The department MODELS AND ALGORITHMS IN IMAGE PROCESSING is primarily working on the following subjects:

- surface inspection
- signal analysis for railway systems
- analysis of 3d microstructures
- analysis of image and video sequences
- cryptology

Our main focus is the development of complex algorithms for image and signal processing, and their implementation into efficient software within complete systems.

The successful year of 2003 was characterized by balance in every domain. We have a wide range of experience in the field of surface inspection – especially with respect to the development of algorithms and systems for the monitoring, examination, and evaluation of textured surfaces (e.g., paper, textiles, nonwovens, wood, fiber plates, and coatings). Also in 2003, especially tailored inspection systems for industrial application were integrated into the production processes of several customers.

The development of autonomous railway monitoring systems, which has been the subject of our research for many years now, also was continued in 2003 without interruption.

The field of 3d image analysis is increasingly gaining importance because the technical possibilities for a three-dimensional high-resolution representation of different materials are developing very fast. Our research is focused on the determination of geometric features of material microstructures. On this basis, 3d models of these materials are developed which reflect the geometric structures very well. These new possibilities of material analysis are also increasingly realized by industry, which can be documented by a growing number of customer inquiries. Besides, the commercial software a4i3d for the analysis of three-dimensional images has been successfully developed and introduced on the market in cooperation with the company aquinto. A library with a similar range of functions for Linux systems is also available.

In the main subject Analysis of Image and Video Sequences, the development of a complex search system for data bases or video sequences, based on image similarities respectively image features, was continued in cooperation with our partners.

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One of the main competences of the department MODELS AND ALGORITHMS IN IMAGE PROCESSING is the surface inspection for industrial quality control.

In contrast to manual quality control, which is still applied very often but either only allows for the examination of random samples or cannot be carried out during the production process, the methods of the Fraunhofer ITWM allow for an online defect detection and classification, so that early intervention in the production process become possible, e.g., in the case of serial defects. Automatic optical surface inspection does not impair the production. Besides, the resulting objectivity guarantees a constant quality of the inspected parts.

The manual control mentioned above is carried out by especially trained personnel. These have enormous visual auditors skills and are specialized on their current task. The automatic surface inspection systems developed at the Fraunhofer ITWM are working in a similar way, i.e., they are adapted to the particular requirements of the customer and the local conditions.

Applications range from paper and textile industry and metal and leather processing industry to the suppliers of automobile industry. In order to meet the requirements of such a large number of possible applications, we have developed a modular system (MASC - Modular Algorithms for Surface Control) comprising a large number of tools and system components ready for use. The components are organized according to a modular structure, thus offering an appropriate basis for fast and flexible solutions for almost every individual task concerning surface inspection.

In the following, several of the applied methods and solutions based thereupon will be presented in detail by means of two current projects.
OPAQ: inspection of unpainted free formed surface parts

During the processing of free-surface parts, surface defects are unavoidable, many of them already resulting from the reshaping process of the parts. In order to reduce post-processing after the painting or anodic oxidation processes and to guarantee a constant quality level, it is necessary to detect and eliminate surface defects as soon as possible. The objective of the joint research project OPAQ, which is funded by the BMBF, is the detection of such defects during the first processing step of the raw material (e.g., during the molding or deep-drawing process).

One of the practical applications, in cooperation with our partner Seidel GmbH in Marburg, is the detection of surface defects in the case of strongly reflective caps for perfume bottles and lipsticks. Very small defects of the surface geometry (bumps, scratches) and surface structure (polishing defects, rough zones) must be detected online during the production process. For example, microscopically small scratches in the raw parts with a depth of only 0.02 mm, due to the high degree of reflection, result in surface defects after the anodic oxidation treatment which can be recognized very clearly, thus leading to customer complaints.

The company Steinbichler Optotechnik GmbH in Neubeuern and the Fraunhofer ITWM have cooperated in the development of new image acquisition and processing methods for the detection of such small defects on reflective surfaces. In order to render the complete lateral surface by one image, a projection system via a conic mirror has been developed. The variety of defect types and their appearance has lead to the development of two measuring systems: in the case of surface deformations, a method of image acquisition by a stripe pattern (stripe image), whereas variations of the surface structure are detected by dark-field illumination (dark-field image) has been selected.

