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Organisations

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Publications:

**Computing segmentations directly from x-ray projection data via parametric deformable curves: Paper**
We describe an efficient algorithm that computes a segmented reconstruction directly from x-ray projection data. Our algorithm uses a parametric curve to define the segmentation. Unlike similar approaches which are based on level-sets, our method avoids a pixel or voxel grid; hence the number of unknowns is reduced to the set of points that define the curve, and attenuation coefficients of the segments. Our current implementation uses a simple closed curve and is capable of separating one object from the background. However, our basic algorithm can be applied to an arbitrary topology and multiple objects corresponding to different attenuation coefficients in the reconstruction. Through systematic tests we demonstrate a high robustness to the noise, and an excellent performance under a small number of projections.

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Scopus rating (2014): SJR 0.657 SNIP 1.319 CiteScore 1.58
Three Dimensional Polarimetric Neutron Tomography of Magnetic Fields

Through the use of Time-of-Flight Three Dimensional Polarimetric Neutron Tomography (ToF 3DPNT) we have for the first time successfully demonstrated a technique capable of measuring and reconstructing three dimensional magnetic field strengths and directions unobtrusively and non-destructively with the potential to probe the interior of bulk samples which is not amenable otherwise. Using a pioneering polarimetric set-up for ToF neutron instrumentation in combination with a newly developed tailored reconstruction algorithm, the magnetic field generated by a current carrying solenoid has been measured and reconstructed, thereby providing the proof-of-principle of a technique able to reveal hitherto unobtainable information on the magnetic fields in the bulk of materials and devices, due to a high degree of penetration into many materials, including metals, and the sensitivity of neutron polarisation to magnetic fields. The technique puts the potential of the ToF time structure of pulsed neutron sources to full use in order to optimise the recorded information quality and
A method to characterize the roughness of 2-D line features: recrystallization boundaries

A method is presented, which allows quantification of the roughness of nonplanar boundaries of objects for which the neutral plane is not known. The method provides quantitative descriptions of both the local and global characteristics. How the method can be used to estimate the sizes of rough features and local curvatures is also presented. The potential of the method is illustrated by quantification of the roughness of two recrystallization boundaries in a pure Al specimen characterized by scanning electron microscopy.
A Probabilistic Framework for Curve Evolution

In this work, we propose a nonparametric probabilistic framework for image segmentation using deformable models. We estimate an underlying probability distribution of image features from regions defined by a deformable curve. We then evolve the curve such that the distance between the distributions is increasing. The resulting active contour resembles a well studied piecewise constant Mumford-Shah model, but in a probabilistic setting. An important property of our framework is that it does not require a particular type of distributions in different image regions. Additional advantages of our approach include ability to handle textured images, simple generalization to multiple regions, and efficiency in computation. We test our probabilistic framework in combination with parametric (snakes) and geometric (level-sets) curves. The experimental results on composed and natural images demonstrate excellent properties of our framework.

General information
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Authors: Dahl, V. A. (Intern), Dahl, A. B. (ed.) (Intern)
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A variational study on BRDF reconstruction in a structured light scanner

Time-efficient acquisition of reflectance behavior together with surface geometry is a challenging problem. In this study, we investigate the impact of system parameter uncertainties when incorporating a data-driven BRDF reconstruction approach into the standard pipeline of a structured light scanning system. The parameters investigated include geometric detail of scanned objects; vertex positions and normals; and position and intensity of light sources. To have full control of uncertainties, experiments are carried out in a simulated environment, mimicking an actual structured light scanning setup. Results show that while uncertainties in vertex positions and normals have a high impact on the quality of reconstructed BRDFs, object geometry and light source properties have very little influence on the reconstructed BRDFs. With this analysis, practitioners now have insight in the tolerances required for accurate BRDF acquisition to work.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Nielsen, J. B. (Intern), Stets, J. D. (Intern), Lyngby, R. A. (Intern), Aanaes, H. (Intern), Dahl, A. B. (Intern), Frisvad, J. R. (Intern)
Number of pages: 10
Characterization of the glucagon-like peptide-1 receptor in male mouse brain using a novel antibody and in situ hybridization

Glucagon-like peptide-1 (GLP-1) is a physiological regulator of appetite and long-acting GLP-1 receptor agonists (GLP-1RA) lower food intake and bodyweight in both human and animal studies. The effects are mediated through brain GLP-1Rs, and several brain nuclei expressing the GLP-1R may be involved. To date, mapping the complete location of GLP-1R protein in the brain has been challenged by lack of good antibodies and the discrepancy between mRNA and protein especially relevant in neuronal axonal processes. Here, we present a novel and specific monoclonal GLP-1R antibody for immunohistochemistry with murine tissue and show detailed distribution of GLP-1R expression as well as mapping of GLP-1R mRNA by non-radioactive in situ hybridization. Semi-automated image analysis was performed to map the GLP-1R distribution to atlas plates from the Allen Institute of Brain Science (AIBS). The GLP-1R was abundantly expressed in numerous regions including the septal nucleus, the hypothalamus and the brain stem. GLP-1R protein expression was also observed on neuronal projections in brain regions devoid of any mRNA which has not been observed in earlier reports. Taken together, these findings provide new knowledge on GLP-1R expression in neuronal cell bodies and neuronal projections.
Development of a New Fractal Algorithm to Predict Quality Traits of MRI Loins

Traditionally, the quality traits of meat products have been estimated by means of physico-chemical methods. Computer vision algorithms on MRI have also been presented as an alternative to these destructive methods since MRI is non-destructive, non-ionizing and innocuous. The use of fractals to analyze MRI could be another possibility for this purpose.

In this paper, a new fractal algorithm is developed, to obtain features from MRI based on fractal characteristics. This algorithm is called OPFTA (One Point Fractal Texture Algorithm). Three fractal algorithms were tested in this study: CFA (Classical fractal algorithm), FTA (Fractal texture algorithm) and OPFTA. The results obtained by means of these three fractal algorithms were correlated to the results obtained by means of physico-chemical methods. OPFTA and FTA achieved correlation coefficients higher than 0.75 and CFA reached low relationship for the quality parameters of loins. The best results were achieved for OPFTA as fractal algorithm (0.837 for lipid content, 0.909 for salt content and 0.911 for moisture). These high correlation coefficients confirm the new algorithm as an alternative to the classical computational approaches (texture algorithms) in order to compute the quality parameters of meat products in a non-destructive and efficient way.
Foreign object detection in multispectral X-ray images of food items using sparse discriminant analysis

Non-invasive food inspection and quality assurance are becoming viable techniques in food production due to the introduction of fast and accessible multispectral X-ray scanners. However, the novel devices produce massive amounts of data and there is a need for fast and accurate algorithms for processing it. We apply a sparse classifier for foreign object detection and segmentation in multispectral X-ray. Using sparse methods makes it possible to potentially use fewer variables than traditional methods and thereby reduce acquisition time, data volume and classification speed. We report our results on two datasets with foreign objects, one set with spring rolls and one with minced meat. Our results indicate that it is possible to limit the amount of data stored to 50% of the original size without affecting classification accuracy of materials used for training. The method has attractive computational properties, which allows for fast classification of items in new images.

Geometrical Characterisation of Individual Fibres From X-Ray Tomograms

We have developed an image analysis pipeline that can extract individual fibre tracks from low contrast X-ray tomograms of unidirectional composites with high fibre volumefraction. Measuring individual fibre tracks opens up the possibility of modelling this empirical data in a statistical manner. Thus, allowing to analyse the spatial distribution of the parameters characterising the orientation and curvature of these individual fibres, which can also provide insights on the interactions amongst the individual fibres. Finite element models (FEMs) can be built from the extracted geometry to simulate the performance of the scanned fibre structure under realistic conditions. Moreover, aspects of the fibre architecture that influence the macroscopic behaviour of the composite can be quantified. Examples are 2D FEMs to predict the transverse stiffness or the quantification of fibre orientations to estimate the compression strength. And last but not least, already developed analytical and numerical models to describe the composite's behaviour can be validated against the observed data.
Graphite nodules in fatigue-tested cast iron characterized in 2D and 3D

Thick-walled ductile iron casts have been studied by applying (i) cooling rate calculations by FVM, (ii) microstructural characterization by 2D SEM and 3D X-ray tomography techniques and (iii) fatigue testing of samples drawn from components cast in sand molds and metal molds. An analysis has shown correlations between cooling rate, structure and fatigue strengths demonstrating the benefit of 3D structural characterization to identify possible causes of premature fatigue failure of ductile cast iron.
The aim of this paper is to characterise the fibre orientation in unidirectional fibre reinforced polymers, namely glass and carbon fibre composites. The compression strength of the composite is related to the orientation of the fibres. Thus the orientation is essential when designing materials for wind turbine blades. The calculation of the fibre orientation distribution is based on segmenting the individual fibres from volumes that have been acquired through X-ray tomography. The segmentation method presented in this study can accurately extract individual fibres from low contrast X-ray scans of composites with high fibre volume fraction. From the individual fibre orientations, it is possible to obtain results which are independent of the scanning quality. The compression strength for both composites is estimated from the average fibre orientations and is found to be of the same order of magnitude as the measured values.

**General information**

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**Organisations:** Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Department of Wind Energy, Composites and Materials Mechanics

**Authors:** Emerson, M. J. (Intern), Jespersen, K. M. (Intern), Dahl, A. B. (Intern), Conradsen, K. (Intern), Mikkelsen, L. P. (Intern)

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Multispectral X-ray CT: multivariate statistical analysis for efficient reconstruction

Recent developments in multispectral X-ray detectors allow for an efficient identification of materials based on their chemical composition. This has a range of applications including security inspection, which is our motivation. In this paper, we analyze data from a tomographic setup employing the MultiX detector, that records projection data in 128 energy bins covering the range from 20 to 160 keV. Obtaining all information from this data requires reconstructing 128 tomograms, which is computationally expensive. Instead, we propose to reduce the dimensionality of projection data prior to reconstruction and reconstruct from the reduced data. We analyze three linear methods for dimensionality reduction using a dataset with 37 equally-spaced projection angles. Four bottles with different materials are recorded for which we are able to obtain similar discrimination of their content using a very reduced subset of tomograms compared to the 128 tomograms that would otherwise be needed without dimensionality reduction.

New approach for validating the segmentation of 3D data applied to individual fibre extraction

We present two approaches for validating the segmentation of 3D data. The first approach consists on comparing the amount of estimated material to a value provided by the manufacturer. The second approach consists on comparing the segmented results to those obtained from imaging modalities that provide a better resolution and therefore a more accurate segmentation. The imaging modalities used for comparison are scanning electron microscopy, optical microscopy and synchrotron CT. The validation methods are applied to the asses the segmentation of individual fibres from X-ray microtomograms.
This work firstly investigates the use of MRI, fractal algorithms, and data mining techniques to determine pork quality parameters non-destructively. The main objective was to evaluate the capability of fractal algorithms (Classical Fractal Algorithm, CFA; Fractal Texture Algorithm, FTA and One Point Fractal Texture Algorithm, OPFTA) to analyse MRI in order to predict quality parameters of loin. In addition, the effect of the sequence acquisition of MRI (Gradient echo, GE; Spin echo, SE and Turbo 3D, T3D) and the predictive technique of data mining (Isotonic regression, IR and Multiple linear regression, MLR) were analysed. Both fractal algorithm, FTA and OPFTA are appropriate to analyse MRI of loins. The sequence acquisition, the fractal algorithm and the data mining technique seems to influence on the prediction results. For most physico-chemical parameters, prediction equations with moderate to excellent correlation coefficients were achieved by using the following combinations of acquisition sequences of MRI, fractal algorithms and data mining techniques: SE-FTA-MLR, SE-OPFTA-IR, GE-OPFTA-MLR, SE-OPFTA-MLR, with the last one offering the best prediction results. Thus, SE-OPFTA-MLR could be proposed as an alternative technique to determine physico-chemical traits of fresh and dry-cured loins in a non-destructive way with high accuracy.
Quantitative evaluation of peptide analogue distribution in mouse tissue using 3D computer modelling

