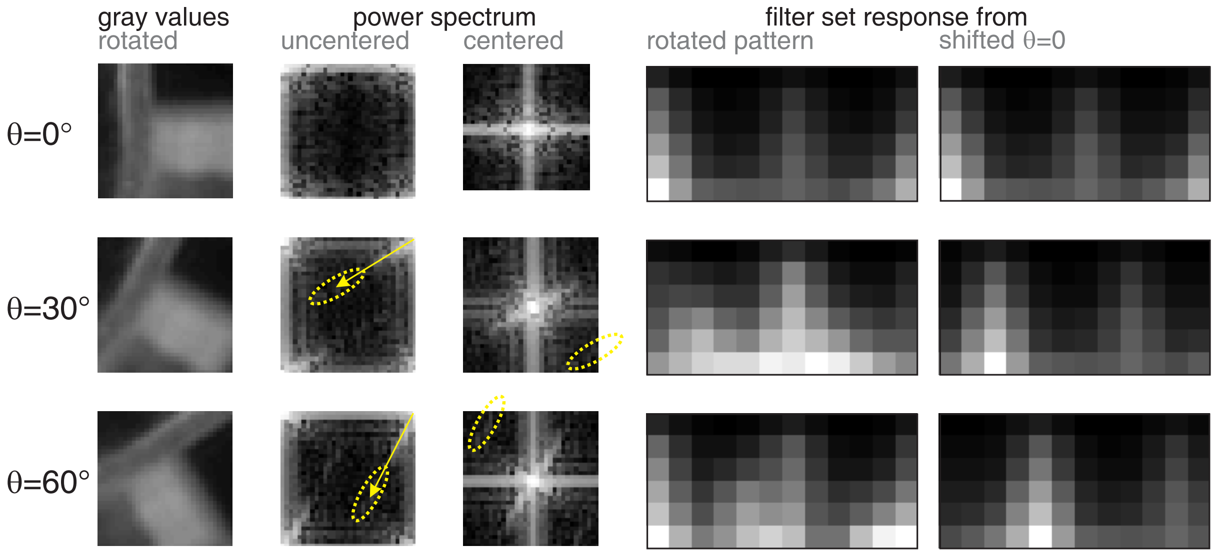


Figure 4: Rotation artifacts on high frequencies and dominant axis for three angles $\theta$.

dependent. In addition Figure 4 shows some artifacts in the Fourier spectrum caused by high frequencies in the gray values.

To overcome this problem we have found, that alignment of the windows before the Fourier transform leads to a more stable matching result. According to the approach used in SIFT (Scale Invariant Feature Transform) by Lowe [2], the orientation of each reference point is calculated from the gradient. Subsequently, each window is rotated by its orientation angle – which also simplifies the comparison because the signature can be assumed to be aligned. Furthermore, the image should be processed by a low-pass filter to avoid the superposition of signals in different quadrants. Gabor filters on the diagonals of the spectrum (at 45° or 135°) may prevail the other filters because they accumulate more coefficients. Therefore all spectral coefficients that are outside the radius of the half window length are set to zero.

Using dense reference point sets makes it very difficult to distinguish between similar looking points. Often the signatures of those points have the same mixture of scales and directions. That is why the descriptors need another extension that not only detects the scales and orientations, but also contains some information about their distribution. In our approach we decided to partition the window around the reference point into four sub-windows, each with the half length of the original window. In doing so the main signature is calculated from a 32×32 window and the 16×16 sub-windows are used to calculate four sub-signatures. Figure 5 shows the chosen layout for the placement.

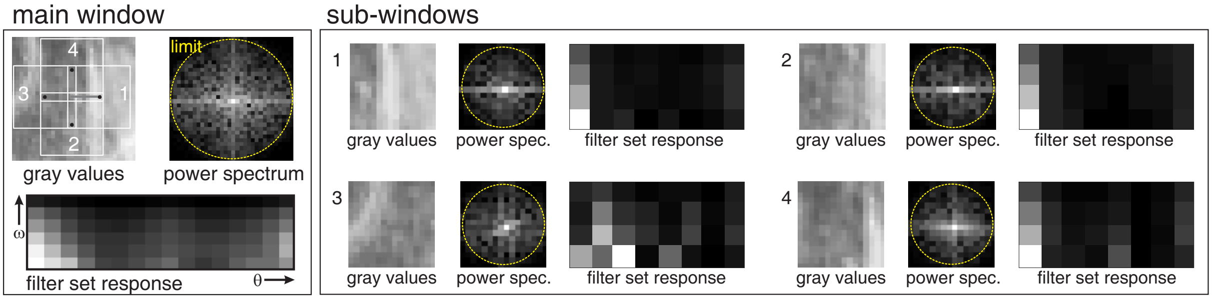


Figure 5: Placement of the four sub-windows and results of the Gabor filtering on the limited spectra.

## RESULTS AND CONCLUSIONS

In this paper we propose a new descriptor for characterising reference points for stereo matching. This descriptor uses nonlinear Gabor filters to extract illumination and rotation invariant features from the Fourier spectrum. Tests with different image pairs have shown, that the descriptors are well suited for the following classes of images:

- random pattern surface with low depth – Figure 6, top (*pothole*)
- TV-lens scene of poor images with noticeable lens distortion and differences in exposure – Figure 6, center (*office room*)
- well structured surface with large depth levels – Figure 6, bottom (*amphora*).