There are two methods for the evaluation of the stripe patterns: the first one is a more or less classical variant, where the variations in the stripe pattern are determined by the formation of gradients. The second variant refers to a 2.5d image computed on the basis of the stripe image. First, on the basis of the image information, the deviation with respect to a defect-free surface is estimated by a linear filter. Defect areas, such as dents or bumps – in contrast to noise –, correspond to relatively large values of this deviation image. In a second step, so-called defect candidates are determined by smoothing and adaptive threshold values. The focus of the dark-field image is the determination of local variances by covariance computation. The relevant defects are computed by an adaptive threshold value.

At the moment, the demonstration system is evaluated by practical tests. The objective of the research project is the development of a (semi-)automatic system with manual feeding which meets practical requirements.
At the company MSC/GAC in Eisenach, up to now the surface quality control of compressor gaskets took place in the following way: a first, very rough control was carried out directly after the punching process. The punched parts were stapled and stored, in order to pass through an individual manual hundred-per-cent-control afterwards. This last step took place considerably later.

The considered gaskets are rubber-laminated metal parts of different geometries which can show different surface defects, such as bubbles, contaminants, or dents and scratches resulting from the punching process. Traces of paint or adhesive may also occur.

The task of the Fraunhofer ITWM consists in developing an inspection system which is integrated into the production process, thus reducing the inspection time considerably. The automatic defect detection reaches a degree of objectivity which is almost impossible in the case of manual control. Besides, the fast detection of serial defects becomes possible, which otherwise can lead to a large number of rejections during production.

The method consists of several steps, always observing the top and bottom side of each gasket. Due to the partly very complex shape of the gaskets, which also show holes and bulges, the method works with samples of the same shape serving as reference for a go-workpiece. After the image acquisition of the inspected part, the relevant image section must be found. In the next step, the image of the gasket to be examined is adjusted to the reference image with respect to displacement as well as rotation, in order to allow for a comparison with the reference parts. In such a way, boundaries and structures are to be recognized as far as possible, so that they are not accounted for during defect detection. Different methods are required for different types of defects (mainly with respect to their size) in order to bring them out in the best possible way and to allow for comparisons with the reference part. When the comparison is completed, the relevant positions are marked; a graphic representation is also possible here. The examined gaskets are sorted with respect to go- and no-go-workpieces, and detected defects are classified. Finally, type and frequency of the occurring defects are documented statistically.

If the respective reference parts are available, a fast and automatic teaching of new types of gaskets with similar surfaces is also possible.

Scratch, bubble, and dent as defect examples (The gaskets are represented at a scale of approximately 1:2.)
The ITWM develops and maintains the software for the chassis monitoring sleeper (FÜS) for the company GE Transportation Systems in Bad Dürkheim. The software is running in more than 400 systems throughout Europe.

The monitoring of overheated axle bearings and stationary brakes on passenger and freight trains requires a remote measurement method. In the solution selected here, the temperatures are measured by registering the infrared profile of the passing chassis, and the resulting data are transferred to a PC. It may also happen that not only the data for a wheel are registered, but also foreign radiation data, e.g., caused by the sun or the brake blocks. These cases are dealt with by special methods, in order to determine wheel or bearing temperatures correctly. The system works without human control, which is why an appropriate self diagnosis system for the hardware and software is also integrated, as well as an exception and error handling system. The results of evaluation and self diagnosis are transferred to a central system which, e.g., arranges for a stop of the train at the next station.

The measurement data also provide information about the type of chassis and brakes, in order to allow for a correct detection of the different type-dependent temperature profiles, thus avoiding false alarms.

The registration hardware and data transfer from the sleeper to the evaluating computer have been modernized thoroughly for the new generation of the chassis monitoring sleeper. The evaluating computer consists of an industrial PC with special additional components and is running under Linux. Apart from the evaluation software, additional software packages have been developed, such as self diagnosis software, drivers, user interfaces, and server software. Measurement data and protocols are saved centrally on an archive server, representing the basis for the refinement of evaluation algorithms.