The use of automated image analysis of microscopy images is increasing to enable high throughput approaches and unbiased analysis of the increasingly large data sets produced. This thesis investigates the use of automated image analysis to quantify peptide analogue distribution in mouse brain tissue. The main group of peptides included in this work was glucagon-like peptide 1 receptors agonists (GLP-1RA) used for treatment in diabetes and obesity. Two main image modalities have been applied for image acquisition; Light Sheet Fluorescence Microscopy (LSFM), and slide scanner images of 2D histology sections. The work demonstrates the use of automated image analysis based on image registration to quantify LSFM data of the peptide brain distribution following peripheral administration. The methodology was expanded during the PhD work to also include study of receptor mapping and brain activation. The automated analysis was enabled by integration with a digital multimodality brain atlas from the Allen Institute of Brain Science (AIBS). The work showed that GLP-1RAs accessed multiple brain regions mainly in the hypothalamus and hindbrain and led to increased brain activation in regions related to decreased food intake. The developed integrated brain atlas provides a novel analysis approach for LSFM data to aid researchers understand the complex brain biology related to development of pharmaceuticals with brain mode of action.
Scene reassembly after multimodal digitization and pipeline evaluation using photorealistic rendering

Transparent objects require acquisition modalities that are very different from the ones used for objects with more diffuse reflectance properties. Digitizing a scene where objects must be acquired with different modalities requires scene reassembly after reconstruction of the object surfaces. This reassembly of a scene that was picked apart for scanning seems unexplored. We contribute with a multimodal digitization pipeline for scenes that require this step of reassembly. Our pipeline includes measurement of bidirectional reflectance distribution functions and high dynamic range imaging of the lighting environment. This enables pixelwise comparison of photographs of the real scene with renderings of the digital version of the scene. Such quantitative evaluation is useful for verifying acquired material appearance and reconstructed surface geometry, which is an important aspect of digital content creation. It is also useful for identifying and improving issues in the different steps of the pipeline. In this work, we use it to improve reconstruction, apply analysis by synthesis to estimate optical properties, and to develop our method for scene reassembly.

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Web of Science (2017): Indexed Yes
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Web of Science (2015): Indexed yes
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Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 1.046 SNIP 1.496 CiteScore 1.79
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Scopus rating (2011): SJR 1.044 SNIP 1.777 CiteScore 1.92
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
The goal of this thesis is to develop statistical image analysis tools to characterise the micro-structure of complex materials used in energy technologies, with a strong focus on fibre composites. These quantification tools are based on extracting geometrical parameters defining structures from 2D and 3D images, especially acquired through X-ray computed tomography (CT). Fibre composites are extensively used in transportation and energy technologies such as wind turbines. It is of high importance to characterise composites accurately and to understand their behaviour under load to ensure efficiency and longevity of these technologies.

Imaging with X-ray CT has been the foundation of the thesis. This enables analysis in 3D and at the micro-scale, where individual fibres are distinguishable. Additionally, ultra-fast X-ray CT and in-situ loading environments are able to image these composites with high resolution both in space and time to observe fast micro-structural changes.

This thesis demonstrates that statistical image analysis combined with X-ray CT opens up numerous possibilities for understanding the behaviour of fibre composites under real life conditions. Besides enabling characterisation of material properties, estimating individual fibre centre lines and diameters allows for quantification of small micro-structural changes with a high degree of accuracy, as it is possible to follow how each individual fibre changes across data-sets acquired under progressive loading conditions. Finally, the thesis demonstrates the precision to which fibre geometry can be characterised through X-ray CT and the developed data analysis tools.

**General information**

State:Submitted

Organisations:Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics

Authors:Emerson, M. J. (Intern), Dahl, A. B. (Intern), Conradsen, K. (Intern)
Unidirectional Fibre Composite Characterisation from X-ray Tomography

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Active Appearance Segmentation for Intensity Inhomogeneity in Light Sheet Fluorescence Microscopy

Active Appearance Models (AAM) are used for annotating or segmenting shapes in biomedical images. Performance relies heavily on the image data used to train the AAM. In this paper we improve the generalization properties of the model by making it robust to slowly varying spatial intensity inhomogeneities which are often seen in Light Sheet Fluorescence Microscopy (LSFM) images. This robustness is achieved by modelling the appearance of an image as a regularized Normalized Gradient Field (rNGF). We perform two experiments to challenge the model. First it is tested using a repeated leave-one-out approach on images with minimal imperfections where the left out images are corrupted by a simulated bias field and segmented using the AAM. Secondly we test the model on LSFM images with common acquisition problems. In both experiments the proposed approach outperforms the often used AAM implementation based on Sum of Squared Differences.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Novo Nordisk A/S
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Active Appearance Model, Regularized Normalized Gradient Field, Light Sheet Fluorescence Microscopy, Segmentation
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Automatic measurement of orbital volume in unilateral coronal synostosis

Premature fusion of the coronal suture on one side of the calvaria (unilateral coronal synostosis, UCS) results in asymmetric craniofacial development and the deformation of the orbits. Often this necessitates surgery, where CT scanning is employed to obtain measures of the bony orbit. These measures are typically computed by guided procedures that require expert time. We propose a method with higher degree of automation based on finding an optimal smooth closed surface. CT scans of 17 infants with UCS are included in our experimental validation, where we compare our method to expert guided segmentations. We obtain similar measures, as well as high Dice scores, compared to the experts. The run time for the proposed approach with a prototype implementation is around 3 minutes on a standard laptop, making the method suitable for rapid evaluation of orbital volume in UCS.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Image Analysis & Computer Graphics, Copenhagen University Hospital, University of Copenhagen, Osaka University
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Large-Scale Data for Multiple-View Stereopsis

The seminal multiple-view stereo benchmark evaluations from Middlebury and by Strecha et al. have played a major role in propelling the development of multi-view stereopsis (MVS) methodology. The somewhat small size and variability of these data sets, however, limit their scope and the conclusions that can be derived from them. To facilitate further development within MVS, we here present a new and varied data set consisting of 80 scenes, seen from 49 or 64 accurate camera positions. This is accompanied by accurate structured light scans for reference and evaluation. In addition all images are taken under seven different lighting conditions. As a benchmark and to validate the use of our data set for obtaining reasonable and statistically significant findings about MVS, we have applied the three state-of-the-art MVS algorithms by Campbell et al., Furukawa et al., and Tola et al. to the data set. To do this we have extended the evaluation protocol from the Middlebury evaluation, necessitated by the more complex geometry of some of our scenes. The data set and accompanying evaluation framework are made freely available online. Based on this evaluation, we are able to observe several characteristics of state-of-the-art MVS, e.g. that there is a tradeoff between the quality of the reconstructed 3D points (accuracy) and how much of an object’s surface is captured (completeness). Also, several issues that we hypothesized would challenge MVS, such as specularities and changing lighting conditions did not pose serious problems. Our study finds that the two most pressing issues for MVS are lack of texture and meshing (forming 3D points into closed triangulated surfaces).

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Main Research Area: Technical/natural sciences
Learned image representations for visual recognition

This thesis addresses the problem of extracting image structures for representing images effectively in order to solve visual recognition tasks. Problems from diverse research areas (medical imaging, material science and food processing) have motivated large parts of the methodological development. The solutions are inspired by and extend state-of-the-art techniques for describing and learning image content.
More specifically, the thesis explores two approaches to constructing image representations, namely feature engineering and feature learning. In the feature engineering approach, we devise a new image representation for texture-like patterns based on count statistics of second-order image structure. We demonstrate the discriminative capabilities of this representation on medical images and perform both cell classification and mitosis detection. Moreover, we develop an object identification method based on vector quantized local image descriptors allowing us to distinguish individual meat cuts along a production line and trace them in a non-intrusive manner. In the feature learning approach, we propose to solve the task of segmenting scanning electron microscopy images of calcite crystals by learning a meaningful pixel description to facilitate the actual segmentation. Finally, we present a new unsupervised generative image model addressing the problem of pixel-based similarity measures for images. We propose a scheme for employing feature-based similarity measures and demonstrate how this improves the ability to learn high-level concepts in images of faces.

The thesis argues in favor of learning features and presents new methods for domains with limited amounts of labeled data allowing feature learning to be applied more broadly.

Noninvasive particle sizing using camera-based diffuse reflectance spectroscopy
Diffuse reflectance measurements are useful for noninvasive inspection of optical properties such as reduced scattering and absorption coefficients. Spectroscopic analysis of these optical properties can be used for particle sizing. Systems based on optical fiber probes are commonly employed, but their low spatial resolution limits their validity ranges for the coefficients. To cover a wider range of coefficients, we use camera-based spectroscopic oblique incidence reflectometry. We develop a noninvasive technique for acquisition of apparent particle size distributions based on this approach. Our technique is validated using stable oil-in-water emulsions with a wide range of known particle size distributions. We also measure the apparent particle size distributions of complex dairy products. These results show that our tool, in contrast to those based on fiber probes, can deal with a range of optical properties wide enough to track apparent particle size distributions in a typical industrial process.
**Segmentation of individual fibres in a uni-directional composite from 3D X-ray computed tomography data**

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Department of Wind Energy, Composites and Materials Mechanics
Authors: Emerson, M. J. (Intern), Jespersen, K. M. (Intern), Dahl, A. B. (Intern), Conradsen, K. (Intern), Mikkelsen, L. P. (Intern)
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Main Research Area: Technical/natural sciences

Simultaneous Reconstruction and Segmentation with Class-Specific Priors

Studying the interior of objects using tomography often require an image segmentation, such that different material properties can be quantified. This can for example be volume or surface area. Segmentation is typically done as an image analysis step after the image has been reconstructed. This thesis investigates computing the reconstruction and segmentation simultaneously. The advantage of this is that because the reconstruction and segmentation are computed jointly, reconstruction errors are not propagated to the segmentation step. Furthermore the segmentation procedure can be used for regularizing the reconstruction process. The thesis provides models and algorithms for simultaneous reconstruction and segmentation and their performance is empirically validated.

Two method of simultaneous reconstruction and segmentation are described in the thesis. Also, a method for parameter selection is given. The reconstruction and segmentation are modeled as two parts: the image that is reconstructed and a so-called Hidden Markov Measure Field Model (HMMFM). Pixel values in the image contain material attenuation coefficients and the HMMFM contains pixelwise probabilities for material classes. The number of material classes and their parameters are assumed known a priori. These parameters are the mean value of the class attenuation coefficients and their standard deviations. Given this input together with projection data, the problem is to find the image and HMMFM. The segmentation is obtained from the HMMFM as the most probable class in each pixel.

The solution for the reconstruction and segmentation problem is found using an algorithm that simultaneously minimizes the reprojection error, deviation of the grey levels of pixels from known mean values and the spatial differences in the class probabilities.

In the first Simultaneous Reconstruction and Segmentation (SRS) method data is assumed Gaussian distributed and the minimization is done using standard optimization techniques in two stages. Experimental validation on both phantom and real data shows that modeling the reconstruction and segmentation simultaneously has superior performance, especially when the problem is underdetermined, i.e. when the number of unknowns in the reconstruction exceeds the number of observations.

The second SRS method assumes Poisson distributed data, which is the case for data originating from discrete events like photon counts. The algorithm is again based on solving a minimization problem. In addition a relaxation strategy is employed in order to avoid being stuck in local minimum. This model is also validated on artificial data.

Selecting appropriate regularization parameters can be difficult, so the last thing that we consider is a parameter selection approach. The most promising approach was a modified L-curve algorithm, which was empirically analyzed.

This thesis contributes with methods for simultaneous reconstruction and segmentation and demonstrates the benefits of this approach in situations where only few projections are available and data is noisy. Here a higher precision image as well as segmentation can be computed.