The reference points are taken from a corner detector. For the right images the number of points and their density is three times higher then for the left images to rise the chance that the corresponding points are within these point sets. The extracted descriptors are compared and the candidate with the minimal distance is chosen iff there is no other candidate with a distance smaller than 1.5 times the minimal distance.

Even though the descriptor works very well for 'unscaled' images, it should be further improved to profit from the ability of the Gabor filters to a scale invariant comparison.

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[2] D. G. Lowe: *Distinctive Image Features from Scale-Invariant Keypoints.* University of British Columbia Vancouver, Computer Science Department, International Journal of Computer Vision, 60, 2, pp. 91-110, 2004.

[3] R. Heintz und G. Schäfer: *Lokale invariante Objektlokalisierung mittels Gaborfiltern.* FH Karlsruhe, GMA-Kongress, VDI-Bericht 1883, S. 441-448, 2005.

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| image pair | size | used points (l/r) | matches |
|---|---|---|---|
| *pothole* | 848×1280 | 1500 / 4500 | 1285 (85.6%) |
| *office room* | 288×352 | 627 / 808 | 285 (45.4%) |
| *amphora* | 640×480 | 1500 / 4500 | 669 (44.6%) |

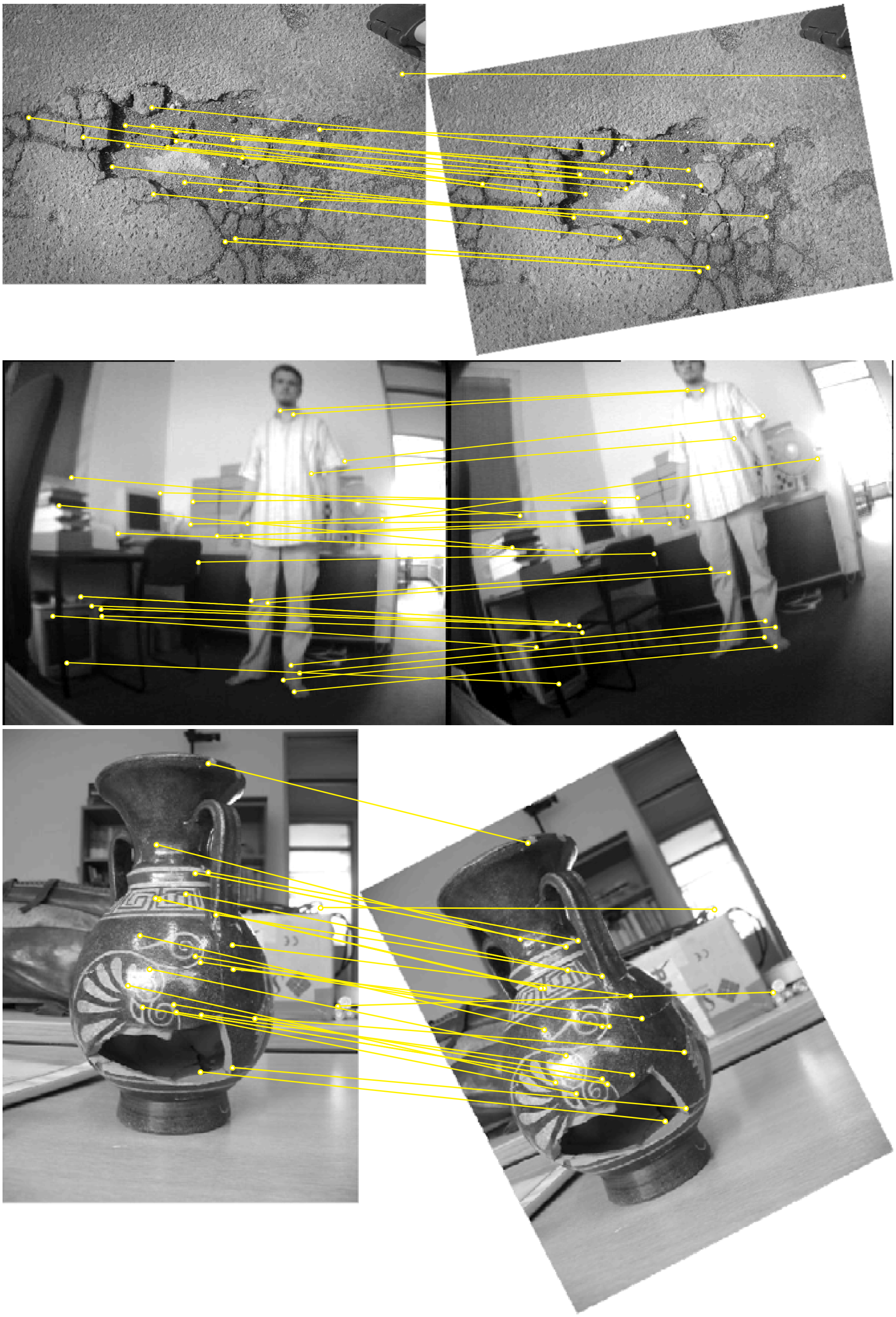

Figure 6: Sample image pairs for three different scene classes with randomly chosen matches and some details of the image pairs.