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Concerning the examination of materials, three-dimensional images of their microstructures are acquired more and more frequently. Usual methods are micro-computer tomography on the basis of X-rays or synchrotron radiation, confocal laser-scanning microscopy, or AFM (atomic force microscopy). In contrast to classical microscopic methods, these methods yield the entire information about the 3d microstructure, which cannot be reconstructed on the basis of 2d images, or only with considerable effort. Moreover, these methods are also able to capture the microstructure of very soft, fragile, or highly porous materials, for which conventional microscopic methods fail because the preparation of planar sections or microsections is impossible.

There are fully developed tools for the visualization of 3d image data sets which usually also include image processing components. In comparison, the methods for the analysis of 3d images of complex microstructures have not yet been developed very far up to now. At the Fraunhofer ITWM, we have provided the mathematical foundations of the 3d image analysis and implemented the respective algorithms. This year, a complete software system (a4i3d for Windows) and a software library (a4iL for Linux) for 3d image analysis have been made available. Both are based on the analysis methods developed at the ITWM.

The combination of stochastic geometry, three-dimensional statistics, and image analysis not only allows for the application-specific analysis of very different 3d structures, but also for the creation and fitting of geometric models for the numerical simulation of macroscopic material properties.

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a4i 3d, which has been developed in cooperation with the company aquinto AG, Berlin, is a system for 3d image processing and analysis, driven by a user-friendly menu and including a visualization tool supporting the analysis. Its modules allow for the analysis of, e.g., open foams by simply pressing a button. A high modularity guarantees the solution of various industrial and research problems. a4i 3d is sold as a complete system for Windows by aquinto.

a4iL is a pure C-library with the same functionality for image processing and analysis under Linux. Besides, a4iL also offers the processing and analysis of two-dimensional images, as well as the modeling of selected structures. a4iL has been created on the basis of the development environment used at the ITWM and is structured in the form of a tool box. Therefore, the adaptation to customer requirements (e.g., loading of a desired image format), the combination with individual software, and the solution of customer-specific problems are possible very quickly. a4i 3d and a4iL are based on analysis algorithms, which are completed by algorithms for image (pre-)processing and segmentation: filter and morphological transforms, distance and watershed transform, skeletonization, Fourier transform.

Geometric parameters of components and particles

a4i 3d and a4iL are specialized on the characterization of the complex geometry of microstructures. The core of the analysis is the determination of basic geometric parameters – of entire components of the structure, if we have to deal with a section of a macroscopically homogeneous material, or individual particles or cells, if these can be identified. Characteristic properties, such as porosity, specific surface, density of the Euler number, mean chord length, fractal dimension, mean fiber length per volume unit (for fiber materials), number of particles (in the case of isolated particles), or information about preferred directions and strength of occurring anisotropies, can be determined fast and robustly. The algorithms combine methods of integral and stochastic geometry with digital image processing methods. They are primarily based on discrete versions of classical results of integral geometry, such as the Crofton formulas. The addition of simple model assumptions also yields the mean cell size (for open or closed foams).

Three-dimensional objects (particles) can be isolated exactly and quickly with an algorithm developed at the ITWM. Object features (volume, surface, curvature, diameter, shape, orientation …) are also determined by methods of integral geometry.

a4i 3d and a4iL also offer spectral analysis as a further analysis tool. Research at the Fraunhofer ITWM with respect to the spectral analysis of random sets has provided the mathematical foundation for the applied methods.

Example System a4i 3d and library a4iL for the analysis and processing of three-dimensional image data

a4iL: graphic user interface (currently being developed) – visualization of refractory concrete by 2d cross-sections in three directions of space

a4i 3d: application example – analysis and 3d visualization of an open foam
Apart from the development of algorithms and their mathematical basis, the ITWM also offers the service of the analysis of microstructures. Depending on the material, the ITWM is cooperating with different partners with respect to image acquisition (Fraunhofer IZFP, RJL Micro & Analytic GmbH, Alfred Wegener Institute for Polar and Marine Research). Examined materials include metal and polymer foams, ceramic materials, concrete, fiber nonwovens for vacuum-cleaner bags, and snow.

Analysis of open foams

If individual objects are to be measured, they must first be separated by object isolation or watershed transform. However, a more complex method is required for the determination of pore size distributions, because the pores or cells must be reconstructed by image analysis. Smoothing, a subsequent distance transform, reduction of the distance transform, a further smoothing step, and finally the watershed transform yield a system of pores whose borders represent the edges of the original image. Size and shape, for example, can then be measured on the basis of these pores.