**General information**
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Authors: Romanov, M. (Intern), Dahl, A. B. (Intern), Hansen, P. C. (Intern)
The Traveling Optical Scanner – Case Study on 3D Shape Models of Ancient Brazilian Skulls
Recovering detailed morphological information from archaeological or paleontological material requires extensive hands-on time. Creating 3D scans based on e.g. computed tomography (CT) will recover the geometry of the specimen, but can inflict bimolecular degradation. Instead, we propose a fast, inoffensive and inexpensive 3D scanning modality based on structured light, suitable for capturing the morphology and the appearance of specimens. Benefits of having 3D models are manifold. The 3D models are easy to share among researchers and can be made available to the general public. Advanced morphological modelling is possible with accurate description of the specimens provided by the models. Furthermore, performing studies on models reduces the risk of damage to the original specimen. In our work we employ a high resolution structured light scanner for digitalizing a collection of 8500 year old human skulls from Brazil. To evaluate the precision of our setup we compare the structured light scan to micro-CT and achieve submillimetre difference. We analyse morphological features of the Brazilian skulls using manual landmarks, but a research goal is to automate this, fully utilize the dense 3D scans, and apply the method to many more samples.

X-ray based micromechanical finite element modeling of composite materials
This is a study of a uni-directional non-crimp fabric reinforced epoxy composite material typically used as the load carrying laminate in wind turbine blades. Based on a 3D x-ray tomography scan, the bundle and fibre/matrix structure of the composite is segmented. This segmentation is used in a multi-scale finite element model bridging the gap from the individual fibers organized in bundles to the stitched non-crimp fabric used for building up the load carrying laminates.
Accuracy in Robot Generated Image Data Sets

In this paper we present a practical innovation concerning how to achieve high accuracy of camera positioning, when using a 6 axis industrial robots to generate high quality data sets for computer vision. This innovation is based on the realization that to a very large extent the robots positioning error is deterministic, and can as such be calibrated away. We have successfully used this innovation in our efforts for creating data sets for computer vision. Since the use of this innovation has a significant effect on the data set quality, we here present it in some detail, to better aid others in using robots for image data set generation.

A Parameter Choice Method for Simultaneous Reconstruction and Segmentation

The problem of finding good regularization parameters for the reconstruction problems without knowledge of the ground truth is a non-trivial task. We overview the existing parameter choice methods and present the modified L-curves approach for a good regularization parameters selection that is suited for our Simultaneous Reconstruction and Segmentation method. We verify the validity of this approach with numerical experiments based on reconstructions of artificial phantoms from noisy data, and the problems in our numerical experiments are underdetermined.
Boundary Fractal Analysis of Two Cube-oriented Grains in Partly Recrystallized Copper

The protrusions and retrusions observed on the recrystallizing boundaries affect the migration kinetics during recrystallization. Characterization of the boundary roughness is necessary in order to evaluate their effects. This roughness has a structure that can be characterized by fractal analysis, and in this study the so-called "Minkowski sausage" method is adopted. Hereby, two cube-oriented grains in partly recrystallized microstructures are analyzed and quantitative information regarding the dimensions of protrusions/retrusions is obtained.

Boundary_Fractal_Analysis.pdf

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10.1088/1757-899X/82/1/012006
Characterization of boundary roughness of two cube grains in partly recrystallized copper

Protrusions and retrusions typically form on recrystallizing boundaries and thus the boundaries often appear rough. Characterization of the boundary roughness is necessary in order to evaluate the effects of protrusions and retrusions on boundary migration. In the current work, a variable termed area integral invariant is employed to provide quantitative information of individual protrusions/retrusions on boundaries surrounding two selected recrystallizing grains in partly recrystallized copper as well as of the overall roughness of the boundaries.
Comparison of a multispectral vision system and a colorimeter for the assessment of meat color

The color assessment ability of a multispectral vision system is investigated by a comparison study with color measurements from a traditional colorimeter. The experiment involves fresh and processed meat samples. Meat is a complex material; heterogeneous with varying scattering and reflectance properties, so several factors can influence the instrumental assessment of meat color. In order to assess whether two methods are equivalent, the variation due to these factors must be taken into account. A statistical analysis was conducted and showed that on a calibration sheet the two instruments are equally capable of measuring color. Moreover the vision system provides a more color rich assessment of fresh meat samples with a glossier surface, than the colorimeter. Careful studies of the different sources of variation enable an assessment of the order of magnitude of the variability between methods accounting for other sources of variation leading to the conclusion that color assessment using a multispectral vision system is superior to traditional colorimeter assessments. (C) 2014 Elsevier Ltd. All rights reserved.
Dictionary Based Image Segmentation

We propose a method for weakly supervised segmentation of natural images, which may contain both textured or non-textured regions. Our texture representation is based on a dictionary of image patches. To divide an image into separated regions with similar texture we use an implicit level sets representation of the curve, which makes our method topologically adaptive. In addition, we suggest a multi-label version of the method. Finally, we improve upon a similar texture representation, by formulating the computation of a texture probability in terms of a matrix multiplication. This results in an efficient implementation of our segmentation method. We experimentally validated our approach on a number of natural as well as composed images.

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Organisations: Department of Applied Mathematics and Computer Science
Authors: Dahl, A. B. (Intern), Dahl, V. A. (Intern)
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Dictionary Based Segmentation in Volumes

We present a method for supervised volumetric segmentation based on a dictionary of small cubes composed of pairs of intensity and label cubes. Intensity cubes are small image volumes where each voxel contains an image intensity. Label cubes are volumes with voxelwise probabilities for a given label. The segmentation process is done by matching a cube from the volume, of the same size as the dictionary intensity cubes, to the most similar intensity dictionary cube, and from the associated label cube we get voxel-wise label probabilities. Probabilities from overlapping cubes are averaged and hereby we obtain a robust label probability encoding. The dictionary is computed from labeled volumetric image data based on weighted clustering. We experimentally demonstrate our method using two data sets from material science – a phantom data set of a solid oxide fuel cell simulation for detecting three phases and their interfaces, and a tomogram of a glass fiber composite used in wind turbine blades for detecting individual glass fibers.

General information

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Dictionary Based Segmentation in Volumes

Method for supervised segmentation of volumetric data. The method is trained from manual annotations, and these annotations make the method very flexible, which we demonstrate in our experiments. Our method infers label information locally by matching the pattern in a neighborhood around a voxel to a dictionary, and hereby accounts for the volume texture.

General information

State: Published
Discriminating Yogurt Microstructure Using Diffuse Reflectance Images

The protein microstructure of many dairy products is of great importance for the consumers’ experience when eating the product. However, studies concerning discrimination between protein microstructures are limited. This paper presents preliminary results for discriminating different yogurt microstructures using hyperspectral (500-900nm) diffuse reflectance images (DRIs) – a technique potentially well suited for inline process control. Comparisons are made to quantified measures of the yogurt microstructure observed through confocal scanning laser microscopy (CSLM). The output signal from both modalities is evaluated on a 24 factorial design covering four common production parameters, which significantly change the chemistry and the microstructure of the yogurt. It is found that the DRIs can be as discriminative as the CSLM images in certain cases, however the performance is highly governed by the chemistry of the sample. Also, the DRIs shows better correlation to the CSLM images and are more discriminative when considering shorter wavelengths.

Evaluation of Yogurt Microstructure Using Confocal Laser Scanning Microscopy and Image Analysis

The microstructure of protein networks in yogurts defines important physical properties of the yogurt and hereby partly its quality. Imaging this protein network using confocal scanning laser microscopy (CSLM) has shown good results, and CSLM has become a standard measuring technique for fermented dairy products. When studying such networks, hundreds of images can be obtained, and here image analysis methods are essential for using the images in statistical analysis. Previously, methods including gray level co-occurrence matrix analysis and fractal analysis have been used with success. However, a range of other image texture characterization methods exists. These methods describe an image by a frequency distribution of predefined image features (denoted textons). Our contribution is an investigation of the choice of image analysis methods by performing a comparative study of 7 major approaches to image texture description. Here, CSLM images from a yogurt fermentation study are investigated, where production factors including fat content, protein content, heat treatment, and incubation temperature are varied. The descriptors are evaluated through nearest neighbor classification, variance analysis, and cluster analysis. Our investigation suggests that the texton-based descriptors provide
a fuller description of the images compared to gray-level co-occurrence matrix descriptors and fractal analysis, while still being as applicable and in some cases as easy to tune.

Practical Application
Confocal laser scanning microscopy images can be used to provide information on the protein microstructure in yogurt products. For large numbers of microscopy images, subjective evaluation becomes a difficult or even impossible approach, if the images should be incorporated in any form of statistical analysis alongside other measuring modalities or sensory data. Instead, automated image texture analysis can be used to provide objective descriptions of the images, and we provide a comparative study for a broad range of the many image texture analysis available. All of the investigated techniques should be applicable for any type of pseudo homogeneous image structures.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, National Food Institute, Research Group for Food Production Engineering, Image Analysis & Computer Graphics, Dublin City University, Arla Strategic Innovation Center, DuPont Nutrition Biosciences Aps
Authors: Skytte, J. L. (Intern), Ghita, O. (Ekstern), Whelan, P. F. (Ekstern), Andersen, U. (Ekstern), Moller, F. (Intern), Dahl, A. B. (Intern), Larsen, R. (Intern)
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BFI (2014): BFI-level 1
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Scopus rating (2013): SJR 1.011 SNIP 1.079 CiteScore 2.24
ISI indexed (2013): ISI indexed yes
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Scopus rating (2011): SJR 0.934 SNIP 1.058 CiteScore 1.9
ISI indexed (2011): ISI indexed yes
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.047 SNIP 1.101
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.969 SNIP 1.001
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.886 SNIP 0.924
Scopus rating (2007): SJR 0.695 SNIP 0.966
Multispectral Imaging of Meat Quality – Color and Texture

The use of computer vision systems in food production and development is increasing. Computer vision systems offer fast, reliable, objective and noninvasive methods for assessment of wanted quality traits. This thesis investigates the applicability of computer vision systems in the assessment of meat quality parameters, especially with regards to meat color and texture. Several image modalities have been applied, all considering multi- or hyper spectral imaging.

The work demonstrates the use of computer vision systems for meat color measurements. The color is assessed by suitable transformations to the CIELAB color space, the common color space within food science. The results show that meat color assessment with a multispectral imaging is a great alternative to the traditional colorimeter, i.e. the vision system meets some of the limitations that the colorimeter possesses. To mention one, it is possible to assess color of very complicated structures, such as salamis, with a vision system. More importantly though, the vision system embraces the complicated scattering properties of meat.

The images can also lead to other analyses, e.g. image texture analysis relating to the structure of the meat. In the thesis it is presented how simple texture measures can be used for characterizing the texture changes in fermented salamis. Moreover, it was investigated if it was possible to relate structure in images to chemical compounds in lard from boars.
Non-Invasive Assessment of Dairy Products Using Spatially Resolved Diffuse Reflectance Spectroscopy

The quality of a dairy product is largely determined by its microstructure which also affects its optical properties. Consequently, an assessment of the optical properties during production may be part of a feedback system for ensuring the quality of the production process. This paper presents a novel camera-based measurement technique that enables robust quantification of a wide range of reduced scattering coefficients and absorption coefficients. Measurements are based on hyperspectral images of diffuse reflectance in the wavelength range of 470 to 1020 nm. The optical properties of commercially available milk and yogurt products with three different levels of fat content are measured. These constitute a relevant range of products at a dairy plant. The measured reduced scattering properties of the samples are presented and show a clear discrimination between levels of fat contents as well as fermentation. The presented measurement technique and method of analysis is thus suitable for a rapid, noncontact, and non-invasive inspection that can deduce physically interpretable properties.

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Organisations: Department of Applied Mathematics and Computer Science, Department of Photonics Engineering, Image Analysis & Computer Graphics, Diode Lasers and LED Systems, NKT Photonics A/S
Authors: Abildgaard, O. H. A. (Intern), Kamran, F. (Intern), Dahl, A. B. (Intern), Skytte, J. L. (Intern), Nielsen, F. D. (Ekstern), Thomsen, C. L. (Ekstern), Andersen, P. E. (Intern), Larsen, R. (Intern), Frisvad, J. R. (Intern)
Pages: 1096-1105
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Scopus rating (2016): SJR 0.48 SNIP 0.967 CiteScore 1.76
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.649 SNIP 1.09 CiteScore 1.96
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.619 SNIP 1.077 CiteScore 1.96
BFI (2013): BFI-level 1
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ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.581 SNIP 1.103 CiteScore 1.81
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.6 SNIP 1.031 CiteScore 1.62
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.687 SNIP 0.989
Web of Science (2010): Indexed yes
Oriented Shape Index Histograms for Cell Classification

We propose a novel extension to the shape index histogram feature descriptor where the orientation of the second-order curvature is included in the histograms. The orientation of the shape index is reminiscent but not equal to gradient orientation which is widely used for feature description. We evaluate our new feature descriptor using a public dataset consisting of HEp-2 cell images from indirect immunofluorescence lighting. Our results show that we can improve classification performance significantly when including the shape index orientation. Notably, we show that shape index orientation outperforms the gradient orientation on the dataset.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Larsen, A. B. L. (Intern), Dahl, A. B. (Intern), Larsen, R. (Intern)
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Series: Lecture Notes in Computer Science
ISSN: 0302-9743
Main Research Area: Technical/natural sciences
Conference: 19th Scandinavian Conference on Image Analysis, Copenhagen, Denmark, 15/06/2015 - 15/06/2015
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Our 3D Vision Data-Sets in the Making

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, IT Service, National Space Institute, Istituto Italiano di Tecnologia, Aston University
Number of pages: 5
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Main Research Area: Technical/natural sciences
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RobDS.pdf

Relaxed Simultaneous Tomographic Reconstruction and Segmentation with Class Priors for Poisson Noise

This work is a continuation of work on algorithms for simultaneous reconstruction and segmentation. In our previous work we developed an algorithm for data with Gaussian noise, and in that algorithm the coefficient matrix for the system is explicitly stored. We improve this algorithm in two ways: our new algorithm can handle Poisson noise in the data, and it can solve much larger problems since it does not store the matrix. We formulate this algorithm and test it on artificial test problems. Our results show that the algorithm performs well, and that we are able to produce reconstructions and segmentations with small errors.

General information
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Number of pages: 19
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ISSN: 1601-2321
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Electronic versions:
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Simultaneous tomographic reconstruction and segmentation with class priors

We consider tomographic imaging problems where the goal is to obtain both a reconstructed image and a corresponding segmentation. A classical approach is to first reconstruct and then segment the image; more recent approaches use a discrete tomography approach where reconstruction and segmentation are combined to produce a reconstruction that is identical to the segmentation. We consider instead a hybrid approach that simultaneously produces both a reconstructed image and segmentation. We incorporate priors about the desired classes of the segmentation through a Hidden Markov Measure Field Model, and we impose a regularization term for the spatial variation of the classes across neighbouring pixels. We also present an efficient implementation of our algorithm based on state-of-the-art numerical optimization algorithms. Simulation experiments with artificial and real data demonstrate that our combined approach can produce better results than the classical two-step approach.

General information
2D Static Light Scattering for Dairy Based Applications

Throughout this thesis we investigate a recently introduced optical technique denoted 2D static light scattering (2DSLS). The technique is remote sensing, non-invasive, highly flexible, and appears to be well suited for in-line process control. Moreover, the output signal contains contributions from several different optical phenomena, which can be utilised to provide information on chemical composition and underlying microstructure of an investigated sample.

The main goal of this thesis is to provide an exploratory study of the 2DSLS technique in relation to dairy based applications. This includes getting an understanding of the various parameters in the setup as well as understanding the output signal in terms of potential and limitations. Furthermore, suitable ways of quantifying the signal are investigated. Here, both established physical models and statistical descriptions of the signal are evaluated and discussed.

There is a major emphasis on using 2DSLS to discriminate between different protein microstructures in yogurt products. This potentially allows for process control, in relation to microstructure, during yogurt manufacture. As microstructure is critical for consumer acceptability, this specific process control can be highly beneficial. To provide suitable reference measures on the actual microstructure, we investigate how to quantify micrographs of yogurts objectively. We provide a comparative study, that includes a broad range of different image texture descriptors.

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State: Published
Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Skytte, J. L. (Intern), Larsen, R. (Intern), Dahl, A. B. (Intern)
Number of pages: 270
Publication date: 2014

Assessment of algorithms for mitosis detection in breast cancer histopathology images

The proliferative activity of breast tumors, which is routinely estimated by counting of mitotic figures in hematoxylin and eosin stained histology sections, is considered to be one of the most important prognostic markers. However, mitosis counting is laborious, subjective and may suffer from low inter-observer agreement. With the wider acceptance of whole slide images in pathology labs, automatic image analysis has been proposed as a potential solution for these issues. In this paper, the results from the Assessment of Mitosis Detection Algorithms 2013 (AMIDA13) challenge are described. The challenge was based on a data set consisting of 12 training and 11 testing subjects, with more than one thousand annotated mitotic figures by multiple observers. Short descriptions and results from the evaluation of eleven methods are presented. The top performing method has an error rate that is comparable to the inter-observer agreement among pathologists.

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Main Research Area: Technical/natural sciences
Broadband optical characterization of material properties

Optical inspection of material properties is of great interest to industry because it can perform objective and non-invasive characterisation of large sample quantities. This may be used in various ways to lower production costs and improve product quality. In this thesis the objective has been to develop and investigate the applicability of optical broadband characterization techniques in industrially relevant production process. Both combined broad and high resolution techniques have the potential to provide important information on scattering properties related to particle size distributions, as well as details of the absorption spectrum which relate to chemical composition.

The thesis focuses on two production process from the food industry. The first process is from the dairy industry where discrimination between chemical and structural properties is of importance. To explore the applicability of optical techniques for this purpose, the fermentation of milk into yogurt has been used as a model system. Studies have been conducted on commercially available products, but also of on-line measurement of the fermentation process. The second process is from the aquaculture industry, quantification of the fish feed additive astaxanthin has been investigated. A measurement campaign has been carried out on a series of pellets specially produced for the purpose.

To investigate these process, the following three measurement techniques have been developed and applied. (I) A camera based inspection system for spectrally resolved Static Light Scattering (SLS). (II) Photon Time-of-Flight (PToF) spectroscopy, which is a state of the art technique for characterization of turbid media. (III) A new hyperspectral imaging system based on full-field illumination by diffuse laser light. This thesis reports on the design and operation of the different measurement techniques together with the necessary theoretical background for the industrial applications.

For the purpose of milk fermentation this work has demonstrated that the reduced scattering properties of milk change significantly throughout the fermentation process. It has also been shown that the optical inspection methods sense changes to structural properties before any are detected by traditional mechanical rheology. Finally, the developed hyperspectral imaging system was used to quantify the content of astaxanthin in fish feed, and performed at an equal level to a state of the art multi-spectral vision system.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Nielsen, O. H. A. (Intern), Dahl, A. B. (Intern), Larsen, R. (Intern)
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Characterization of graphite nodules in thick-walled ductile cast iron

General information
State: Published
Authors: Mukherjee, K. (Intern), Fæster, S. (Intern), Dahl, A. B. (Intern), Sturlason, A. (Ekstern)
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Main Research Area: Technical/natural sciences
Dictionary Snakes

Visual cues like texture, color and context make objects appear distinct from the surroundings, even without gradients between regions. Texture-rich objects are often difficult to segment because algorithms need advanced features which are unique for the image. In this paper we suggest a method for image segmentation that operates without training data. Our method is based on a probabilistic dictionary of image patches coupled with a deformable model inspired by snakes and active contours without edges. We separate the image into two classes based on the information provided by the evolving curve, which moves according to the probabilistic information obtained from the dictionary. Initially, the image patches are assigned to the nearest dictionary element, where the image is sampled at each pixel such that patches overlap. The curve divides the image into an inside and an outside region allowing us to estimate the pixel-wise probability of the dictionary elements. In each iteration we evolve the curve and update the probabilities, which merges similar texture patterns and pulls dissimilar patterns apart. We experimentally evaluate our approach, and show how textured objects are precisely segmented without any prior assumptions about image features. In addition, a texture probability image is obtained.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Statistics and Data Analysis
Authors: Dahl, A. B. (Intern), Dahl, V. A. (Intern)
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, University of Copenhagen
Authors: Aanæs, H. (Intern), Dahl, A. L. (Intern), Kim, S. P. (Ekstern)
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Scopus rating (2016): SJR 8.269 SNIP 5.054 CiteScore 11.06
Web of Science (2016): Indexed yes
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BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.834 SNIP 4.735 CiteScore 6
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Scopus rating (2013): SJR 3.767 SNIP 5.083 CiteScore 7.59
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.315 SNIP 5.445 CiteScore 5.92
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.67 SNIP 5.37 CiteScore 7.45
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.055 SNIP 5.827
BFI (2009): BFI-level 2
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.751 SNIP 6.056
Scopus rating (2005): SJR 3.073 SNIP 5.509
Scopus rating (2004): SJR 1.627 SNIP 3.883
Scopus rating (2002): SJR 1.57 SNIP 3.277
Evaluation of the ID220 single photon avalanche diode for extended spectral range of photon time-of-flight spectroscopy

This paper describes the performance of the ID220 single photon avalanche diode for single photon counting, and investigates its performance for photon time-of-flight (PToF) spectroscopy. At first this report will serve as a summary to the group for PToF spectroscopy at the Department of Physics, Lund University (Sweden) together with ID Quantique Inc. (Geneve, Switzerland). As such, the report does not give an introduction to PToF spectroscopy, which may be found in the Doctoral on the topic [2, 18, 1]. The report focuses on a description of the detector's ability to measure the PToF distribution of infrared light.

First, a motivation for using the ID220 for measuring PToF distribution is given, followed by a brief description of the experimental setup in which the detector was characterized. Following this, the quantification of delay using cross correlation between PToF distributions is described. This allows the changes in delay and shape to be characterized. A technique for reducing measurement artefacts by lowering the repetition rate of the light source is also investigated. Lastly, the applicability of the detector for PTOF spectroscopy is discussed and conclusions drawn about its suitability for this application.

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Authors: Nielsen, O. H. A. (Intern), Dahl, A. B. (Intern), Anderson-Engels, S. (Ekstern), Nielsen, F. D. (Ekstern), Thomsen, C. L. (Ekstern), Khoptyar, D. (Ekstern)
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Publication: Research › Report – Annual report year: 2014

Large Scale Multi-view Stereopsis Evaluation
The seminal multiple view stereo benchmark evaluations from Middlebury and by Strecha et al. have played a major role in propelling the development of multi-view stereopsis methodology. Although seminal, these benchmark datasets are limited in scope with few reference scenes. Here, we try to take these works a step further by proposing a new multi-view stereo dataset, which is an order of magnitude larger in number of scenes and with a significant increase in diversity. Specifically, we propose a dataset containing 80 scenes of large variability. Each scene consists of 49 or 64 accurate camera positions and reference structured light scans, all acquired by a 6-axis industrial robot. To apply this dataset we propose an extension of the evaluation protocol from the Middlebury evaluation, reflecting the more complex geometry of some of our scenes. The proposed dataset is used to evaluate the state of the art multiview stereo algorithms of Tola et al., Campbell et al. and Furukawa et al. Hereby we demonstrate the usability of the dataset as well as gain insight into the workings and challenges of multi-view stereopsis. Through these experiments we empirically validate some of the central hypotheses of multi-view stereopsis, as well as determining and reaffirming some of the central challenges.
Pattern recognition approach to quantify the atomic structure of graphene

We report a pattern recognition approach to detect the atomic structure in high-resolution transmission electron microscopy images of graphene. The approach provides quantitative information such as carbon-carbon bond lengths and bond length variations on a global and local scale alike. © 2014 Elsevier Ltd. All rights reserved.
Quantification Tools for Analyzing Tomograms of Energy Materials

The efficiency and lifetime of devices depend critically on the details of the materials’ 3D microstructure and the relation between such structures. Recently developed X-ray imaging techniques provide a resolution that allows for seeing inside a device without destroying it.