Examples
Modeling of sintered structures

In the framework of the SINTERDICT part of the Fraunhofer-internal MAVO project “Development of Comprehensive Multiscale Material Modeling (MMM tools)” (see also page 40), the department MODELS AND ALGORITHMS IN IMAGE PROCESSING develops models for the microstructure geometry of diverse sintered materials at different states of the sintering process. The selected models must be very flexible, because even identical materials show completely different geometric structures under different conditions. Dense packing is a good model for the initial state of the sintering process. In the final state, the sintered particles fill the space completely, i.e. they form tessellations, which is why Voronoi tessellations and generalized Voronoi tessellations (Laguerre and Johnson-Mehl) are suitable for the description of the final state. In order to give the user also access to arbitrary intermediate states, it is desirable that intermediate states should be developed continuously on the basis of the initial state by a kind of growth process. Models are fitted using the information about the sintered particles which have been used and by simple geometric parameters, such as porosity. Other characteristics, such as the pair correlation function of the centers or the chord length distribution, serve for the model validation.

As initial state, we use a packing of 200 spheres with a discrete radius distribution in a cube of a side length of 600 pixels. During the growth process, the spheres are expanding (1), touching each other (2), and finally forming a Laguerre tessellation which fills up the entire cube (3).
Analysis of Image and Video Sequences

I-Search: development of a contents-based image search engine on distributed systems

The aim of this project supported by the BMBF is the development of algorithms and of a parallel software architecture as a basis for a high-performance contents-based video and image search engine.

The subject of security, which is strongly in discussion at the moment, for example involves the task of searching for a lost piece of luggage at an airport monitored by intelligent web cameras, or of detecting and identifying a person of conspicuous behavior. The solution requires robust and event-controlled video analysis and face recognition methods on distributed systems which are able to provide online results for the security personnel. In the fields of broadcasting and internet, the main problems are the fast finding of scenes in media archives or the contents-based search for images.

In cooperation with partners from industry and research, methods of fast online image processing on distributed systems are combined with high-performance algorithms and, depending on the requirements, connected to the respective database and internet technologies. The ITWM develops a component-oriented parallel software architecture which can be operated on a failure-proof system of SMP(PC) clusters and computing grids, as well as on highly distributed systems of small high-performance computers, as they are occasionally offered in the web cameras.

The application of the I-Search cluster requires the system to meet high standards of performance and reliability, which is why load distribution and fault tolerance mechanisms are necessary within the architecture. These have partly been designed and implemented during the framework of a master’s thesis. The integration of these strategies enables cluster nodes to detect failures of their own components and also of other nodes, and to initiate the respective fault recovery mechanisms.

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In order to guarantee the protection of information from unauthorized access in a time relying on electronic data transfer, a continuous development and refinement of cryptologic methods is necessary. The application of asymmetric methods is essentially important for achieving the objective of secure communication.

The most well-known asymmetric cryptosystem is RSA. Its security is based on the fact that the factorization of a large integer number is generally considered to be difficult. The current factorization record is held at 158 decimal digits for the composite number. Today, even 512-bit RSA keys cannot guarantee security any longer. It is therefore important that alternatives are available, which, however, mostly have not yet been able to compete with RSA with respect to run time and security.

Elliptic curves have proved to be a good basis for cryptosystems which can seriously compete with RSA. Their security is based on the problem of computing discrete logarithms in the group of rational points on an elliptic curve. Generally, this is already difficult for relatively small parameters, which is why these systems guarantee high security also for small keys. Therefore, they are used particularly in the case of Smart Cards and comparable environments. Hyperelliptic curves are generalizations of elliptic curves. Their advantage is a larger selection of appropriate parameters and the resulting higher security.

Within a project in cooperation with the company BGS Systemplanung AG, the Fraunhofer ITWM has developed algorithms for the determination of subfields and the explicit computation in the ring of endomorphisms of hyperelliptic function fields. These algorithms allow for a test with respect to possible weaknesses of the selected parameters and provide information about the structure of the Jacobian. Essential parts of the research results were presented during the conference “Efficient Methods in Algebraic Geometry” (MEGA) 2003.

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