There are a number of analysis tasks that need to be carried out in order to harvest the benefits from state of the art X-ray imaging techniques. This includes image segmentation of the reconstructed volumes. It is not feasible to segment manually, this could take months.

By segmenting structures we are able to measure size and shape and quantify important structures. Examples include pores and interface distributions in a catalyst, or glass fiber size, shape and length distributions in a wind turbine blade.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Emerson, M. J. (Intern), Dahl, A. B. (Intern), Larsen, R. (Intern)
Number of pages: 1
Publication date: 2014
Event: Poster session presented at Conference on Energy and Environment for the Future, Copenhagen, Denmark.
Structure Identification in High-Resolution Transmission Electron Microscopic Images: An Example on Graphene

A connection between microscopic structure and macroscopic properties is expected for almost all material systems. High-resolution transmission electron microscopy is a technique offering insight into the atomic structure, but the analysis of large image series can be time consuming. The present work describes a method to automatically estimate the atomic structure in two-dimensional materials. As an example graphene is chosen, in which the positions of the carbon atoms are reconstructed. Lattice parameters are extracted in the frequency domain and an initial atom positioning is estimated. Next, a plausible neighborhood structure is estimated. Finally, atom positions are adjusted by simulation of a Markov random field model, integrating image evidence and the strong geometric prior. A pristine sample with high regularity and a sample with an induced hole are analyzed. False discovery rate-controlled large-scale simultaneous hypothesis testing is used as a statistical framework for interpretation of results. The first sample yields, as expected, a homogeneous distribution of carbon–carbon (C–C) bond lengths. The second sample exhibits regions of shorter C–C bond lengths with a preferred orientation, suggesting either strain in the structure or a buckling of the graphene sheet. The precision of the method is demonstrated on simulated model structures and by its application to multiple exposures of the two graphene samples.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Center for Electron Nanoscopy, Center for Nanostructured Graphene, Image Analysis & Computer Graphics
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Surface Detection using Round Cut

We propose an iterative method for detecting closed surfaces in a volumetric data, where an optimal search is performed in a graph build upon a triangular mesh. Our approach is based on previous techniques for detecting an optimal terrain-like or tubular surface employing a regular grid. Unlike similar adaptations for triangle meshes, our method is capable of capturing complex geometries by iteratively refining the surface, where we obtain a high level of robustness by applying explicit mesh processing to intermediate results. Our method uses on-surface data support, but it also exploits data information about the region inside and outside the surface. This provides additional robustness to the algorithm. We demonstrate the capabilities of the approach by detecting surfaces of CT scanned objects.
Automated Structure Detection in HRTEM Images: An Example with Graphene

Graphene, as the forefather of 2D-materials, attracts much attention due to its extraordinary properties like transparency, flexibility and outstanding high conductivity, together with a thickness of only one atom. The properties seem to be dependent on the atomic structure of graphene and therefore characterizations on the atomic level are of interest. High-resolution transmission electron microscopy (HRTEM) is a state-of-the-art method to characterize the atomic structure of materials. Due to the inherently low mass-thickness of graphene, the contrast levels in the recorded images are often challenging to interpret. In order to increase the signal-to-noise ratio of the images two routes can be pursued: 1) the exposure time can be increased; or 2) acquiring series of images and summarize them after alignment. Both methods have the disadvantage of summing images acquired over a certain period of time making it difficult to resolve dynamic processes or unstable structures. Tools that assist to get the maximum of information out of recorded images are therefore greatly appreciated.

In order to get the most accurate results out of the structure detection, we have optimized the imaging conditions used for the FEI Titan ETEM with a monochromator and an objective-lens Cs-corrector. To reduce the knock-on damage of the carbon atoms in the graphene structure, the microscope was operated at 80kV. As this strongly increases the influence of the chromatic aberration of the lenses, the energy spread of the electron gun was reduced. Using the monochromator an energy spread of <0.2eV can be achieved. This gives a resolution better then 1.2Å which allow us to resolve the second order reflection of graphene and to visualize the atomic structure in HRTEM (fig. 1).

These images serve as a basis for the image analysis. Single-layer graphene with its regular honeycomb lattice is a perfect model structure to apply automated structure detection. By utilizing Fourier analysis the initial perfect hexagonal structure can easily be recognized. The recorded hexagonal tessellation reflects the unperturbed structure in the image. The centers of the C-hexagons are displayed as nodes. To segment the image into “pure” and “impure” regions, like areas with residual amorphous contamination or defects e.g. holes, a sliding window approach is used. The magnitude of the Fourier transformation within a window is compared to that of a perfect hexagonal tessellation. Areas where this relation exceeds a threshold are recognized as “impure” and a mask is created. As a result, the hexagonal tessellation overlays only the “pure” graphene structure in the image.

As the real graphene structure is never perfect and undisturbed, at least at a length-scale of several nm, the model structure has to be adjusted to the real structure. At this point, the image quality plays a crucial role. The algorithm assumes that irregularities in the graphene can be explained by a deformation in the xy-plane. To model this, a set of tensor B-splines is employed, which is deformed by matching model grid points with the C-hexagon centers. Dependent on the Cs and defocus-settings during microscopy these centers appear either dark or bright. One ends up with a deformed hexagonal tessellation, which can easily be transformed into a honeycomb lattice with the C-atom positions included. As the microstructure is now available in the model, information like the C-C distance can be visualized as shown in fig. 2.

Applying this method, the perfect graphene structure in recorded HRTEM-images can be determined fast and accurate over a wide length scale, and at the same time lattice deformations can be visualized. The method will be refined to facilitate the detection of larger defects like holes and the determination of the edge terminations.

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Correlation of iris biometrics and DNA
The presented work concerns prediction of complex human phenotypes from genotypes. We were interested in correlating iris color and texture with DNA. Our data consist of 212 eye images along with DNA: 32 single-nucleotide polymorphisms (SNPs). We used two types of biometrics to describe the eye images: One for iris color and one for iris texture. Both biometrics were high dimensional and a sparse principle component analysis (SPCA) reduced the dimensions and resulted in a representation of data with good interpretability. The correlations between the sparse principal components (SPCs) and the 32 SNPs were found using a canonical correlation analysis (CCA). The result was a single significant canonical correlation (CC) for both biometrics. Each CC comprised two correlated canonical variables, consisting of a linear combination of SPCs and a linear combination of SNPs, respectively. The significant canonical variables for color and texture were primarily explained by the first SPC (SPC1). Therefore, we made a visual inspection of the first SPCs. The color based SPC1 explained a blue to brown variation in iris color and the texture based SPC1 gave a general explanation of iris texture. The SNPs (rs12896399, rs3733542, rs6475555, rs12913832) and (rs12896399, rs3733542, rs12913832) had the highest correlation to the canonical variable for color and texture, respectively. Three of the most contributing SNPs were the same for both biometrics, revealing a covariance between iris color and texture.

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Decomposition of Diffuse Reflectance Images - Features for Monitoring Structure in Turbid Media
Light scattering in turbid media can be related to the microstructure of media. Thus, light scattering can potentially be used for process control of products where the structure is a key component. However process control requires robust and sensitive input data to function properly. In this study we investigate different decomposition methods for extracting light scattering information from images of diffuse reflectance. Both well-established theoretical methods and data driven methods are considered and evaluated based on their robustness and sensitivity to changes in light scattering properties.

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Genetic analyses of the human eye colours using a novel objective method for eye colour classification

In this study, we present a new objective method for measuring the eye colour on a continuous scale that allows researchers to associate genetic markers with different shades of eye colour.

With the use of the custom designed software Digital Iris Analysis Tool (DIAT), the iris was automatically identified and extracted from high resolution digital images. DIAT was made user friendly with a graphical user interface. The software counted the number of blue and brown pixels in the iris image and calculated a Pixel Index of the Eye (PIE-score) that described the eye colour quantitatively. The PIE-score ranged from −1 to 1 (brown to blue). The software eliminated the need for user based interpretation and qualitative eye colour categories. In 94% (570) of 605 analyzed eye images, the iris region was successfully extracted and a PIE-score was calculated. A very high correlation between the PIE-score and the human perception of eye colour was observed. The correlations between the PIE-scores and the six IrisPlex SNPs (HERC2 rs12913832, OCA2 rs1800407, SLC24A4 rs12896399, TYR rs1393350, SLC45A2 rs16891982 and IRF4 rs12203592) were analyzed in 570 individuals. Significant differences (p < 10−6) in the PIE-scores of the individuals typed as HERC2 rs12913832 G (PIE = 0.99) and rs12913832 GA (PIE = −0.71) or A (PIE = −0.87) were observed. We adjusted for the effect of HERC2 rs12913832 and showed that the quantitative PIE-scores were significantly associated with SNPs with minor effects (OCA2 rs1800407, SLC24A4 rs12896399 and TYR rs1393350) on the eye colour. We evaluated the two published prediction models for eye colour (IrisPlex [1] and Snipper[2]) and compared the predictions with the PIE-scores. We found good concordance with the prediction from individuals typed as HERC2 rs12913832 G. However, both methods had difficulties in categorizing individuals typed as HERC2 rs12913832 GA because of the large variation in eye colour in HERC2 rs12913832 GA individuals. With the use of the DIAT software and the PIE-score, it will be possible to automatically compare the iris colour of large numbers of iris images obtained by different studies and to perform large meta-studies that may reveal loci with small effects on the eye colour.

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Spectral characterisation of dairy products using photon time-of-flight spectroscopy

In this paper, we present, for the first time, the absorption and reduced scattering spectra of commercially available milk and yoghurt products, obtained using photon-time-of-flight spectroscopy. The ability of this technique to separate the contributions from absorption and scattering in the sample provides important information on the chemical composition and micro-structural properties, which are not available with the traditional techniques used in dairy production. The instrument operates in the spectral range from 500 nm to 1030 nm. The reduced scattering coefficient varies from 5 cm(-1) for milk with 0.1% fat in the near infrared range, to 60 cm(-1) for yoghurt with 3.0% fat in the green wavelength regime. The absorption is within the range of 0.05-0.5 cm(-1), with only small variation in the absolute value between products. Our results show that the reduced scattering clearly distinguishes milk and yoghurt with the same fat content and can offer a reliable way of monitoring structural formation during milk fermentation.

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What Genes Tell about Iris Appearance

Predicting phenotypes based on genotypes is generally hard, but has shown good results for prediction of iris color. We propose to correlate the appearance of iris with DNA. Six single-nucleotide polymorphisms (SNPs) have previously been shown to correlate with human iris color, and we demonstrate that especially one of the six SNPs are correlated with iris appearance. To perform this analysis we need a method to model the iris appearance, and we suggest an iris characterization based on a bag of visual words, which gives us a similarity measure between images of eyes. We have a dataset of 215 eye images with corresponding SNP types, where the image of the iris has been segmented. We perform two experiments based on the iris characterization. An agglomerative clustering is performed and the result is that one SNP - rs12913832 (HERC2) is highly correlated with the image clustering. Furthermore subspace projections are performed supporting that this SNP is very important for eye color expression. With the suggested image characterizations we are able to investigate the correlation between the phenotypic iris appearance and specific SNPs. This has potential for further investigation of the relation between DNA and iris appearance, especially with focus on iris texture. © 2013 Springer-Verlag.
Automatic quantification of iris color

An automatic algorithm to quantify the eye colour and structural information from standard hi-resolution photos of the human iris has been developed. Initially, the major structures in the eye region are identified including the pupil, iris, sclera, and eyelashes. Based on this segmentation, the iris is resampled into a standardized quadratic coordinate system, where occluded and invalid regions are masked out. Secondly, a pixel classification approach has been evaluated with good results. It is based on a so-called Markov Random Field spatial classification into dominantly brown and blue regions. The result is a blue-brown ratio for each eye. Furthermore, an image clustering approach has been used with promising results. The approach is based on using a sparse dictionary of feature vectors learned from a training set of iris regions. The feature vectors contain both local structural information and colour information. For each iris an explanatory histogram is build, containing information about the weighted occurrence of each visual word. A hierarchical agglomerative clustering of the entire set of photos is performed using the distance between the explanatory histograms. The approach is completely data driven and it can divide a group of eye images into classes based on structure, colour or a combination of the two. The methods have been tested on a large set of photos with promising results.

Classification of Polarimetric SAR Data Using Dictionary Learning

This contribution deals with classification of multilook fully polarimetric synthetic aperture radar (SAR) data by learning a dictionary of crop types present in the Foulum test site. The Foulum test site contains a large number of agricultural fields, as well as lakes, forests, natural vegetation, grasslands and urban areas, which make it ideally suited for evaluation of classification algorithms.

Dictionary learning centers around building a collection of image patches typical for the classification problem at hand. This requires initial manual labeling of the classes present in the data and is thus a method for supervised classification. Sparse coding of these image patches aims to maintain a proficient number of typical patches and associated labels. Data is consecutively classified by a nearest neighbor search of the dictionary elements and labeled with probabilities of each class.

Each dictionary element consists of one or more features, such as spectral measurements, in a neighborhood around each pixel. For polarimetric SAR data these features are the elements of the complex covariance matrix for each pixel. We quantitatively compare the effect of using different representations of the covariance matrix as the dictionary element features. Furthermore, we compare the method of dictionary learning, in the context of classifying polarimetric SAR data, with standard classification methods based on single-pixel measurements.
Digital Prototyping of Milk Products

Digital prototyping has revolutionised the automotive industry by providing designers and engineers with digital models of their products that enable virtual product design, visualisation, and simulation [1]. However, digital prototyping does not
exist in the food industry as the colloidal nature of most foods make them much more challenging to visualise and simulate realistically. We present models and methods that take steps toward digital prototyping of milk products and other food colloids. To simulate the dynamics of liquid products that only exist digitally, we use deformable simplicial complexes with an optimisation-based, linear finite element method [2,3]. Visualisation of products that only exist digitally requires a model for predicting the optical properties of the product materials. The optical properties (absorption coefficient, scattering coefficients, and phase function or asymmetry parameter) are the input needed for a Monte Carlo based graphical rendering. We have developed a model for predicting the optical properties of milk as a function of its fat and protein contents [4]. However, the model has only been validated to a limited extent. We suggest that diffuse reflectance measurements can be used for more extensive validation and for gathering data that can be used to extend our current model such that it can also predict how the optical properties develop during fermentation or acidification of milk to yogurt. A well-established way of measuring optical properties is by static light scattering measurements. This, however, is an invasive procedure where a sample must be placed in a relatively small container (like a cuvette) and scanned by a photon detector orbiting the sample. The container must be small enough to ensure that the sample enters the single scattering regime. Diffuse reflectance measurements have the advantage of being noninvasive. However, the analysis becomes more complex as such measurements include multiple scattering effects. To measure optical properties using diffuse reflectance, we capture high dynamic range images of laser at different wavelengths incident on a sample in situ. The wavelength of the laser is easily adjustable as we use an NKT Photonics SuperK laser [5]. This enables us to retrieve spatially and spectrally resolved diffuse reflectance images. We also acquire images with the laser at several angles of incidence to enable oblique-incidence reflectometry. This enables us to use existing techniques [6,7] for retrieving the apparent optical properties of a sample. The validation consists in comparison of measured optical properties with predicted optical properties.

One of our goals is to extend our model for digital prototyping of milk products such that it can also predict how the optical properties develop during gelation of milk to yogurt. The influence of the colloidal aggregation on the optical properties is described by the static structure factor. As our method is noninvasive, we can use our setup for monitoring an acidification process over time. The challenge is to investigate whether we can use the resulting diffuse reflectance images to measure the static structure factor or similar optical properties of gels. We can see some correlation between measured diffuse reflectance and the rheology of the gel. This indicates that some quantity similar to the static structure factor is measurable using spatially resolved diffuse reflectance. There are ways of predicting the static structure factor for different types of colloids [8]. Thus if we succeed in measuring a similar quantity, we can extend our model and validate the extension.

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Interesting Interest Points: A Comparative Study of Interest Point Performance on a Unique Data Set

Not all interest points are equally interesting. The most valuable interest points lead to optimal performance of the computer vision method in which they are employed. But a measure of this kind will be dependent on the chosen vision application. We propose a more general performance measure based on spatial invariance of interest points under changing acquisition parameters by measuring the spatial recall rate. The scope of this paper is to investigate the performance of a number of existing well-established interest point detection methods. Automatic performance evaluation of interest points is hard because the true correspondence is generally unknown. We overcome this by providing an extensive data set with known spatial correspondence. The data is acquired with a camera mounted on a 6-axis industrial robot providing very accurate camera positioning. Furthermore the scene is scanned with a structured light scanner resulting in precise 3D surface information. In total 60 scenes are depicted ranging from model houses, building material,
fruit and vegetables, fabric, printed media and more. Each scene is depicted from 119 camera positions and 19 individual LED illuminations are used for each position. The LED illumination provides the option for artificially relighting the scene from a range of light directions. This data set has given us the ability to systematically evaluate the performance of a number of interest point detectors. The highlights of the conclusions are that the fixed scale Harris corner detector performs overall best followed by the Hessian based detectors and the difference of Gaussian (DoG). The methods based on scale space features have an overall better performance than other methods especially when varying the distance to the scene, where especially FAST corner detector, Edge Based Regions (EBR) and Intensity Based Regions (IBR) have a poor performance. The performance of Maximally Stable Extremal Regions (MSER) is moderate. We observe a relatively large decline in performance with both changes in viewpoint and light direction. Some of our observations support previous findings while others contradict these findings.

**General information**

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Jet-Based Local Image Descriptors

We present a general novel image descriptor based on higher-order differential geometry and investigate the effect of common descriptor choices. Our investigation is twofold in that we develop a jet-based descriptor and perform a comparative evaluation with current state-of-the-art descriptors on the recently released DTU Robot dataset. We demonstrate how the use of higher-order image structures enables us to reduce the descriptor dimensionality while still achieving very good performance. The descriptors are tested in a variety of scenarios including large changes in scale, viewing angle and lighting. We show that the proposed jet-based descriptor is superior to state-of-the-art for DoG interest points and show competitive performance for the other tested interest points.

Large scale tracking of stem cells using sparse coding and coupled graphs

Stem cell tracking is an inherently large scale problem. The challenge is to identify and track hundreds or thousands of cells over a time period of several weeks. This requires robust methods that can leverage the knowledge of specialists on the field. The tracking pipeline presented here consists of a dictionary learning method for segmentation of phase contrast microscopy images. Linking of the cells between two images is solved by a graph formulation of the tracking problem.
Monitoring structure development in milk acidification using diffuse reflectance profiles

The structure of dairy products is important for the consumer, and milk acidification plays a central role for structural development. To ensure the best possible consumer experience, it is important that a product's structural properties are stable. Therefore process and quality control tools are needed so that the production can be carried out consistently, regardless of day-to-day variations in the raw materials.

Casein micelles aggregate during milk acidification, which leads to formation of a gel network. This change of structure is important for the development of a range of dairy products. It is therefore essential to monitor these structural changes and a variety of methods have been proposed to continuously follow this coagulation of milk [1]. Especially non-invasive methods for in situ production line application have been of interest.

We propose a method for analyzing structural changes in milk based on hyper-spectral light scattering. Our approach is motivated by Carstensen and Møller [2]. They demonstrated the correlation between diffuse reflectance profiles and rheology of a milk sample during acidification. In this work we employ a super-continuum laser light source coupled with an acousto-optical tuneable filter to illuminate the sample. The generated beam is spectrally narrow and can be tuned in the spectral range from 450-1050 nm. This system is described in detail in [3]. It is a research platform, which is constantly developed and adjusted according to research needs. Besides providing a non-invasive method, the system also has potential as a design platform for creating specialized and cost-efficient vision systems.

Our preliminary results are highly encouraging and show a clear relation between rheology and diffuse reflectance. A factorial experiment studying the effects of the content of fat, protein, and temperature in the acidification process is conducted. The purpose of the experiment is to investigate how the change of these parameters affects the diffuse reflectance properties as well as to demonstrate the relation between the optical parameters and structure formation in milk acidification. These measurements are compared to conventional methods such as pH, oscillatory rheology, confocal laser scanning microscopy, and sensory data.

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Pipeline for Tracking Neural Progenitor Cells
Automated methods for neural stem cell lineage construction become increasingly important due to the large amount of data produced from time lapse imagery of in vitro cell growth experiments. Segmentation algorithms with the ability to adapt to the problem at hand and robust tracking methods play a key role in constructing these lineages. We present here a tracking pipeline based on learning a dictionary of discriminative image patches for segmentation and a graph formulation of the cell matching problem incorporating topology changes and acknowledging the fact that segmentation errors do occur. A matched filter for detection of mitotic candidates is constructed to ensure that cell division is only allowed in the model when relevant. Potentially the combination of these robust methods can simplify the initiation of cell lineage construction and extraction of statistics.

3D Surface Scanner Using Structured Light & Industrial Robot
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A Deformable Model for Bringing Particles in Focus

We provide a deformable model for particle analysis. We investigate particle images from a backlit microscope system where particles suffer from out-of-focus blur. The blur is a result of particles being in front or behind the focus plane, and the out-of-focus gives a bias towards overestimating the particle size. This can be handled by only including the particles in focus, but most of the depicted particles will be left out of the analysis, which weakens the statistical estimate of the monitored process. We propose a new method for particle analysis. The model incorporates particle shape, size and intensity, which enables an estimation of the out-of-focus blur of the particle. Using the particle model parameters in a regression model we are able to infer 3D information about individual particles. Based on the defocus information we are able to infer the true size and shape of the particles. We demonstrate the capabilities of our model on both real and simulated data, and our approach shows promising results for a reliable particle analysis. The potential is more process information obtained over shorter sampling time.

Classification Methods for CT-Scanned Carcass Midsections: A Study of Noise Stability

Computed tomography (CT) has successfully been applied in medical environments for decades. In recent years CT has also made its entry to the industrial environments, including the slaughterhouses. In this paper we investigate classification methods for an online CT system, in order to assist in the segmentation of the outer fat layer in the mid-section of CT-scanned pig carcasses. Prior information about the carcass composition can potentially be applied for a fully automated solution, in order to optimize the slaughter line. The methods comprise Markov Random Field and contextual Bayesian classification, and are adapted to use neighbourhood information in 2D and 3D. Articial Poisson noise is added to the provided dataset to determine how well each of the methods handles noise. Good noise handling will allow lower dose scannings. The investigated methods did not perform better than the reference model in terms of classification, but the MRF segmentation showed promising results in a case with extreme simulated noise.
Finding the Best Feature Detector-Descriptor Combination

Addressing the image correspondence problem by feature matching is a central part of computer vision and 3D inference from images. Consequently, there is a substantial amount of work on evaluating feature detection and feature description methodology. However, the performance of the feature matching is an interplay of both detector and descriptor methodology. Our main contribution is to evaluate the performance of some of the most popular descriptor and detector combinations on the DTU Robot dataset, which is a very large dataset with massive amounts of systematic data aimed at two view matching. The size of the dataset implies that we can also reasonably make deductions about the statistical significance of our results. We conclude, that the MSER and Difference of Gaussian (DoG) detectors with a SIFT or DAISY descriptor are the top performers. This performance is, however, not statistically significantly better than some other methods. As a byproduct of this investigation, we have also tested various DAISY type descriptors, and found that the difference among their performance is statistically insignificant using this dataset. Furthermore, we have not been able to produce results collaborating that using affine invariant feature detectors carries a statistical significant advantage on general scene types.

In Depth Analysis of Food Structures: Hyperspectral Subsurface Laser Scattering

In this paper we describe a computer vision system based on SLS (Subsurface Laser Scattering) for industrial food inspection. To obtain high and uniform quality, in for example dairy products like yoghurt and cheese, it is important to
monitor the change in size and shape of microscopic particles over time. In this paper we demonstrate the use-fulness of our SLS system for characterizing food items. We use a laser source that can be tuned to any wavelength in the range of 455 nm - 1020 nm by applying an AOTF (Acousto-Optical Tunable Filter) to an optical beam generated by a SuperK (supercontinuum) laser system. In our experiments we show how the system can be used for discriminating dairy products with different structure and how the structural change of a foam can be monitored over time. Time stability of the system is essential for measurements over several hours, and we demonstrate the time stability by measuring the reflectance profile of an inorganic phantom. The SLS technique is a very promising technique for non-intrusive food inspection, especially for homogenous products where particle size and shape are important parameters.

**General information**

State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Danisco AS, NKT Photonics A/S
Number of pages: 98
Pages: 29-34
Publication date: 2011

**Host publication information**

Title of host publication: Scandinavian Workshop on Imaging Food Quality 2011 : Ystad, May 27, 2011 - Proceedings
Place of publication: Kgs. Lyngby, Denmark
Publisher: Technical University of Denmark (DTU)

Number: 15
Main Research Area: Technical/natural sciences
Workshop: Scandinavian Workshop on Imaging Food Quality 2011, Ystad, Sweden, 27/05/2011 - 27/05/2011

Electronic versions:

Pages from tr11_15-3.pdf
Links:
http://www2.imm.dtu.dk/projects/SWIFQ/
Source: orbit
Source-ID: 279480
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

**Learning Dictionaries of Discriminative Image Patches**

Remarkable results have been obtained using image models based on image patches, for example sparse generative models for image inpainting, noise reduction and superresolution, sparse texture segmentation or texton models. In this paper we propose a powerful and yet simple approach for segmentation using dictionaries of image patches with associated label data. The approach is based on ideas from sparse generative image models and texton based texture modeling. The intensity and label dictionaries are learned from training images with associated label information of (a subset) of the pixels based on a modified vector quantization approach. For new images the intensity dictionary is used to encode the image data and the label dictionary is used to build a segmentation of the image. We demonstrate the algorithm on composite and real texture images and show how successful training is possible even for noisy image and low-quality label training data. In our experimental evaluation we achieve state-of-the-art performance for segmentation.

**General information**

State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Dahl, A. L. (Intern), Larsen, R. (Intern)
Publication date: 2011

**Host publication information**

Title of host publication: Proceedings of the British Machine Vision Conference
Publisher: BMVA Press
Main Research Area: Technical/natural sciences

Electronic versions:

BMVC_discriminative.pdf
DOIs:
10.5224/C.25.77
Links:
Learning Histopathological Patterns

We propose a technique for analyzing images of immunohistochemically stained tissue samples for extracting features that correlate with patient disease. We address the problem of quantifying tumor tissue and segmenting and counting nuclei. Our method utilizes a flexible segmentation technique trained from representative image samples. Nuclei counting is based on a nucleus model that takes size, shape and nucleus probability into account. We obtain the probability of a nucleus from our segmentation procedure. Our method is experimentally validated on images stained with nuclear markers for the Estrogen Receptor (ER) and proliferation marker KI-67. In addition we qualitatively validate our method for tumor tissue segmentation and we obtain state of the art results on cell nuclei separation.

On Inferring Image Label Information Using Rank Minimization for Supervised Concept Embedding

Concept-based representation —combined with some classifier (e.g., support vector machine) or regression analysis (e.g., linear regression)—induces a popular approach among image processing community, used to infer image labels. We propose a supervised learning procedure to obtain an embedding to a latent concept space with the pre-defined inner product. This learning procedure uses rank minimization of the sought inner product matrix, defined in the original concept space, to find an embedding to a new low dimensional space. The empirical evidence show that the proposed supervised learning method can be used in combination with another computational image embedding procedure, such as bag-of-features method, to significantly improve accuracy of label inference, while producing embedding of low complexity.
Supercontinuum Light Sources for Hyperspectral Subsurface Laser Scattering: Applications for Food Inspection

A materials structural and chemical composition influences its optical scattering properties. In this paper we investigate the use of subsurface laser scattering (SLS) for inferring structural and chemical information of food products. We have constructed a computer vision system based on a supercontinuum laser light source and an Acousto-Optic Tunable Filter (AOTF) to provide a collimated light source, which can be tuned to any wavelength in the range from 480 to 900 nm. We present the newly developed hyperspectral vision system together with a proof-of-principle study of its ability to discriminate between dairy products with either similar chemical or structural composition. The combined vision system is a new way for industrial food inspection allowing non-intrusive online process inspection of parameters that is hard with existing technology.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Department of Photonics Engineering, NKT Photonics A/S
Pages: 327-337
Publication date: 2011

Host publication information
Publisher: Springer
ISBN (Print): 978-3-642-21226-0
Series: Lecture Notes in Computer Science
Number: 6688
ISSN: 0302-9743
Main Research Area: Technical/natural sciences
DOIs: 10.1007/978-3-642-21227-7_31
Links: http://www.maths.lth.se/vision/scia2011/
Source: orbit
Source-ID: 277939
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

Geometric Total Variation for Texture Deformation

In this work we propose a novel variational method that we intend to use for estimating non-rigid texture deformation. The method is able to capture variation in grayscale images with respect to the geometry of its features. Our experimental evaluations demonstrate that accounting for geometry of features in texture images leads to significant improvements in localization of these features, when textures undergo geometrical transformations. Accurate localization of features in the presence of unknown deformations is a crucial property for texture characterization methods, and we intend to exploit this property for estimation of non-rigid deformations in our future work.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Drexel University
Authors: Bespalov, D. (Ekstern), Dahl, A. L. (Intern), Shokoufandeh, A. (Ekstern)
Pages: 4597-4600
Publication date: 2010

Host publication information
Title of host publication: Proceedings of 20th International Conference of Pattern Recognition 2010
ISBN (Print): 978-1-4244-7542-1
Main Research Area: Technical/natural sciences
Conference: 20th International Conference on Pattern Recognition, Istanbul, Turkey, 01/01/2010
On Recall Rate of Interest Point Detectors
In this paper we provide a method for evaluating interest point detectors independently of image descriptors. This is possible because we have compiled a unique data set enabling us to determine if common interest points are found. The data contains 60 scenes of a wide range of object types, and for each scene we have 119 precisely located camera positions obtained from a camera mounted on an industrial robot arm. The scene surfaces have been scanned using structured light, providing precise 3D ground truth. We have investigated a number of the most popular interest point detectors. This is done in relation to the number of interest points, the recall rate as a function of camera position and light variation, and the sensitivity relative to model parameter change. The overall conclusion is that the Harris corner detector has a very high recall rate, but is sensitive to change in scale. The Hessian corners perform overall well followed by MSER (Maximally Stable Extremal Regions), whereas the FAST corner detector, IBR (Intensity Based Regions) and EBR (Edge Based Regions) performs poorly. Furthermore, the repeatability of the corner detectors is quite unaffected by the parameter setting, and only the number of interest points change.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, University of Copenhagen
Authors: Aanæs, H. (Intern), Dahl, A. L. (Intern), Pedersen, K. S. (Ekstern)
Publication date: 2010

Host publication information
Title of host publication: Electronic Proceedings of 3DPVT’10 : Fifth International Symposium on 3D Data Processing, Visualization and Transmission
Volume: 5
Main Research Area: Technical/natural sciences
Conference: 3DPVT 2010 : Fifth International Symposium on 3D Data Processing, Visualization and Transmission, Paris, France, 01/01/2010
Interest point detectors, Image correspondence, Stereo, Surface reconstruction

Segmentation by Large Scale Hypothesis Testing - Segmentation as Outlier Detection
We propose a novel and efficient way of performing local image segmentation. For many applications a threshold of pixel intensities is sufficient but determine the appropriate threshold value can be difficult. In cases with large global intensity variation the threshold value has to be adapted locally. We propose a method based on large scale hypothesis testing with a consistent method for selecting an appropriate threshold for the given data. By estimating the background distribution we characterize the segment of interest as a set of outliers with a certain probability based on the estimated densities thus with what certainty the segmented object is not a part of the background. Because the method relies on local information it is very robust to changes in lighting conditions and shadowing effects. The method is applied to endoscopic images of small particles submerged in fluid captured through a microscope and we show how the method can handle transparent particles with significant glare point. The method generalizes to other problems. This is illustrated by applying the method to camera calibration images and MRI of the midsagittal plane for gray and white matter separation and segmentation of the corpus callosum. Comparing the methods corpus callosum segmentation to manual segmentation an average dice score of 0.86 is obtained over 40 images.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics
Publication date: 2010
Shape and Size from the Mist: A Deformable Model for Particle Characterization

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Teraherts Technologies and Biophotonics, Department of Photonics Engineering
Authors: Dahl, A. L. (Intern), Jørgensen, T. M. (Intern), Gundu, P. N. (Intern), Larsen, R. (Intern)
Publication date: 2010

Computer Vision for Timber Harvesting
The goal of this thesis is to investigate computer vision methods for timber harvesting operations. The background for developing computer vision for timber harvesting is to document origin of timber and to collect qualitative and quantitative parameters concerning the timber for efficient harvest planning. The investigations in this thesis is done as initial work on a planning and logistic system for timber harvesting called logTracker. In this thesis we have focused on three methods for the logTracker project, which includes image segmentation, image classification, and image retrieval. Segmentation is to partition an image based on image characteristics and in our study we have focused on image texture. Our segmentation method is inspired by iterative function systems and contractive maps, which makes the basis for both our texture characterization and our method for obtaining the image segments. The purpose of image segmentation is to make the basis for more advanced computer vision methods like object recognition and classification. Our second method concerns image classification and we present a method where we classify small timber samples to tree species based on Active Appearance Models and texture characteristics. The last method is image retrieval based on the so called "bag of visual words" procedure. An image is characterized as a distribution of local image descriptors, which is the basis for effective image search. These methods are described and discussed in relation to the logTracker project and ideas for further development of the system is provided. Building a complete logTracker system is a very demanding task and the conclusion is that it is important to focus on the elements that can bring most value to timber harvest planning. Besides contributing to the development of the logTracker system the described methods have a general applicability making them useful for many other computer vision problems.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, DTU Data Analysis
Authors: Dahl, A. L. (Intern), Ersbøll, B. K. (Intern), Aanæs, H. (Intern)
Publication date: May 2009
Texture Segmentation by Contractive Decomposition and Planar Grouping

Image segmentation has long been an important problem in the computer vision community. In our recent work we have addressed the problem of texture segmentation, where we combined top-down and bottom-up views of the image into a unified procedure. In this paper we extend our work by proposing a modified procedure which makes use of graphs of image regions. In the top-down procedure a quadtree of image region descriptors is obtained in which a novel affine contractive transformation based on neighboring regions is used to update descriptors and determine stable segments. In the bottom-up procedure we form a planar graph on the resulting stable segments, where edges are present between vertices representing neighboring image regions. We then use a vertex merging technique to obtain the final segmentation. We verify the effectiveness of this procedure by demonstrating results which compare well to other recent techniques.

Effective Image Database Search via Dimensionality Reduction

Image search using the bag-of-words image representation is investigated further in this paper. This approach has shown promising results for large scale image collections making it relevant for Internet applications. The steps involved in the bag-of-words approach are feature extraction, vocabulary building, and searching with a query image. It is important to keep the computational cost low through all steps. In this paper we focus on the efficiency of the technique. To do that we substantially reduce the dimensionality of the features by the use of PCA and addition of color. Building of the visual vocabulary is typically done using k-means. We investigate a clustering algorithm based on the leader follower principle (LF-clustering), in which the number of clusters is not fixed. The adaptive nature of LF-clustering is shown to improve the quality of the visual vocabulary using this. In the query step, features from the query image are assigned to the visual vocabulary. The dimensionality reduction enables us to do exact feature labeling using kD-tree, instead of approximate approaches normally used. Despite the dimensionality reduction to between 6 and 15 dimensions we obtain improved results compared to the traditional bag-of-words approach based on 128 dimensional SIFT feature and k-means clustering.
Classification of Biological Objects Using Active Appearance Modelling and Color Cooccurrence Matrices

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Dahl, A. B. (Intern), Aanæs, H. (Intern), Larsen, R. (Intern), Ersbøll, B. K. (Intern)
Pages: 938-947
Publication date: 2007

Host publication information
Title of host publication: Lecture Notes in Computer Science
Volume: 4522
Publisher: Springer
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202518
Publication: Research - peer-review › Book chapter – Annual report year: 2007

Projects:

Machine Learning for Ultrasonic Fault Detection
Technical University of Denmark
Period: 15/08/2017 → 14/08/2020
Number of participants: 4
Phd Student:
Jeppesen, Niels (Intern)
Supervisor:
Christensen, Anders Nymark (Intern)
Vesth, Lars (Ekstern)
Main Supervisor:
Dahl, Anders Bjorholm (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

A Traceable 3D Scanning and Reconstruction Pipeline
Technical University of Denmark
Period: 15/11/2016 → 14/11/2019
Number of participants: 3
Phd Student: Gawrilowicz, Florian (Intern)
Supervisor: Dahl, Anders Bjorholm (Intern)
Main Supervisor: Bærentzen, Jakob Andreas (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

3D image analysis methods for security X-ray screening
Technical University of Denmark
Period: 01/06/2016 → 31/07/2017
Number of participants: 3
Phd Student: Kheirabadi, Mina (Intern)
Supervisor: Olsen, Ulrik Lund (Intern)
Main Supervisor: Dahl, Anders Bjorholm (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

3D Shape Analysis for Morphometric Evolutionary Modelling- based on 3D X-ray Tomography and Optical Scanning
Technical University of Denmark
Period: 01/06/2016 → 31/05/2019
Number of participants: 4
Phd Student: Messer, Dolores (Intern)
Supervisor: Dahl, Vedrana Andersen (Intern)
Orlando, Ludovic Antoine Alexandre (Ekstern)
Main Supervisor: Dahl, Anders Bjorholm (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

3D imaging center
Department of Physics
Neutrons and X-rays for Materials Physics
Department of Applied Mathematics and Computer Science
Image Analysis & Computer Graphics
Department of Energy Conversion and Storage
Imaging and Structural Analysis
Electrofunctional materials
Centre for oil and gas – DTU
Period: 01/01/2016 → 01/01/2021
Number of participants: 14
Project participant:
Dahl, Anders Bjorholm (Intern)
Oddershede, Jette (Intern)
Trinderup, Camilla Himmelstrup (Intern)
Simonsen, Søren Bredmose (Intern)
Zheng, Yi (Intern)
Brink, Bastian (Intern)
Lauridsen, Torsten (Ekstern)
Thydén, Karl Tor Sune (Intern)
Sanna, Simone (Intern)
Baier, Sina (Intern)
Bentzen, Janet Jonna (Intern)
Christensen, Anders Nymark (Intern)
Project Manager, organisational:
Gundlach, Carsten (Intern)
Project Manager, academic:
Poulsen, Henning Friis (Intern)

Relations
Related projects:
Alliance for Imaging and Modelling of Energy Applications
Publications:
Powder embossing method for selective loading of polymeric microcontainers with drug formulation
Crack Tip Flipping under Mode I Tearing: Investigated by X-Ray Tomography
In-Situ X-ray Tomography Study of Cement Exposed to CO₂ Saturated Brine
Graphite nodules in fatigue-tested cast iron characterized in 2D and 3D
Scene reassembly after multimodal digitization and pipeline evaluation using photorealistic rendering
From concept to in vivo testing: Microcontainers for oral drug delivery
Synthesis and characterization of Fe–Ni/γ-Al₂O₃ egg-shell catalyst for H₂ generation by ammonia decomposition
Microstructure and micromechanics of the heart urchin test from X-ray tomography
Surface Detection using Round Cut
Characterization of graphite nodules in thick-walled ductile cast iron
High-Performance Microchanneled Asymmetric Gd₀.₁Ce₀.₉O₁.₉₅-La₀.₆Sr₀.₄FeO₃.₅-Based Membranes for Oxygen Separation

Big Data Modelling with Applications to Airports
Technical University of Denmark
Period: 01/08/2015 → 31/12/2018
Number of participants: 3
Phd Student:
Nielsen, Agnes Martine (Intern)
Supervisor:
Dahl, Anders Bjorholm (Intern)
Main Supervisor:
Clemmensen, Line Katrine Harder (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD
Verification of large scale surface geometry including shape and texture variation of injection molded surfaces

Technical University of Denmark
Period: 15/01/2015 → 15/07/2018
Number of participants: 4
Phd Student:
Lyngby, Rasmus Ahrenkiel (Intern)
Supervisor:
Aanæs, Henrik (Intern)
Nielsen, Ewa (Ekstern)
Main Supervisor:
Dahl, Anders Bjorholm (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD
Project: PhD

Image analysis and segmentation using sparse coding dictionaries

Technical University of Denmark
Period: 01/09/2014 → 01/12/2017
Number of participants: 6
Phd Student:
Emerson, Monica Jane (Intern)
Supervisor:
Conradsen, Knut (Intern)
Main Supervisor:
Dahl, Anders Bjorholm (Intern)
Examiner:
Bærentzen, Jakob Andreas (Intern)
Hansen, Dan Witzner (Intern)
Sladoje, Natasa (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Quantitative evaluation of peptide analogue distribution in mouse tissue using 3D computer modelling

Technical University of Denmark
Period: 01/09/2014 → 15/11/2017
Number of participants: 6
Phd Student:
Jensen, Casper Bo (Intern)
Supervisor:
Conradsen, Knut (Intern)
Main Supervisor:
Dahl, Anders Bjorholm (Intern)
Examiner:
Dyrby, Tim Bjørn (Intern)
Kirik, Deniz (Ekstern)
Nielsen, Mads (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD

Relations
Publications:
Quantitative evaluation of peptide analogue distribution in mouse tissue using 3D computer modelling
Alliance for Imaging and Modelling of Energy Applications
The CINEMA research alliance will develop unique 3D micro-structural characterization methods, which make it possible to investigate components under realistic conditions and in real time. This will enable correlation between performance and local changes in the microstructure.

Department of Energy Conversion and Storage
Imaging and Structural Analysis
Department of Physics
Neutrons and X-rays for Materials Physics
Department of Wind Energy
Composites and Materials Mechanics
Department of Applied Mathematics and Computer Science
Image Analysis & Computer Graphics
Scientific Computing
Mixed Conductors
Statistics and Data Analysis
University of Copenhagen
Northwestern University
University of Manchester
MaxLab
LM Wind Power
Haldor Topsoe AS
Xnovo Technology ApS
Rockwool International
Amminex Emissions Technology A/S
Period: 01/01/2014 → 31/12/2018
Number of participants: 26
Acronym: CINEMA
Project participant:
Mikkelsen, Lars Pilgaard (Intern)
Sørensen, Bent F. (Intern)
Bowen, Jacob R. (Intern)
Kuhn, Luise Theil (Intern)
Larsen, Rasmus (Intern)
Hansen, Per Christian (Intern)
Frandsen, Henrik Lund (Intern)
Gundlach, Carsten (Intern)
Dahl, Anders Bjørholm (Intern)
Yang, Shu-Yi (Intern)
Poulsen, Stefan Othmar (Intern)
Lykkegaard, Allan (Intern)
Lauridsen, Erik Mejdal (Intern)
Sørensen, Henning Osholm (Ekstern)

Project Manager, organisational:
Sørensen, Hanne (Intern)

Phd Student:
Jespersen, Kristine Munk (Intern)
Beil, Johannes (Ekstern)
Andersen, Michael (Intern)
Emerson, Monica Jane (Intern)
De Angelis, Salvatore (Intern)
Birkelund, Klaus (Ekstern)
Jacobsen, Hjalte Sylvest (Intern)
Chapelle, Lucie (Intern)
Supervisor:
Frandsen, Henrik Lund (Intern)
Project Manager, academic:
Andreasen, Jens Wenzel (Intern)
Project Coordinator:
Poulsen, Henning Friis (Intern)

Relations
Activities:
DTU Energy Conversion 2nd International PhD Summer School
W. Wilson K. S. Chiu
Gerardina Carbone
High resolution ptychographic tomography of soft matter
Publications:
3D X-Ray Computed Tomography (XCT) of Fatigue Damage Evolution in UD Glass Fibre Composite
Enabling Flexible Polymer Tandem Solar Cells by 3D Ptychographic Imaging
Dictionary Based Segmentation in Volumes
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites
Improving organic tandem solar cells based on water-processed nanoparticles by quantitative 3D nanoimaging
Fatigue damage evolution in fibre composites for wind turbine blades
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites

Statistical Priors in Variational Reconstruction Methods
Technical University of Denmark
Period: 01/11/2012 → 24/02/2016
Number of participants: 6
Phd Student:
Romanov, Mikhail (Intern)
Supervisor:
Hansen, Per Christian (Intern)
Main Supervisor:
Dahl, Anders Bjorholm (Intern)
Examiner:
Bærentzen, Jakob Andreas (Intern)
Batenburg, Kees Jost (Ekstern)
Lauze, Francois Bernard (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

Statistical Shape Modelling of the Human Cochlear with Application to Cochlear Implant Surgical Procedures
Technical University of Denmark
Period: 01/09/2012 → 30/09/2015
Number of participants: 5
Phd Student:
Trainilng sets in Large-Scale Reconstruction Methods

Technical University of Denmark
Period: 01/09/2012 → 23/10/2015
Number of participants: 6
Phd Student:
Soltani, Sara (Intern)
Supervisor:
Andersen, Martin Skovgaard (Intern)
Main Supervisor:
Hansen, Per Christian (Intern)
Examiner:
Dahl, Anders Bjorholm (Intern)
Siltanen, Samuli (Ekstern)
Van Huffel, Sabine (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

Control and Surveillance of Automated Production Steps using Computer Vision

Technical University of Denmark
Period: 15/07/2012 → 25/08/2016
Number of participants: 6
Phd Student:
Larsen, Anders Boesen Lindbo (Intern)
Supervisor:
Dahl, Anders Bjorholm (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Nielsen, Allan Aasbjerg (Intern)
Belongie, Serge (Ekstern)
Nielsen, Mads (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

Spectral imaging of meat quality - color, texture and structure

Technical University of Denmark
Period: 01/12/2011 → 19/03/2015
Number of participants: 6
Phd Student:
Trinderup, Camilla Himmelstrup (Intern)
Supervisor: Dahl, Anders Bjorholm (Intern)
Main Supervisor: Conradsen, Knut (Intern)
Examiner: Clemmensen, Line Katrine Harder (Intern)
Christensen, Lars Bager (Intern)
Parker, Alan (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

**SLS based dairy process control systems**
Technical University of Denmark
Period: 15/12/2010 → 29/08/2014
Number of participants: 6
Phd Student: Skytte, Jacob Lercke (Intern)
Supervisor: Dahl, Anders Bjorholm (Intern)
Main Supervisor: Larsen, Rasmus (Intern)
Examiner: Nielsen, Allan Aasbjerg (Intern)
Parkkinen, Jussi (Ekstern)
Åström, Kalle (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

**Optimization of super continuum light sources for vision systems**
Technical University of Denmark
Period: 15/06/2010 → 29/08/2014
Number of participants: 6
Phd Student: Abildgaard, Otto Højager Attermann (Intern)
Supervisor: Larsen, Rasmus (Intern)
Main Supervisor: Dahl, Anders Bjorholm (Intern)
Examiner: Christensen, Niels Jørgen (Intern)
Parker, Alan (Ekstern)
Strömberg, Tomas (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

**Godkendelse og sporing af tømmerstokke ved 3D-billedbehandling**
Department of Informatics and Mathematical Modeling
Period: 15/10/2005 → 27/05/2009
Number of participants: 7
Phd Student:
Dahl, Anders Bjørholm (Intern)
Supervisor:
Aanæs, Henrik (Intern)
Tarp-Johansen, Mads Jeppe (Ekstern)
Main Supervisor:
Ersbøll, Bjarne Kjær (Intern)
Examiner:
Hansen, Lars Kai (Intern)
Demirci, M. Fatih (Ekstern)
Sauter, Udo Hans (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD