Can we train a single deep learning model to detect and segment nuclei images acquired with any microscope or staining modality?

General information
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Shihavuddin, A. (Intern), Gawrilowicz, F. (Intern), Jeppesen, N. (Intern), Paulsen, R. R. (Intern)
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Computerized feedback during colonoscopy training leads to improved performance: a randomized trial
Background and Aims: Simulation-based training in colonoscopy is increasingly replacing the traditional apprenticeship method to avoid patient-related risk. Mentoring during simulation is necessary to provide feedback and to motivate, but expert supervisors are a scarce resource. We aimed to determine whether computerized feedback in simulated colonoscopy would improve performance, optimize time spent practicing, and optimize the pattern of training. Methods: Forty-four participants were recruited and randomized to either a feedback group (FG) or a control group (CG). Participants were allowed 2 hours of self-practice where they could practice as they saw fit on 2 different cases: one easy and one difficult. The CG practiced without feedback but the FG was given a score of progression every time they reached the cecum. All participants were tested on a different case after end of training. The primary outcome was progression score in the final case and secondary outcomes were time spent practicing and training pattern. Results: Regression analysis adjusting for sex was done due to an uneven sex distribution between groups (P = 0.026) and significantly higher performance scores by men (37.6, SD 25.9) compared with women (19.7, SD 18.7), P = 0.012. The FG outperformed the
CG in the final case (FG scoring 14.4 points (95% CI, 1.2 - 27.6) more than the CG, P = 0.033) and spent more time practicing (FG practicing 25.8 minutes [95% CI, 11.6 - 39.9] more than the CG; P = 0.001). The FG practiced more on the easy case and reached the cecum 3.2 times more (95% CI, 2 - 4.5) during practice (P <0.001). Conclusions: Our findings of this study revealed that an automatic, computerized score of progression during simulated colonoscopy motivates the novices to improve performance, optimize time spent practicing, and optimize their pattern of training (Clinical trial registration number: NCT03248453).

FastSME: faster and smoother manifold extraction from 3D stack

A personalized estimation of the cochlear shape can be used to create computational anatomical models to aid cochlear implant (CI) surgery and CI audio processor programming ultimately resulting in improved hearing restoration. The purpose of this work is to develop and test a method for estimation of the detailed patient-specific cochlear shape from CT images. From a collection of temporal bone [Formula: see text]CT images, we build a cochlear statistical deformation
model (SDM), which is a description of how a human cochlea deforms to represent the observed anatomical variability. The model is used for regularization of a non-rigid image registration procedure between a patient CT scan and a [Formula: see text]CT image, allowing us to estimate the detailed patient-specific cochlear shape. We test the accuracy and precision of the predicted cochlear shape using both [Formula: see text]CT and CT images. The evaluation is based on classic generic metrics, where we achieve competitive accuracy with the state-of-the-art methods for the task. Additionally, we expand the evaluation with a few anatomically specific scores. The paper presents the process of building and using the SDM of the cochlea. Compared to current best practice, we demonstrate competitive performance and some useful properties of our method.

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Scopus rating (2014): SJR 0.551 SNIP 1.277 CiteScore 1.79
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Scopus rating (2010): SJR 0.361 SNIP 0.79
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Perceptually motivated analysis of numerically simulated head-related transfer functions generated by various 3D surface scanning systems
Numerical simulations offer a feasible alternative to the direct acoustic measurement of individual head-related transfer functions (HRTFs). For the acquisition of high quality 3D surface scans, as required for these simulations, several approaches exist. In this paper, we systematically analyze the variations between different approaches and evaluate the influence of the accuracy of 3D scans on the resulting simulated HRTFs. To assess this effect, HRTFs were numerically simulated based on 3D scans of the head and pinna of the FABIAN dummy head generated with 6 different methods. These HRTFs were analyzed in terms of interaural time difference, interaural level difference, energetic error in auditory filters and by their modeled localization performance. From the results, it is found that a geometric precision of about 1 mm is needed to maintain accurate localization cues, while a precision of about 4 mm is sufficient to maintain the overall spectral shape.
Data Descriptor: A multiscale imaging and modelling dataset of the human inner ear
Understanding the human inner ear anatomy and its internal structures is paramount to advance hearing implant technology. While the emergence of imaging devices allowed researchers to improve understanding of intracochlear structures, the difficulties to collect appropriate data has resulted in studies conducted with few samples. To assist the cochlear research community, a large collection of human temporal bone images is being made available. This data descriptor, therefore, describes a rich set of image volumes acquired using cone beam computed tomography and micro-CT modalities, accompanied by manual delineations of the cochlea and sub-compartments, a statistical shape model encoding its anatomical variability, and data for electrode insertion and electrical simulations. This data makes an important asset for future studies in need of high-resolution data and related statistical data objects of the cochlea used to leverage scientific hypotheses. It is of relevance to anatomists, audiologists, computer scientists in the different domains of image analysis, computer simulations, imaging formation, and for biomedical engineers designing new strategies for cochlear implantations, electrode design, and others.

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 amount 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.
Medial structure generation for registration of anatomical structures

Medial structures (skeletons and medial manifolds) have shown capacity to describe shape in a compact way. In the field of medical imaging, they have been employed to enrich the description of organ anatomy, to improve segmentation, or to describe the organ position in relation to surrounding structures. Methods for generation of medial structures, however, are prone to the generation of medial artifacts (spurious branches) that traditionally need to be pruned before the medial structure can be used for further computations. The act of pruning can affect main sections of the medial surface, hindering its performance as shape descriptor. In this work, we present a method for the computation of medial structures that generates smooth medial surfaces that do not need to be explicitly pruned. Additionally, we present a validation framework for medial surface evaluation. Finally, we apply this method to create a parametric model of the cochlea shape that yields better registration results between cochleae.

A framework for geometry acquisition, 3-D printing, simulation, and measurement of head-related transfer functions with a focus on hearing-assistive devices

Individual head-related transfer functions (HRTFs) are essential in applications like fitting hearing-assistive devices (HADs) for providing accurate sound localization performance. Individual HRTFs are usually obtained through intricate acoustic measurements. This paper investigates the use of a three-dimensional (3D) head model for acquisition of individual HRTFs. Two aspects were investigated; whether a 3D-printed model can replace measurements on a human listener and whether numerical simulations can replace acoustic measurements. For this purpose, HRTFs were acoustically measured for four human listeners and for a 3D printed head model of one of these listeners. Further, HRTFs were simulated by applying the finite element method to the 3D head model. The monaural spectral features and spectral distortions were very similar between re-measurements and between human and printed measurements, however larger
deviations were observed between measurement and simulation. The binaural cues were in agreement among all HRTFs of the same listener, indicating that the 3D model is able to provide localization cues potentially accessible to HAD users. Hence, the pipeline of geometry acquisition, printing, and acoustic measurements or simulations, seems to be a promising step forward towards in-silico design of HADs.

**General information**

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Copenhagen Center for Health Technology, Austrian Academy of Sciences, Oticon A/S, Eriksholm Research Centre

Authors: Harder, S. (Intern), Paulsen, R. R. (Intern), Larsen, M. (Ekstern), Laugesen, S. (Ekstern), Mihocic, M. (Ekstern), Majdak, P. (Ekstern)

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Scopus rating (2010): SJR 0.844 SNIP 2.463

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Scopus rating (2001): SJR 1.28 SNIP 2.506

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Automatic Model Generation Framework for Computational Simulation of Cochlear Implantation

Recent developments in computational modeling of cochlear implantation are promising to study in silico the performance of the implant before surgery. However, creating a complete computational model of the patient's anatomy while including an external device geometry remains challenging. To address such a challenge, we propose an automatic framework for the generation of patient-specific meshes for finite element modeling of the implanted cochlea. First, a statistical shape model is constructed from high-resolution anatomical μCT images. Then, by fitting the statistical model to a patient's CT image, an accurate model of the patient-specific cochlea anatomy is obtained. An algorithm based on the parallel transport frame is employed to perform the virtual insertion of the cochlear implant. Our automatic framework also incorporates the surrounding bone and nerve fibers and assigns constitutive parameters to all components of the finite element model. This model can then be used to study in silico the effects of the electrical stimulation of the cochlear implant. Results are shown on a total of 25 models of patients. In all cases, a final mesh suitable for finite element simulations was obtained, in an average time of 94 s. The framework has proven to be fast and robust, and is promising for a detailed prognosis of the cochlear implantation surgery.

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.2 SNIP 1.345 CiteScore 3.21
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.12 SNIP 1.49 CiteScore 3.29
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Scopus rating (2013): SJR 1.28 SNIP 1.434 CiteScore 3.38
ISI indexed (2013): ISI indexed yes
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Cochlear implant electrode localization in post-operative CT using a spherical measure

When implanting cochlear implants the positions of electrodes have a large impact on the quality of the restored hearing. Due to metal artifacts it is difficult to estimate the precise location in post-operative scans. In this paper we present a method for automatically locating and determining the ordering of electrode contacts on implanted electrode arrays from post-operative CT images. Our method applies a specialized filter chain to the images based on a threshold and spherical measure, and selects contact positions at local maxima in the filtered image. Two datasets of 13 temporal bone specimens scanned in CBCT are used to validate the method, which successfully locates the electrode array in every image.

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Authors: Braithwaite, B. M. (Intern), Kjer, H. M. (Intern), Fagertun, J. (Intern), González Ballester, M. A. (Ekstern), Dhanasingh, A. (Ekstern), Mistrik, P. (Ekstern), Gerber, N. (Ekstern), Paulsen, R. R. (Intern)
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Cochlear Implant, Electrode array
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Free-form image registration of human cochlear μCT data using skeleton similarity as anatomical prior

Better understanding of the anatomical variability of the human cochlear is important for the design and function of Cochlear Implants. Proper non-rigid alignment of high-resolution cochlear μCT data is a challenge for the typical cubic B-spline registration model. In this paper we study one way of incorporating skeleton-based similarity as an anatomical registration prior. We extract a centerline skeleton of the cochlear spiral, and generate corresponding parametric pseudo-landmarks between samples. These correspondences are included in the cost function of a typical cubic B-spline registration model to provide a more global guidance of the alignment. The resulting registrations are evaluated using different metrics for accuracy and model behavior, and compared to the results of a registration without the prior.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Alma IT Systems, Universidad Autonoma de Barcelona, Catalan Institution for Research and Advanced Studies
Authors: Kjer, H. M. (Intern), Fagertun, J. (Intern), Vera, S. (Ekstern), Gil, D. (Ekstern), González Ballester, M. A. (Ekstern), Paulsen, R. R. (Intern)
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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.95 SNIP 1.979 CiteScore 2.87
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.73 SNIP 2.148 CiteScore 2.72
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.768 SNIP 2.495 CiteScore 2.86
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 0.66 SNIP 2.325 CiteScore 2.57
ISI indexed (2012): ISI indexed yes
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Scopus rating (2011): SJR 0.662 SNIP 1.945 CiteScore 2.56
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.721 SNIP 1.951
Web of Science (2010): Indexed yes
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Scopus rating (2009): SJR 0.767 SNIP 2.306
Web of Science (2009): Indexed yes
Modelling of the Human Inner Ear Anatomy and Variability for Cochlear Implant Applications

This thesis takes the biomedical engineering approach to working with and understanding the anatomy and physiology of the inner ear. The purpose is to apply the acquired knowledge in the development of implantable hearing aids.

The so-called Cochlear Implant (CI) is a fascinating technology that without underselling it provides hearing for the deaf. The technology faces a number of challenges, and a part of the solution to those is closely connected with an improved understanding of the inner ear anatomy, both with regards to the individual patient but also to the variation in the population.

The inner ear is a relatively small structure and even with modern medical scanners only the coarsest details are revealed about the specific patient anatomy. To study the anatomy it is required to work on specimens from deceased subjects scanned with for instance μCT. The anatomy is complex and presents several challenges concerning data processing and analysis.

Our approach is to describe the inner ear as a statistical shape model. The thesis covers our work with regards to data segmentation, shape characterization, development of image registration model suited for the inner ear and construction of statistical deformation models.

The thesis results in a series of applications relating to CIs. The shape model can be used by CI-manufacturers for virtual product development and testing. At the same time, it can be applied to estimate the detailed inner ear shape from a clinical patient CT scan. This opens up for tools to optimize the programming of the CI, such that the hearing restoration is improved.

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Monopolar Stimulation of the Implanted Cochlea: A Synthetic Population-Based Study

Cochlear implantation is carried out to recover the sense of hearing. However, its functional outcome varies highly between patients. In the current work, we present a study to assess the functional outcomes of cochlear implants considering the inter-variability found among a population of patients. In order to capture the cochlear anatomical details, a statistical shape model is created from high-resolution human μCT data. A population of virtual patients is automatically generated by sampling new anatomical instances from the statistical shape model. For each virtual patient, an implant insertion is simulated and a finite element model is generated to estimate the electrical field created into the cochlea. These simulations are defined according to the monopolar stimulation protocol of a cochlear implant and a prediction of the voltage spread over the population of virtual patients is evaluated.

Motion Tracking of Infants in Risk of Cerebral Palsy

Every year 2-3 out of 1000 infants are born with cerebral cerebral palsy. Among others, the disorder often affects motor, cognitive and perceptual skills. The disorder is usually detected when the infants are old enough the crawl and walk, i.e. when the infant is 1-2 years old. However, studies show that the infant’s movements are affected already in the first year of life and methods exist for assessing the movements. The methods often require observation of the movements and qualitative evaluation of these. A more objective measure is desired in order to be able to diagnose cerebral palsy much earlier.

The goal with this thesis is to describe the development of a markerless motion tracking system for infants. Based on data recorded with a low-cost depth sensor, image analysis and mathematical modeling is used to model the infant’s body and its movements. Two methods are considered, where the first method is able to do single frame pose estimation, based on simple assumptions on the infant’s body. The second method uses an articulated model that incorporates anatomical constraints. Combining the two methods results in a robust motion tracking system for infants.

The results from the motion tracking are used to extract physical features such as velocity and acceleration of the individual body parts. A novel method for estimating scene ow in human motion data is presented, utilizing the results from the motion tracking. A number of examples are given for potential applications for automatic assessment of infant movement. This includes a preliminary study on automatic classification of movements related to cerebral palsy.
The contributions included in this thesis can be divided into two groups. The first two contributions consider the analysis in order to estimate and track the body of the infants. The remaining contributions consider different motion features derived from the motion tracking results. Both pose and motion features are extracted and used for assessing the infants’ motor development.

The presented work is a step closer to automatic motion assessment of infants with focus on early diagnosis of infants with cerebral palsy. Further collaboration with clinicians can result in breakthroughs in the way infants are monitored and assessed during the early years of life.

The main motivation is to be able to assess infants in risk of cerebral palsy based on the previously established connection between infant movement and brain injuries. However, as the data used in this study is recorded simultaneously with the study, the true outcome is not known. Even though some of the included infants were born preterm, none of them have to date been diagnosed with cerebral palsy.

**Real Time Structured Light and Applications**

Structured light scanning is a versatile method for 3D shape acquisition. While much faster than most competing measurement techniques, most high-end structured light scans still take in the order of seconds to complete.

Low-cost sensors such as Microsoft Kinect and time of flight cameras have made 3D sensor ubiquitous and have resulted in a vast amount of new applications and methods. However, such low-cost sensors are generally limited in their accuracy and precision, making them unsuitable for e.g. accurate tracking and pose estimation.

With recent improvements in projector technology, increased processing power, and methods presented in this thesis, it is possible to perform structured light scans in real time with 20 depth measurements per second. This offers new opportunities for studying dynamic scenes, quality control, human-computer interaction and more.

This thesis discusses several aspects of real time structured light systems and presents contributions within calibration, scene coding and motion correction aspects. The problem of reliable and fast calibration of such systems is addressed with a novel calibration scheme utilising radial basis functions [Contribution B]. A high performance flexible open source software toolkit is presented [Contribution C], which makes real time scanning possible on commodity hardware. Further, an approach is presented to correct for motion artifacts in dynamic scenes [Contribution E].

An application for such systems is presented with a head tracking approach for medical motion correction [Contribution A, F]. This aims to solve the important problem of motion artifacts, which occur due to head movement during long acquisition times in MRI and PET scans. In contrast to existing methods, the one presented here is MRI compatible [Contribution D], not dependent on fiducial markers, and suitable for prospective correction.

Factors contributing to accuracy and precision of structured light systems are investigated with a study of performance factors [Contribution G]. This is also done in the context of biological tissue, which exhibit subsurface effects and other undesirable effects [Contribution H], and it is shown that this error is to a large extent deterministic and can be corrected.
Anatomically Correct Surface Recovery: A Statistical Approach

We present a method for 3D surface recovery in partial surface scans. The method is based on an Active Shape Model, which is used to predict missing data. The model is constructed using a bootstrap framework, where an initially small collection of hand-annotated samples is used to fit to and register unknown samples, resulting in an extensive statistical model. The statistical recovery uses a multivariate point prediction, where the distribution of the points is given by the Active Shape Model. We show how missing data in a partial scan, once point correspondence is achieved, can be predicted using the learned statistics. A quantitative evaluation is performed on a data set of 10 laser scans of ear canal impressions with minimal noise and artificial holes. We also present a qualitative evaluation on authentic partial scans from an actual direct in ear scanner prototype. Compared to a state-of-the-art surface reconstruction algorithm, the presented method gives matching prediction results for the synthetic evaluation samples and superior results for the direct scanner data.

General information

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Assisting doctors on assessing movements in infants using motion tracking
In this work, we consider the possibilities of having an automatic computer-based system for tracking the movements of infants. An existing motion tracking system is used to process recorded video sequences containing both color and spatial information of the infant's body pose and movements. The system uses these sequences of data to estimate the underlying skeleton of the infant and parametrize the movements. Post-processing of these parameters can yield objective measurements of an infant's movement patterns. This could e.g. be quantification of (a)symmetry and recognition of certain gestures/actions such as kicking, crying, roll over and bringing hands together. Clinicians could benefit from such a system, as it would ease the task of diagnosing infants with motor disorders, and in some cases, this could initiate an intervention earlier than usual. It should be clear, that we do not seek to substitute the task of the clinicians, but the system should instead be considered as a tool for easy extraction of objective measurements describing the movements and as well as a screening tool for highlighting certain patterns in the movements.

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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.23 SJR 1.591 SNIP 1.546
Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 1.714 SNIP 1.709 CiteScore 2.26
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.749 SNIP 1.712 CiteScore 2.24
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.54 SNIP 1.809 CiteScore 2.27
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.298 SNIP 1.49 CiteScore 2.06
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.361 SNIP 1.595 CiteScore 2.16
BFI (2010): BFI-level 1
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Scopus rating (2008): SJR 1.506 SNIP 1.573
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Automatic Generation of a Computational Model for Monopolar Stimulation of Cochlear Implants

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Authors: Mangado, N. (Ekstern), Ceresa, M. (Ekstern), Duchateau, N. (Ekstern), Dejea Velardo, H. (Ekstern), Kjer, H. M. (Intern), Paulsen, R. R. (Intern), Vera, S. (Ekstern), Mistrik, P. (Ekstern), Herrero, J. (Ekstern), Ballester, M. G. (Ekstern)
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Scopus rating (2009): SJR 0.198 SNIP 0.323
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Cochlear Implant Planning, Selection and Simulation with Patient Specific Data

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Copenhagen Center for Health Technology, Alma IT Systems, MED-EL GMBH, UPF/ICREA
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Correction of Motion Artifacts for Real-Time Structured Light

While the problem of motion is often mentioned in conjunction with structured light imaging, few solutions have thus far been proposed. A method is demonstrated to correct for object or camera motion during structured light 3D scene acquisition. The method is based on the combination of a suitable pattern strategy with fast phase correlation image registration. The effectiveness of this approach is demonstrated on motion corrupted data of a real-time structured light system, and it is shown that it improves the quality of surface reconstructions visually and quantitively.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Authors: Wilm, J. (Intern), Olesen, O. V. (Intern), Paulsen, R. R. (Intern), Larsen, R. (Intern)
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Authors: Paulsen, R. R. (ed.) (Intern), Pedersen, K. S. (ed.) (Ekstern)
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The 19th Scandinavian Conference on Image Analysis was held at the IT University of Copenhagen in Denmark during June 15-17, 2015. The SCIA conference series has been an ongoing biannual event for more than 30 years and over the years it has nurtured a world-class regional research and development area within the four participating Nordic countries. It is a regional meeting of the International Association for Pattern Recognition (IAPR).

We would like to thank all authors who submitted works to this year’s SCIA, the invited speakers, and our Program Committee.

In total 67 papers were submitted to SCIA 2015 and were reviewed by members of the Program Committee and additional reviewers. Each paper was reviewed by at least two independent reviewers followed by a meta-review by the Program Committee. Finally, 26 papers were chosen for oral presentation and 19 papers for poster presentation. The topics of the accepted papers range from novel applications of vision systems, pattern recognition, machine learning, feature
extraction, segmentation, 3D vision, to medical and biomedical image analysis. The papers originate from all the
Scandinavian countries and several other European countries.
It is our sincere hope that the participants had an enjoyable and fruitful experience, both scientifically and socially, in
Copenhagen.

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Image Registration of Cochlear µCT Data Using Heat Distribution Similarity
Better understanding of the anatomical variability of the human cochlear is important for the design and function of
Cochlear Implants. Good non-rigid alignment of high-resolution cochlear µCT data is a challenging task.

In this paper we study the use of heat distribution similarity between samples as an anatomical registration prior. We set-
up and present our heat distribution model for the cochlea and utilize it in a typical cubic B-spline registration model.
Evaluation and comparison is done against a corresponding normal registration of binary segmentations.

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Medical Systems, Universidad Autonoma de Barcelona, Universitat Pompeu Fabra, Catalan Institution for Research and
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Authors: Kjer, H. M. (Intern), Vera, S. (Ekstern), Fagertun, J. (Intern), Gil, D. (Ekstern), González Ballester, M. A. (Ekstern)
, Paulsen, R. R. (Intern)
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Individualized directional microphone optimization in hearing aids based on reconstructing the 3D geometry of the head and ear from 2D images

The goal of this thesis is to improve intelligibility for hearing-aid users by individualizing the directional microphone in a hearing aid. The general idea is a three step pipeline for easy acquisition of individually optimized directional filters. The first step is to estimate an individual 3D head model based on 2D images, the second step is to simulate individual head related transfer functions (HRTFs) based on the estimated 3D head model and the final step is to calculate optimal directional filters based on the simulated HRTFs. The pipeline is employed on a Behind-The-Ear (BTE) hearing aid.

We verify the directional filters optimized from simulated HRTFs based on a listener-specific head model against two set of optimal filters. The first set of optimal filters is calculated from HRTFs measured on a 3D printed version of the head model. The second set of optimal filters is calculated from HRTFs measured on the actual human subject.

A verification of the 'simulated' directional filters against the optimal filters for the human subject revealed a 0.5 dB reduction in articulation-index weighted directivity index, which corresponds to 5% less speech intelligibility. A comparison against non-individual directional filters revealed equally high Articulation-Index weighted Directivity Index (AI-DI) values for our specific test subject. However, measurements on other individuals indicate that the performance of the non-individual filters vary among subjects, and in particular individuals who deviate from an average of the population could benefit from having individualized filters.

We developed a pipeline for 3D printing of full size human heads. The 3D printed head facilitated the second verification step, which revealed a 0.3 dB reduction from optimal to simulated directional filters. This indicates that the simulation are more similar to measurements on the 3D printed head than measurements on the human subject. We suggest that the larger difference between simulation and human measurements could arise due to small geometrical errors in the head model or due to differences in acoustical properties between human skin and virtual material properties in the simulation.

The BTE hearing aid showed very little room for improvement using individualized directional filters, however the directional filters in an In-The-Ear (ITE) hearing aid revealed an improvement in AI-DI values of up to 3.6 dB between an average filter and an optimal filter. This suggests that hearing-aid users with ITE hearing aids could benefit more from having individualized directional filters than what was shown for a BTE hearing aid.

This thesis is a step towards individualizing the directional microphone in hearing aids, which could contribute with improved sound for a group of hearing-aid users. In particular, we believe that ITE hearing-aid users could have a large benefit from an individualized directional microphone.

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Predicting Detailed Inner Ear Anatomy from Pre-Oppreoperational CT for cochlear implant surgery

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Authors: Kjer, H. M. (Intern), Vera, S. (Ekstern), Fagertun, J. (Intern), Peréz, F. (Ekstern), Herrero, J. (Ekstern), Ballester, M. G. (Ekstern), Paulsen, R. R. (Intern)
Predicting facial characteristics from complex polygenic variations

Research into the importance of the human genome in the context of facial appearance is receiving increasing attention and has led to the detection of several Single Nucleotide Polymorphisms (SNPs) of importance. In this work we attempt a holistic approach predicting facial characteristics from genetic principal components across a population of 1,266 individuals. For this we perform a genome-wide association analysis to select a large number of SNPs linked to specific facial traits, recode these to genetic principal components and then use these principal components as predictors for facial traits in a linear regression. We show in this proof-of-concept study for facial trait prediction from genome-wide SNP data that some facial characteristics can be modeled by genetic information: facial width, eyebrow width, distance between eyes, and features involving mouth shape are predicted with statistical significance ($p < 0.03$).
Reliability in Measuring Head Related Transfer Functions of Hearing Aids

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Authors: Harder, S. (Intern), Paulsen, R. R. (Intern), Larsen, M. (Ekstern), Laugesen, S. (Ekstern), Mihocic, M. (Ekstern), Majdak, P. (Ekstern)
Pages: 1064-1066
Using Motion Tracking to Detect Spontaneous Movements in Infants

We study the characteristics of infants’ spontaneous movements, based on data obtained from a markerless motion tracking system. From the pose data, the set of features are generated from the raw joint-angles of the infants and different classifiers are trained and evaluated using annotated data. Furthermore, we look at the importance of different features and outline the most significant features for detecting spontaneous movements of infants. Using these findings for further analysis of infants’ movements, this might be used to identify infants in risk of cerebral palsy.

VirtualTable: a projection augmented reality game

VirtualTable is a projection augmented reality installation where users are engaged in an interactive tower defense game. The installation runs continuously and is designed to attract people to a table, which the game is projected onto. Any number of players can join the game for an optional period of time. The goal is to prevent the virtual stylized soot balls, spawning on one side of the table, from reaching the cheese. To stop them, the players can place any kind of object on the table, that then will become part of the game. Depending on the object, it will become either a wall, an obstacle for the soot balls, or a tower, that eliminates them within a physical range. The number of enemies is dependent on the number of objects in the field, forcing the players to use strategy and collaboration and not the sheer number of objects to win the game.
3D facial landmarks: Inter-operator variability of manual annotation

Background
Manual annotation of landmarks is a known source of variance, which exist in all fields of medical imaging, influencing the accuracy and interpretation of the results. However, the variability of human facial landmarks is only sparsely addressed in the current literature as opposed to e.g. the research fields of orthodontics and cephalometrics. We present a full facial 3D annotation procedure and a sparse set of manually annotated landmarks, in effort to reduce operator time and minimize the variance.

Method
Facial scans from 36 voluntary unrelated blood donors from the Danish Blood Donor Study was randomly chosen. Six operators twice manually annotated 73 anatomical and pseudo-landmarks, using a three-step scheme producing a dense point correspondence map. We analyzed both the intra- and inter-operator variability, using mixed-model ANOVA. We then compared four sparse sets of landmarks in order to construct a dense correspondence map of the 3D scans with a minimum point variance.

Results
The anatomical landmarks of the eye were associated with the lowest variance, particularly the center of the pupils. Whereas points of the jaw and eyebrows have the highest variation. We see marginal variability in regards to intra-operator and portraits. Using a sparse set of landmarks (n=14), that capture the whole face, the dense point mean variance was reduced from 1.92 to 0.54 mm.

Conclusion
The inter-operator variability was primarily associated with particular landmarks, where more leniently landmarks had the highest variability. The variables embedded in the portray and the reliability of a trained operator did only have marginal influence on the variability. Further, using 14 of the annotated landmarks we were able to reduced the variability and create a dense correspondences mesh to capture all facial features.
Body-Part Tracking of Infants

Motion tracking is a widely used technique to analyze and measure adult human movement. However, these methods cannot be transferred directly to motion tracking of infants due to the big differences in the underlying human model. However, motion tracking of infants can be used for automatic analysis of infant development and might be able to tell something about possible motor disabilities such as cerebral palsy. In this paper, we address markerless 3D body part detection of infants using a widely available depth sensor and discuss some of the major challenges that arise. We present a method to detect and identify a set of the anatomical extremities and the results are evaluated based on manually annotated 3D positions.
In this paper we present a novel sensing system, robust Near-infrared Structured Light Scanning (NIRSL) for three-dimensional human model scanning application. Human model scanning due to its nature of various hair and dress appearance and body motion has long been a challenging task. Previous structured light scanning methods typically emitted visible coded light patterns onto static and opaque objects to establish correspondence between a projector and a camera for triangulation. In the success of these methods rely on scanning objects with proper reflective surface for visible light, such as plaster, light colored cloth. Whereas for human model scanning application, conventional methods suffer from low signal to noise ratio caused by low contrast of visible light over the human body. The proposed robust NIRSL, as implemented with the near infrared light, is capable of recovering those dark surfaces, such as hair, dark jeans and black shoes under visible illumination. Moreover, successful structured light scan relies on the assumption that the subject is static during scanning. Due to the nature of body motion, it is very time sensitive to keep this assumption in the case of human model scan. The proposed sensing system, by utilizing the new near-infrared capable high speed LightCrafter DLP projector, is robust to motion, provides accurate and high resolution three-dimensional point cloud, making our system more efficient and robust for human model reconstruction. Experimental results demonstrate that our system is effective and efficient to scan real human models with various dark hair, jeans and shoes, robust to human body motion and produces accurate and high resolution 3D point cloud.
Genus zero graph segmentation: Estimation of Intracranial Volume

The intracranial volume (ICV) in children with premature fusion of one or more sutures in the calvaria is of interest due to the risk of increased intracranial pressure. Challenges for automatic estimation of ICV include holes in the skull e.g. the foramen magnum and fontanelles. In this paper, we present a fully automatic 3D graph-based method for segmentation of the ICV in non-contrast CT scans. We reformulate the ICV segmentation problem as an optimal genus 0 segmentation...
problem in a volumetric graph. The graph is the result of a volumetric spherical subsampling. The equidistantly sampled data points are connected using Delaunay tetrahedralisation creating a highly connected neighborhood. A Markov Random Field (MRF) is constructed on the graph with probabilities learned from an Expectation Maximisation algorithm matching a Mixture of Gaussians to the data. The result of the MRF segmentation is compared to manual segmentations performed by an expert. We have achieved very high Dice scores ranging from 98.14% to 99.00%, while volume deviation from the manual segmentation ranges from 0.7% to 3.7%. The Hausdorff distance, which shows the maximum error from automatic to manual segmentation, ranges from 4.73 to 9.81 mm. Since this is sensitive to single error, we have also found the 95% Hausdorff distance, which ranges from 1.10 to 3.65 mm. The segmentation is very consistent with the reference and differs only in difficult areas, where it seems that our method is much more slice-wise consistent than a manual segmentation. The proposed method is expected to perform well for other volumetric segmentations.
Model-Based Motion Tracking of Infants

Even though motion tracking is a widely used technique to analyze and measure human movements, only a few studies focus on motion tracking of infants. In recent years, a number of studies have emerged focusing on analyzing the motion pattern of infants, using computer vision. Most of these studies are based on 2D images, but few are based on 3D information. In this paper, we present a model-based approach for tracking infants in 3D. The study extends a novel study on graph-based motion tracking of infants and we show that the extension improves the tracking results. A 3D model is constructed that resembles the body surface of an infant, where the model is based on simple geometric shapes and a hierarchical skeleton model.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, University of Copenhagen
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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Computer Vision Center, MED-EL GMBH, University of Bern, Technical University of Denmark, Alma IT Systems, Universitat Pompeu Fabra, Catalan Institution for Research and Advanced Studies

Authors: Vera, S. (Ekstern), Perez, F. (Ekstern), Balust, C. (Ekstern), Trueba, R. (Ekstern), Rubió, J. (Ekstern), Calvo, R. (Ekstern), Mazaira, X. (Ekstern), Danasingh, A. (Ekstern), Barazzetti, L. (Ekstern), Reyes, M. (Ekstern), Ceresa, M. (Ekstern), Fagertum, J. (Ekstern), Kjer, H. M. (Intern), Paulsen, R. R. (Intern), González Ballester, M. A. (Ekstern)

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**Patient-Specific Simulation of Implant Placement and Function for Cochlear Implantation Surgery Planning**

We present a framework for patient specific electrical stimulation of the cochlea, that allows to perform in-silico analysis of implant placement and function before surgery. A Statistical Shape Model (SSM) is created from high-resolution human μCT data to capture important anatomical details. A Finite Element Model (FEM) is built and adapted to the patient using the results of the SSM. Electrical simulations based on Maxwell’s equations for the electromagnetic field are performed on this personalized model. The model includes implanted electrodes and nerve fibers. We present the results for the bipolar stimulation protocol and predict the voltage spread and the locations of nerve excitation.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Universitat Pompeu Fabra, Centre for Genomic Regulation, MED-EL GMBH, Alma IT Systems, Catalan Institution for Research and Advanced Studies

Authors: Ceresa, M. (Ekstern), Mangado Lopez, N. (Ekstern), Dejea Velardo, H. (Ekstern), Herrezuelo, N. C. (Ekstern), Mistrik, P. (Ekstern), Kjer, H. M. (Intern), Vera, S. (Ekstern), Paulsen, R. R. (Intern), González Ballester, M. A. (Ekstern)

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Main Research Area: Technical/natural sciences
Rapid Generation of Personalized HRTFs

Numerical simulations offer a viable alternative to measurements for generating personalized head-related transfer functions (HRTFs). The fast multipole boundary element method (FM-BEM) is a popular method for simulating the HRTFs since it requires a surface mesh of the head (and torso) only. The FM-BEM simulation of the HRTF at a single frequency can be computed in a few minutes. Utilizing cloud computing, the entire audible frequency range can be simulated in less than an hour. A bottleneck in the fast acquisition of the personalized HRTFs has been the complexity of generating good quality head models for the simulation. We compare three photography based geometry acquisition methods, ranging from a system of 52 cameras to a method using a single mobile phone camera only.

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Shape modelling of the inner ear from micro-CT data

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The effect of gender on eye colour variation in European populations and an evaluation of the IrisPlex prediction model

In two recent studies of Spanish individuals [1,2], gender was suggested as a factor that contributes to human eye colour variation. However, gender did not improve the predictive accuracy on blue, intermediate and brown eye colours when gender was included in the IrisPlex model [3]. In this study, we investigate the role of gender as a factor that contributes to
eye colour variation and suggest that the gender effect on eye colour is population specific. A total of 230 Italian individuals were typed for the six IrisPlex SNPs (rs12913832, rs1800407, rs12896399, rs1393350, rs16891982 and rs12203592). A quantitative eye colour score (Pixel Index of the Eye: PIE-score) was calculated based on digital eye images using the custom made DIAT software. The results were compared with those of Danish and Swedish population samples. As expected, we found HERC2 rs12913832 as the main predictor of human eye colour independently of ancestry. Furthermore, we found gender to be significantly associated with quantitative eye colour measurements in the Italian population sample. We found that the association was statistically significant only among Italian individuals typed as heterozygote GA for HERC2 rs12913832. Interestingly, we did not observe the same association in the Danish and Swedish population. This indicated that the gender effect on eye colour is population specific. We estimated the effect of gender on quantitative eye colour in the Italian population sample to be 4.9%. Among gender and the IrisPlex SNPs, gender ranked as the second most important predictor of human eye colour variation in Italians after HERC2 rs12913832. We, furthermore, tested the five lower ranked IrisPlex predictors, and evaluated all possible 36 (729) genotype combinations of the IrisPlex assay and their corresponding predictive values using the IrisPlex prediction model [4]. The results suggested that maximum three (rs12913832, rs1800407, rs16891982) of the six IrisPlex SNPs are useful in practical forensic genetic casework.

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3D gender recognition using cognitive modeling

We use 3D scans of human faces and cognitive modeling to estimate the “gender strength”. The “gender strength” is a continuous class variable of the gender, superseding the traditional binary class labeling. To visualize some of the visual trends humans use when performing gender classification, we use linear regression. In addition, we use the gender strength to construct a smaller but refined training set, by identifying and removing ill-defined training examples. We use this refined training set to improve the performance of known classification algorithms. Results are presented using a 5-fold cross-validation scheme and also reproduced using an unseen data set.

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Apparatus and method for motion tracking in brain imaging

Disclosed is apparatus and method for motion tracking of a subject in medical brain imaging. The method comprises providing a light projector and a first camera; projecting a first pattern sequence (S1) onto a surface region of the subject with the light projector, wherein the subject is positioned in a scanner borehole of a medical scanner, the first pattern sequence comprising a first primary pattern (P1,1) and/or a first secondary pattern (P1,2); detecting the projected first pattern sequence (S1') with the first camera; determining a second pattern sequence (S2) comprising a second primary pattern (P2,1) based on the detected first pattern sequence (S1'); projecting the second pattern sequence (S2) onto a surface region of the subject with the light projector; detecting the projected second pattern sequence (S2') with the first camera; and determining motion tracking parameters based on the detected second pattern sequence (S2').

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Biomedical Engineering
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A three dimensional children head database for acoustical research and development

Most computational-acoustic work within spatial hearing relies on head-related transfer functions from databases of sound measurements taken on adult humans or dummy heads. We aim to provide a set of 3D digital heads including children, from which head-related transfer functions can be computed instead of measured. However, current volumetric scanning techniques do not have sufficient resolution for accurately scanning the external ear, and computed tomography also involves radiation. In this paper we propose a framework for scanning, stitching and meshing complete human heads. The process starts by acquisition of multiple 3D surface scans of the same subject using a high-resolution photogrammetric scanner. Secondly, the scans are semi-automatically aligned and noise and incoherence is removed. This is followed by an iterative process where a volumetric implicit representation of the head is optimized. The process consists of a regularized surface reconstruction step followed by an alignment step. Finally, a surface representation of the entire head is extracted using a triangulation of the zero-level iso-surface of the implicit volume. The process has been used to reconstruct the heads of children aged 10 months to 9 years. The data and the associated reconstruction algorithms will be made publicly available for use in acoustical research and development.

General information
Challenges in 3D scanning: Focusing on Ears and Multiple View Stereopsis

It is the goal of this thesis to address some of the challenges in 3D scanning. This has been done with focus on direct in-ear scanning and on Multiple View Stereopsis. Seven papers have been produced over the course of the Ph.D., out of which, six have been included. Two papers concern volumetric segmentation based on Markov Random Fields. These have been formulated to address problems relating to noise filtering in direct in-ear scanning and Intracranial Volume estimation. Another two papers have been produced on the topic of recovering surface data based on a strong statistical prior. This was done in particular on scans of ear canals, but the methods are general. Finally, an experimental setup has been constructed, which has produced a large versatile data set. The data set has been used as the foundation for two papers on the evaluation of Multiple View Stereopsis. The data have a great potential to be used for advances in Multiple View Stereopsis, robust surface reconstruction and photorealistic modelling.

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, 3Shape
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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.

Facial Analysis: Looking at Biometric Recognition and Genome-Wide Association

The goal of this Ph.D. project is to present selected challenges regarding facial analysis within the fields of Human Biometrics and Human Genetics. In the course of the Ph.D. nine papers have been produced, eight of which have been included in this thesis.

Three of the papers focus on face and gender recognition, where in the gender recognition papers the process of human perception of gender is analyzed and used to improve machine learning algorithms.

One paper addresses the issues of variability in human annotation of facial landmarks, which most papers regard as a static “gold standard”. However, we document intra- and inter-operator variability associated with annotating these landmarks, which is a valuable result for applications that are sensitive to such variability.

One paper presents a comprehensive proof-of-concept study of the prediction of facial characteristics based solely on genetic information, a new area that holds great potential.

Two papers explore the connection between minor physical anomalies in the face and schizophrenic disorders. Schizophrenia is a life long disease, but early discovery and treatment can have a significant impact on the course of the disease.

Finally, one paper presents a novel appearance model that is a fusion of the active appearance models and the Riemannian elasticity framework.
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.
The intracranial volume (ICV) in children with premature fusion of one or more sutures in the calvaria is of interest due to the risk of increased intracranial pressure. Challenges for automatic estimation of ICV include holes in the skull e.g. the foramen magnum and fontanelles. In this paper, we present a fully automatic 3D graph-based method for segmentation of the ICV in non-contrast CT scans. We reformulate the ICV segmentation problem as an optimal genus 0 segmentation problem in a volumetric graph. The graph is the result of a volumetric spherical subsample from the data connected using Delaunay tetrahedralisation. A Markov Random Field is constructed on the graph with probabilities learned from an Expectation Maximisation algorithm matching a Mixture of Gaussians to the data. Results are compared to manual segmentations performed by an expert. We have achieved very high Dice scores ranging from 98.14% to 99.00%, while volume deviation from the manual segmentation ranges from 0.7%-3.7%. The Hausdorff distance, which shows the maximum error from automatic to manual segmentation ranges, from 4.73-9.81mm. Since this is sensitive to single error, we have also found the 95% Hausdorff distance, which ranges from 1.10-3.65mm. The proposed method is expected to perform well for other volumetric segmentations.
List-Mode PET Motion Correction Using Markerless Head Tracking: Proof-of-Concept With Scans of Human Subject

A custom designed markerless tracking system was demonstrated to be applicable for positron emission tomography (PET) brain imaging. Precise head motion registration is crucial for accurate motion correction (MC) in PET imaging. State-of-the-art tracking systems applied with PET brain imaging rely on markers attached to the patient's head. The marker attachment is the main weakness of these systems. A healthy volunteer participating in a cigarette smoking study to image dopamine release was scanned twice for 2 h with $^{11}$C-raclopride on the high resolution research tomograph (HRRT) PET scanner. Head motion was independently measured, with a commercial marker-based device and the proposed vision-based system. A list-mode event-by-event reconstruction algorithm using the detected motion was applied. A phantom study with hand-controlled continuous random motion was obtained. Motion was time-varying with long drift motions of up to 18 mm and regular step-wise motion of 1–6 mm. The evaluated measures were significantly better for motion-corrected images compared to no MC. The demonstrated system agreed with a commercial integrated system. Motion-corrected images were improved in contrast recovery of small structures.
The topic of this thesis is automatic analysis of craniofacial images with respect to changes due to growth and surgery, inter-subject variation and intracranial volume estimation. The methods proposed contribute to the knowledge about specific craniofacial anomalies, as well as provide a tool for detailed analyses for clinical and research purposes.

Most of the applications in this thesis rely on non-rigid image registration by the means of warping one image into the coordinate system of another image. This warping results in a deformation field that describes the anatomical correspondence between the two images. To elaborate further: a computational atlas of the average anatomy was constructed. Using non-rigid registration, image data from a subject is automatically transformed into the coordinate space of the atlas. In this process, all knowledge built into the atlas is transferred to the subject, thus creating a personalized atlas. The knowledge built into the atlas is e.g. location of anatomical regions and landmarks of importance to surgery planning and evaluation or population studies. With these correspondences, various analyses could be carried out e.g. quantification of growth, inter-subject variation etc. Besides image registration, a volumetric segmentation method using graph cuts was developed and applied for intracranial volume estimation. Graph cut is a fast method for segmentation utilizing a suitable graph.

Three different craniofacial anomalies were examined in this thesis: Cleft lip and palate, unicoronal synostosis, and Crouzon syndrome. Using the proposed methods, highly detailed variation was assessed for cleft lip and palate, correspondence between images obtained before and after lip repair was established for cleft lip and palate, the intracranial volume was estimated for infants with unicoronal synostosis, and finally, craniofacial growth patterns were
quantified for Crouzon syndrome in a mouse model.

The genetics of eye colours in an Italian population measured with an objective method for eye colour quantification

Brown and blue eye colours are primarily explained by the single nucleotide polymorphism (SNP) HERC2 rs12913832. However, the genetics of eye colours that appear to be neither blue nor brown are not well understood. In this study, 230 unrelated Italian individuals were typed for 32 SNP loci in pigmentary genes. High resolution digital images of the participants’ eyes were taken and the iris region was successfully extracted with the use of the custom designed software Digital Iris Analysis Tool (DIAT) from 218 of the 230 (95%) images. The software counted the numbers of blue and brown pixels in the iris region and calculated a Pixel Index of the Eye (PIE-score) that described the eye colours quantitatively. The PIE-score ranged from -1 to 1 (brown to blue). We investigated the association of the PIE-scores extracted from the eye images with the genotypes of the 32 pigmentary SNPs. We observed a statistically significant association between the PIE-scores and the SNP loci rs12913832, rs4778241, rs7495174 in the HERC2/OCA2 region and the locus rs16891982 in SLC45A2.
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.

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Adaptive RT for H&N Cancer: The Usefulness of Deformable Image Registration

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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.

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Dosimetric- and geometric evaluation of adaptive H&N IMRT using deformable image registration

Purpose/Objective: Anatomical changes can occur during RT treatment of H&N cancer patients. This can lead to a difference between planned and delivered dose. Adaptive RT has the potential to overcome this, utilizing deformable image registration (DIR). The purpose of this study was to evaluate the performance of a DIR algorithm, using geometric and dosimetric measures.

Materials and Methods: Seven patients treated with IMRT were included in this study, each with a planning and midterm CT (pCT, ReCT) as well as a CBCT, acquired on the same day as the ReCT. ReCT served as the ground truth for evaluation of the DIR. A deformed CT (dCT) with contours was created by deforming the pCT and associated manually drawn contours to the CBCT. A commercially software using the Demons DIR algorithm (SmartAdapt, Varian Medical Systems, v.11.0) was utilized. A geometrical comparison was based on the estimated volumes from the contours on the dCT, and the manually drawn contours on the ReCT. Center of mass shifts (CMS) and dice similarity coefficients (DSC) were found between contours on dCT and ReCT. In the treatment planning system (Eclipse, Varian Medical system, v.10.0) the initial treatment plan was copied to the dCT and ReCT and the dose recalculated. DVH points (D50 for parotid glands and Dmax for spinal cord) were evaluated. Conformity index (CI), lesion coverage fraction (LCF) and normal tissue overdose fraction (NTOF) was evaluated with regard to target coverage.

Results: The PTV volume was estimated larger for dCT than ReCT with a median of 4.4% (range 4.0; 69.3). In four of seven patients, the volume difference was <5%. Six patients had a median CMS for PTV of 0.28 cm (range 0.05; 0.43). The median DSC was 0.88 (range 0.60; 0.95). Similar results were obtained for GTV and CTV. The median relative volume deviation from ReCT was 11.2% (range 28.0; 16.7), 26.2% (range 42.1; 3.4) and 10.9% (range 33.3; 32.3) for parotid dxt, parotid sin and spinal cord, respectively. The median CMS was 0.51 cm (range 0.19; 2.22). DSC had a
The median relative deviation from ReCT in DVH points for parotid dxt, parotid sin and spinal cord was 8.3% (range 8.4; 25.3), 12.7% (range 28.6; 31.0), and 1.3% (range 5.4; 31.8), respectively. CI, LCF and NTOF are visualized in the figure. Ideal values of CI and LCF are unity and zero for NTOF.

**Conclusions.** The DIR produced geometrical results similar to the ReCT in four of seven patients with regard to the target. Larger geometrical variations were observed for organs at risk (OAR). OAR contours obtained with the DIR were for nearly all patients estimated smaller than in the ReCT whereas target contours were estimated larger. The dosimetric results for OAR showed some variation between dCT and ReCT, especially for the parotid glands. The LCF were similar for dCT and ReCT, whereas NTOF were larger for ReCT than for dCT. Despite variation in volume and dose, between dCT and ReCT, the differences were within acceptable limits for most of the patients.

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  - BFI (2011): BFI-level 1
  - Scopus rating (2011): SJR 3.054 SNIP 1.676 CiteScore 4.85
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  - Web of Science (2011): Indexed yes
  - BFI (2010): BFI-level 1
  - Scopus rating (2010): SJR 2.232 SNIP 1.511
  - BFI (2009): BFI-level 1
  - Scopus rating (2009): SJR 2.042 SNIP 1.729
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  - Scopus rating (2008): SJR 1.894 SNIP 1.252
Dosimetric- and geometric evaluation of adaptive H&N IMRT using deformable image registration

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Copenhagen University Hospital
Authors: Eiland, R. B. (Ekstern), Behrens, C. F. (Ekstern), Sjöström, D. (Ekstern), Maare, C. (Ekstern), Paulsen, R. R. (Intern), Samsoe, E. (Ekstern)
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Main Research Area: Technical/natural sciences
Electronic versions:
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Dosimetric- and Geometric Evaluation of Adaptive H&N IMRT Using Deformable Image Registration
Purpose/Objective: Anatomical changes can occur during RT treatment of H&N cancer patients. This can lead to a difference between planned- and delivered dose. Adaptive RT has the potential to overcome this, utilizing deformable image registration (DIR). The purpose of this study was to evaluate the performance of a DIR algorithm, using geometric and dosimetric measures.
Materials and Methods: Seven patients treated with IMRT were included in this study, each with a planning- and midterm CT (pCT, ReCT) as well as a CBCT, acquired on the same day as the ReCT. ReCT served as the ground truth for evaluation of the DIR. A deformed CT (dCT) with contours was created by deforming the pCT and associated manually drawn contours to the CBCT. A commercially software using the Demons DIR algorithm (SmartAdapt, Varian Medical Systems, v.11.0) was utilized. A geometrical comparison was based on the estimated volumes from the contours on the dCT, and the manually drawn contours on the ReCT. Center of mass shifts (CMS) and dice similarity coefficients (DSC) were found between contours on dCT and ReCT. In the treatment planning system (Eclipse, Varian Medical system, v.10.0) the initial treatment plan was copied to the dCT and ReCT and the dose recalculated. DVH points (D50 for parotid glands and Dmax for spinal cord) were evaluated. Conformity index (CI), lesion coverage fraction (LCF) and normal tissue overdose fraction (NTOF) was evaluated with regard to target coverage.
Results: The PTV volume was estimated larger for dCT than ReCT with a median of 4.4% (range -4.0; 69.3). In four of seven patients, the volume difference was <5%. Six patients had a median CMS for PTV of 0.28 cm (range 0.05; 0.43). Similar results were obtained for GTV and CTV. The median relative volume deviation from ReCT was -11.2% (range -28.0; 16.7), -26.2% (range -42.1; 3.4) and -10.9% (range -33.3; 32.3) for parotid dxt, parotid sin and spinal cord, respectively. The median CMS was 0.51 cm (range 0.19; 2.22). DSC had a median of 0.47 (range 0.45; 0.85). The median relative deviation from ReCT in DVH points for parotid dxt, parotid sin and spinal cord was 8.3% (range -8.4; 25.3), -12.7% (range -28.6; 31.0), and 1.3% (range -5.4; 31.8), respectively. CI, LCF and NTOF are visualized in the figure. Ideal values of CI and LCF are unity and zero for NTOF.
Conclusions: The DIR produced geometrical results similar to the ReCT in four of seven patients with regard to the target. Larger geometrical variations were observed for organs at risk (OAR). OAR contours obtained with the DIR were for nearly
all patients estimated smaller than in the ReCT whereas target contours were estimated larger. The dosimetric results for OAR showed some variation between dCT and ReCT, especially for the parotid glands. The LCF were similar for dCT and ReCT, whereas NTOF were larger for ReCT than for dCT. Despite variation in volume and dose, between dCT and ReCT, the differences were within acceptable limits for most of the patients.
Gender Recognition Using Cognitive Modeling

In this work, we use cognitive modeling to estimate the "gender strength" of frontal faces, a continuous class variable, superseding the traditional binary class labeling. To incorporate this continuous variable we suggest a novel linear gender classification algorithm, the Gender Strength Regression. In addition, we use the gender strength to construct a smaller but refined training set, by identifying and removing ill-defined training examples. We use this refined training set to improve the performance of known classification algorithms. Also the human performance of known data sets is reported, and surprisingly it seems to be quite a hard task for humans. Finally our results are reproduced on a data set of above 40,000 public Danish LinkedIn profile pictures.

Mesh Processing in Medical Image Analysis: MeshMed 2012 Proceedings

The following topics are dealt with: mesh processing; medical image analysis; interactive freeform modeling; statistical shape analysis; clinical CT images; statistical surface recovery; automated segmentation; cerebral aneurysms; and real-time particle-based representation.
Mesh Processing in Medical-Image Analysis—a Tutorial

Medical-image analysis requires an understanding of sophisticated scanning modalities, constructing geometric models, building meshes to represent domains, and downstream biological applications. These four steps form an image-to-mesh pipeline. For research in this field to progress, the imaging, modeling, and simulation communities will need to work together more closely.

General information

State: Published
Authors: Levine, J. A. (Ekstern), Paulsen, R. R. (Intern), Zhang, Y. (Ekstern)
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Web of Science (2018): Indexed yes
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Scopus rating (2015): SJR 0.321 SNIP 0.835 CiteScore 1.05
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.364 SNIP 1.194 CiteScore 1.04
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Scopus rating (2013): SJR 0.414 SNIP 1.232 CiteScore 1.44
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BFI (2012): BFI-level 2
Scopus rating (2012): SJR 0.409 SNIP 1.89 CiteScore 1.46
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.384 SNIP 1.458 CiteScore 1.58
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BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.467 SNIP 1.91
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Scopus rating (2009): SJR 0.497 SNIP 2.162
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.416 SNIP 1.901
Motion Tracking for Medical Imaging: A Non-Visible Structured Light Tracking Approach

We present a system for head motion tracking in 3D brain imaging. The system is based on facial surface reconstruction and tracking using a structured light (SL) scanning principle. The system is designed to fit into narrow 3D medical scanner geometries limiting the field of view. It is tested in a clinical setting on the high resolution research tomograph (HRRT), Siemens PET scanner with a head phantom and volunteers. The SL system is compared to a commercial optical tracking system, the Polaris Vicra system, from NDI based on translatory and rotary ground truth motions of the head phantom. The accuracy of the systems was similar, with root-mean-square (RMS) errors of 0.09° for 20° axial rotations, and RMS errors of 0.24 mm for 25 mm translations. Tests were made using 1) a light emitting diode (LED) based miniaturized video projector, the Pico projector from Texas Instruments, and 2) a customized version of this projector replacing a visible light LED with a 850 nm near infrared LED. The latter system does not provide additional discomfort by visible light projection into the patient's eyes. The main advantage over existing head motion tracking devices, including the Polaris Vicra system, is that it is not necessary to place markers on the patient. This provides a simpler workflow and eliminates uncertainties related to marker attachment and stability. We show proof of concept of a marker less tracking system especially designed for clinical use with promising results.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Siemens Healthcare
Authors: Olesen, O. V. (Intern), Paulsen, R. R. (Intern), Højgaard, L. (Intern), Roed, B. (Ekstern), Larsen, R. (Intern)
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Scopus rating (2016): SJR 1.596 SNIP 2.388 CiteScore 4.83
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Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 1.604 SNIP 2.675 CiteScore 4.66
Optimized Acquisition Parameters for MRI Only RT Using Ultrashort Echo Times

General information
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Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Copenhagen University Hospital
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Journal: International Journal of Radiation: Oncology - Biology - Physics
Purpose/Objective: Multimodality imaging is increasingly combined for better tumour delineation. MRI provides additional soft tissue contrast to CT, but registration of MRI and CT introduce a systematic error. Further, adaptive RT introduces an increase in scans and additional systematic errors. MRI only based RT eliminates these errors and reduce the time and

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**Statistical analysis of MRI-only based dose planning**

**Purpose/Objective:** Multimodality imaging is increasingly combined for better tumour delineation. MRI provides additional soft tissue contrast to CT, but registration of MRI and CT introduce a systematic error. Further, adaptive RT introduces an increase in scans and additional systematic errors. MRI only based RT eliminates these errors and reduce the time and
costs of a CT scan. The aim of this study is to investigate the dosimetric differences of a treatment plan when the dose calculation is based on MRI as compared to CT.

Materials and Methods: Four diagnostic groups are investigated; 12 Head and Neck (HN) patients treated with static IMRT, 5 sarcoma (extremities only) patients treated with APPA, 21 prostate and 5 pelvic (not prostate) patients treated with VMAT. Data for each patient contains a CT scan (Phillips Big Bore CT) and a T2 weighted MRI scan (1T Panorama Phillips) as well as a clinically approved treatment plan. The treatment planning software is Eclipse v.10.0 (Varian Medical Systems). The dose calculation based on MRI data is evaluated in two different ways; a homogeneous density assigned MRI (MRI unit), where the entire body is assigned an HU equal to water and a heterogeneous density assigned MRI (MRI bulk) where in addition the CT segmented bone is transferred to the MRI and assigned an age dependent HU based on ICRU report 46. The CT based clinical treatment plan and structure set are registered to the corresponding MRI unit and MRI bulk. The body is outlined on both the MRI and the CT. The differences in dose distributions of the MRI bulk, MRI unit and CT data are quantified using DVH points. The reported DVH points for the PTV and CTV are Dmedian, D98% and D2% in accordance with ICRU report 83. The DVH points for the organs at risk are based on clinically guidelines used at our hospital and QUANTEC. One way two tailed ANOVA and paired t test are used to investigate the differences in dose, based on MRI bulk, MRI unit and CT. The assumptions of ANOVA are found to be fulfilled, since data is normal distributed with constant variances.

Results: The results of differences in DVH points are displayed in the table. MR-only based RT requires bulk density correction for prostate patients. For the remaining diagnostic groups both the unit and bulk density corrected MRI show nonsignificant deviation for the selected DVH points. The mean differences are in the order of 2 %.

Conclusions: The investigated DVH points show that MR-only based RT seems to be a feasible alternative to CT based RT. However, the analysis only describes similarities in DVH points and not in the shape of the DVH. Even though the mean differences are nonsignificant there might be unacceptable differences for the individual patient. In addition, significant differences may not be detected due to a large variance within a diagnostic group. The obtained results are consistent with those previous reported.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Copenhagen University Hospital
Authors: Korsholm, M. E. (Ekstern), Waring, L. W. (Ekstern), Paulsen, R. R. (Intern), Edmund, J. M. (Ekstern)
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Scopus rating (2016): CiteScore 4.36 SJR 2.099 SNIP 1.549
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.777 SNIP 1.707 CiteScore 4.87
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 2.605 SNIP 1.706 CiteScore 4.46
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.98 SNIP 1.795 CiteScore 4.84
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
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Statistical analysis of MRI-only based dose planning

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State: Published
Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Copenhagen University Hospital
Authors: Korsholm, M. E. (Ekstern), Waring, L. W. (Ekstern), Paulsen, R. R. (Intern), Edmund, J. M. (Ekstern)
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Main Research Area: Technical/natural sciences
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Statistical_Analysis_of_MRI_only_based_dose_planning.pdf
Links:
http://www.estro-events.org/Pages/ESTRO31.aspx
Publication: Research - peer-review › Conference abstract in journal – Annual report year: 2012

Statistical Surface Recovery: A Study on Ear Canals

We present a method for surface recovery in partial surface scans based on a statistical model. The framework is based on multivariate point prediction, where the distribution of the points are learned from an annotated data set. The training set consist of surfaces with dense correspondence that are Procrustes aligned. The average shape and point covariances can be estimated from this set. It is shown how missing data in a new given shape can be predicted using the learned statistics. The method is evaluated on a data set of 29 scans of ear canal impressions. By using a leave-one-out approach we reconstruct every scan and compute the point-wise prediction error. The evaluation is done for every point on the surface and for varying hole sizes. Compared to state-of-the art surface reconstruction algorithm, the presented methods gives very good prediction results.

General information
State: Published
We present a complete system for motion correction in high resolution brain positron emission tomography (PET) imaging. It is based on a compact structured light scanner mounted above the patient tunnel of the Siemens High Resolution Research Tomograph PET brain scanner. The structured light system is equipped with a near infrared diode and uses phase-shift interferometry to compute 3D representations of the forehead of the patient. These 3D point clouds are progressively aligned to a reference surface and thereby giving the head pose changes. The estimated pose changes are used to reposition a sequence of reconstructed PET frames. To align the structured light system with the PET coordinate system a novel registration algorithm based on the PET transmission scan and an initial surface has been developed.

The performance of the complete setup has been evaluated using a custom made phantom based on a plastic mannequin head equipped with two positron emitting line sources. Two experiments were performed. The first simulates rapid and short head movements, while the second simulates slow and continuous movements. In both cases, the system was able to produce PET scans with focus on PET reconstructions. The system is near ready for clinical testing.

Comparison of external motion tracking systems for PET list-mode reconstruction

The present improvement that we see in 3D medical scanner technology including increasing spatio-temporal resolution and increasing signal-to-noise ratio underlines the need for reliable motion correction. Many motion correction schemes assume that the motions are known [1-3]. However, a reliable markerless tracking system is not trivial to provide and to our knowledge not presently existent. The Polaris Vicra optical tracking system (Northern Digital Inc.) is generally used with PET brain imaging and has been demonstrated to work very well on phantoms [4]. However, it suffers from the necessary attachment of markers to the subject introducing image artifacts on human scans. We have previously designed a camera-based structured light (SL) system for 3D head tracking used with the high resolution research tomograph (HRRT, Siemens, Knoxville, USA) [5]. The system was modified to use invisible light and the accuracy was demonstrated similar to a commercial system [6]. Presently, we show the SL system integrated with the HRRT PET scanner ready for PET motion correction. We show a comparison study with the Polaris Vicra based on list-mode motion
Geometric calibration between PET scanner and structured light scanner

Head movements degrade the image quality of high resolution Positron Emission Tomography (PET) brain studies through blurring and artifacts. Many image reconstruction methods allow for motion correction if the head position is tracked continuously during the study. Our method for motion tracking is a structured light scanner placed just above the patient tunnel on the High Resolution Research Tomograph (HRRT, Siemens). It continuously registers point clouds of a part of the patient's face. The relative motion is estimated as the rigid transformation between frames. A geometric calibration between the HRRT scanner and the tracking system is needed in order to reposition the PET listmode data or image frames in the HRRT scanner coordinate system. This paper presents a method where obtained transmission scan data is segmented in order to create a point cloud of the patient's head. The point clouds from both systems can then be aligned to each other using the Iterative Closest Point (ICP) algorithm.
Markerless 3D Head Tracking for Motion Correction in High Resolution PET Brain Imaging

This thesis concerns application specific 3D head tracking. The purpose is to improve motion correction in position emission tomography (PET) brain imaging through development of markerless tracking. Currently, motion correction strategies are based on either the PET data itself or tracking devices relying on markers. Data-driven motion correction is problematic due to the physiological dynamics. Marker-based tracking is potentially unreliable, and it is extremely hard to validate when the tracking information is correct. The motion estimation is essential for proper motion correction of the PET images. Incorrect motion correction can in the worst cases result in wrong diagnosis or treatment. The evolution of a markerless custom-made structured light 3D surface tracking system is presented. The system is targeted at state-of-the-art high resolution dedicated brain PET scanners with a resolution of a few millimeters. State-of-the-art hardware and software solutions are integrated into an operational device. This novel system is tested against a commercial tracking system popular in PET brain imaging. Testing and demonstrations are carried out in clinical settings. A compact markerless tracking system was developed with an accuracy sufficient for PET imaging (<0.1 degrees and <0.3 mm). Furthermore, the first non-visible structured light system using Pico DLP technology was used. In a proof-of-principle study with two human PET scans, the system was demonstrated to improve PET image quality significantly. The results were similar to motion correction using an integrated commercial marker-based system. Furthermore, phantom studies were performed supporting the system's abilities for PET motion correction.

General information
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Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Olesen, O. V. (Intern), Larsen, R. (Intern), Paulsen, R. R. (Intern)
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Project Supervision - An Engineering Approach

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, DTU Data Analysis
Authors: Paulsen, R. R. (Intern), Larsen, R. (Intern), Ersbøll, B. K. (Intern), Conradsen, K. (Intern)
Publication date: 2011
Event: Abstract from 7th International CDIO Conference, Copenhagen, Denmark.
Project Supervision – An Engineering Approach

For more than twenty years, a group based supervision strategy has been used when supervising engineering bachelor- and master thesis students at our research group. In recent years, we have formalised the approach and used our industry experience to create a very successful framework for project supervision. This paper is a best practice guide aimed at research groups that would like to try to implement our supervision approach or parts of it. The approach is based on the belief that engineering students should be prepared for their new role as development engineers or PhD students as part of their master thesis writing. The supervision principles are: Ownership: The student should feel that their project is their own. Ideally, they should formulate the project themselves. Write early: We strongly encourage the students to write and generate figures and images already from the first week of the project period. Management: The student is considered project manager of his own project. The supervisor is a guide or coach (or a project owner) Plans: The student is asked to write a project plan during the first week of the project together with a risk-analysis. Group Meetings: A group of students and supervisors meet every week on a fixed weekday. In our team, it is normal that one supervisor supervises three to five projects simultaneously. The core of the supervision is the weekly meetings where the students present what they have been doing and what they plan to do. By default, all students are present at all meetings. Weekly meetings are scheduled to be at a specific day at a specific place for the entire process.

Real Time Surface Registration for PET Motion Tracking

Head movement during high resolution Positron Emission Tomography brain studies causes blur and artifacts in the images. Therefore, attempts are being made to continuously monitor the pose of the head and correct for this movement. Specifically, our method uses a structured light scanner system to create point clouds representing parts of the patient's face. The movement is estimated by a rigid registration of the point clouds. The registration should be done using a robust algorithm that can handle partial overlap and ideally operate in real time. We present an optimized Iterative Closest Point algorithm that operates at 10 frames per second on partial human face surfaces. © 2011 Springer-Verlag.
Sparse Similarity-Based Fisherfaces

In this work, the effect of introducing Sparse Principal Component Analysis within the Similarity-based Fisherfaces algorithm is examined. The technique aims at mimicking the human ability to discriminate faces by projecting the faces in a highly discriminative and easy interpretative way. Pixel intensities are used by Sparse Principal Component Analysis and Fisher Linear Discriminant Analysis to assign a one dimensional subspace projection to each person belonging to a reference data set. Experimental results performed in the AR dataset show that Similarity-based Fisherfaces in a sparse version can obtain the same recognition results as the technique in a dense version using only a fraction of the input data. Furthermore, the presented results suggest that using SPCA in the technique offers robustness to occlusions.

Ultra Fast Optical Sectioning: Signal preserving filtering and surface reconstruction

In 3D surface scanning it is desirable to filter away bad data without altering the quality of the remaining good data. Filtering of raw scanner data before surface reconstruction can minimize the induced error and improve on the probability of reconstructing the true surface. If outliers consist of actual data such as hair, and not just evenly distributed noise, these outliers tend to err smoothing algorithms away from the wanted result. We present a novel algorithm based on a Markov Random Field that uses a distance constraint to robustly classify a 3D scan volume. Through this classification a signal preserving filtering of the data set is done. The remaining data are used for a smooth surface reconstruction creating very...
plausible surfaces. The data used in our work comes from a newly developed hand held 3D scanner. The scanner is an Ultra Fast Optical Sectioning scanner, which is able to extract high quality 3D surface points from 2D images recorded at over 3000 fps. The scanner has been developed for digital impression taking in the dental area. Our work relates to future in-ear scanning for fitting custom hearing aids without impression taking.

General information
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Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Department of Photonics Engineering
Authors: Jensen, R. R. (Intern), Poel, M. V. D. (Intern), Larsen, R. (Intern), Paulsen, R. R. (Intern)
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Anatomically Plausible Surface Alignment and Reconstruction
With the increasing clinical use of 3D surface scanners, there is a need for accurate and reliable algorithms that can produce anatomically plausible surfaces. In this paper, a combined method for surface alignment and reconstruction is proposed. It is based on an implicit surface representation combined with a Markov Random Field regularisation method. Conceptually, the method maintains an implicit ideal description of the sought surface. This implicit surface is iteratively updated by realigning the input point sets and Markov Random Field regularisation. The regularisation is based on a prior energy that has earlier proved to be particularly well suited for human surface scans. The method has been tested on full cranial scans of ten test subjects and on several scans of the outer human ear.

General information
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Authors: Paulsen, R. R. (Intern), Larsen, R. (Intern)
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Main Research Area: Technical/natural sciences
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Surface reconstruction, Markov Random Field, Surface Alignment
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Source: orbit
Source-ID: 268635
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

Dealing with difficult deformations: Construction of a knowledge-based deformation atlas
Twenty-three Taiwanese infants with unilateral cleft lip and palate (UCLP) were CT-scanned before lip repair at the age of 3 months, and again after lip repair at the age of 12 months. In order to evaluate the surgical result, detailed point correspondence between pre- and post-surgical images was needed. We have previously demonstrated that non-rigid registration using B-splines is able to provide automated determination of point correspondences in populations of infants without cleft lip. However, this type of registration fails when applied to the task of determining the complex deformation from before to after lip closure in infants with UCLP. The purpose of the present work was to show that use of prior
information about typical deformations due to lip closure, through the construction of a knowledge-based atlas of deformations, could overcome the problem. Initially, mean volumes (atlases) for the pre- and post-surgical populations, respectively, were automatically constructed by non-rigid registration. An expert placed corresponding landmarks in the cleft area in the two atlases; this provided prior information used to build a knowledge-based deformation atlas. We model the change from pre- to post-surgery using thin-plate spline warping. The registration results are convincing and represent a first move towards an automatic registration method for dealing with difficult deformations due to this type of surgery.

New or breakthrough work to be presented: The method provides a simple way of dealing with complex morphological changes using knowledge of typical deformations.

General information
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Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Technical University of Denmark
Authors: Thorup, S. S. (Intern), Darvann, T. (Ekstern), Herrmann, N. (Ekstern), Larsen, P. (Ekstern), Olafsdottir, H. (Ekstern), Paulsen, R. R. (Intern), Kane, A. (Ekstern), Govier, D. (Ekstern), Lo, L. (Ekstern), Kreiborg, S. (Ekstern), Larsen, R. (Intern)
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External motion tracking for brain imaging: structured light tracking with invisible light
The importance of motion correction in 3D medical imaging increases with increasing scanner resolution. It is necessary for scanners with long image acquisition and low contrast images to correct for patient motion in order to optimize image quality. We present a near infrared structured light stereo depth map system for head motion estimation inside 3D medical scanners with limited space.

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State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Siemens Healthcare, Copenhagen University Hospital
Authors: Olesen, O. V. (Intern), Paulsen, R. R. (Intern), Hejgaard, L. (Ekstern), Roed, B. (Ekstern), Larsen, R. (Intern)
Publication date: 2010

Host publication information
Title of host publication: Conference Record of the IEEE Nuclear Science Symposium and Medical Imaging Conference
Main Research Area: Technical/natural sciences
Conference: External motion tracking for brain imaging: structured light tracking with invisible light, Nuclear Science Symposium and Medical Imaging Conference, Knoxville, USA, 01/01/2010
Links:
http://www.nss-mic.org/2010
Source: orbit
Source-ID: 269347
Publication: Research › Article in proceedings – Annual report year: 2010

Markov Random Field Surface Reconstruction
A method for implicit surface reconstruction is proposed. The novelty in this paper is the adaption of Markov Random Field regularization of a distance field. The Markov Random Field formulation allows us to integrate both knowledge about the type of surface we wish to reconstruct (the prior) and knowledge about data (the observation model) in an orthogonal fashion. Local models that account for both scene-specific knowledge and physical properties of the scanning device are described. Furthermore, how the optimal distance field can be computed is demonstrated using conjugate gradients, sparse Cholesky factorization, and a multiscale iterative optimization scheme. The method is demonstrated on a set of scanned human heads and, both in terms of accuracy and the ability to close holes, the proposed method is shown to
have similar or superior performance when compared to current state-of-the-art algorithms.

**General information**

State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Paulsen, R. R. (Intern), Bærentzen, J. A. (Intern), Larsen, R. (Intern)
Pages: 636-646
Publication date: 2010
Main Research Area: Technical/natural sciences

**Publication information**

Volume: 16
Issue number: 4
ISSN (Print): 1077-2626
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- BFI (2018): BFI-level 2
- Web of Science (2018): Indexed yes
- BFI (2017): BFI-level 2
- Scopus rating (2017): SNIP 2.212 SJR 0.869 CiteScore 4.1
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 2
- Scopus rating (2016): CiteScore 3.49 SJR 1.169 SNIP 2.319
- BFI (2015): BFI-level 2
- Scopus rating (2015): SJR 0.809 SNIP 1.982 CiteScore 2.91
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 1.215 SNIP 2.472 CiteScore 3.37
- BFI (2013): BFI-level 2
- Scopus rating (2013): SJR 1.109 SNIP 2.567 CiteScore 3.39
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 2
- Scopus rating (2012): SJR 0.845 SNIP 2.418 CiteScore 2.96
- ISI indexed (2012): ISI indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 1.02 SNIP 2.659 CiteScore 3.39
- ISI indexed (2011): ISI indexed yes
- BFI (2010): BFI-level 2
- Scopus rating (2010): SJR 1.061 SNIP 2.335
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 2
- Scopus rating (2009): SJR 1.068 SNIP 2.709
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 0.852 SNIP 2.577
- Scopus rating (2007): SJR 0.687 SNIP 2.478
- Scopus rating (2006): SJR 0.624 SNIP 2.984
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 0.522 SNIP 3.149
- Web of Science (2005): Indexed yes
- Scopus rating (2004): SJR 0.437 SNIP 3.356
- Scopus rating (2003): SJR 0.808 SNIP 3.542
- Scopus rating (2002): SJR 1.916 SNIP 3.949
- Scopus rating (2001): SJR 1.837 SNIP 4.156
- Scopus rating (2000): SJR 0.85 SNIP 2.636
- Scopus rating (1999): SJR 0.772 SNIP 1.844

Original language: English
Mesh Generation, Markov Random Field, Bayesian Approach, Surface Reconstruction, Implicit Surface
Motion tracking in narrow spaces: A structured light approach

We present a novel tracking system for patient head motion inside 3D medical scanners. Currently, the system is targeted at the Siemens High Resolution Research Tomograph (HRRT) PET scanner. Partial face surfaces are reconstructed using a miniaturized structured light system. The reconstructed 3D point clouds are matched to a reference surface using a robust iterative closest point algorithm. A main challenge is the narrow geometry requiring a compact structured light system and an oblique angle of observation. The system is validated using a mannequin head mounted on a rotary stage. We compare the system to a standard optical motion tracker based on a rigid tracking tool. Our system achieves an angular RMSE of 0.11 degrees demonstrating its relevance for motion compensated 3D scan image reconstructions as well as its competitiveness against the standard optical system with an RMSE of 0.08 degrees. Finally, we demonstrate qualitative result on real face motion estimation.
Multivariate Analysis of Variance: Finding significant growth in mice with craniofacial dysmorphology caused by the Crouzon mutation

Crouzon syndrome is characterized by growth disturbances caused by premature fusion of the cranial growth zones. A mouse model with mutation Fgfr2C342Y, equivalent to the most common Crouzon syndrome mutation (henceforth called the Crouzon mouse model), has a phenotype showing many parallels to the human counterpart. Quantifying growth in the Crouzon mouse model could test hypotheses of the relationship between craniosynostosis and dysmorphology, leading to better understanding of the causes of Crouzon syndrome as well as providing knowledge relevant for surgery planning. In the present study we used micro-CT scans of 4-week-old mice (N=5) and 6-week-old mice (N=10) with Crouzon syndrome (Fgfr2 C342Y/+) were compared to control groups of 4-week-old wild-type mice (N=5) and 6-week-old wild-type mice (N=10), respectively.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, University of Copenhagen
Publication date: 2010

Host publication information
Title of host publication: The Eighth French-Danish Workshop on Spatial Statistics and Image Analysis in Biology : Book of Abstracts
Project supervision - an engineering approach

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Paulsen, R. R. (Intern)
Publication date: 2010

Semi-automated tracking of behaviour of Betta splendens
In this paper, a novel software system for animal behaviour tracking is described. It is used for tracking fish filmed in aquariums using a low quality acquisition system. The tracking is based on a multiscale template matching technique that finds both the position and the orientation of the tracked fish. The template is matched in the background subtracted frames, where the background is estimated using a median based approach. The system is very stable and has been used in a large behavioural study design to the use of the behavioural pattern known as mate choice copying in Betta splendens.

Structured light 3D tracking system for measuring motions in PET brain imaging
Patient motion during scanning deteriorates image quality, especially for high resolution PET scanners. A new proposal for a 3D head tracking system for motion correction in high resolution PET brain imaging is set up and demonstrated. A prototype tracking system based on structured light with a DLP projector and a CCD camera is set up on a model of the High Resolution Research Tomograph (HRRT). Methods to reconstruct 3D point clouds of simple surfaces based on phase-shifting interferometry (PSI) are demonstrated. The projector and camera are calibrated using a simple stereo vision procedure where the projector is treated as a camera. Additionally, the surface reconstructions are corrected for the non-linear projector output prior to image capture. The results are convincing and a first step toward a fully automated tracking system for measuring head motions in PET imaging.
Shape and Deformation Analysis of the Human Ear Canal

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Darkner, S. (Intern), Olsen, O. F. (Ekstern), Paulsen, R. R. (Intern), Larsen, R. (Intern)
Publication date: Jan 2009

Publication information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark, DTU Informatics, Building 321
Original language: English
Series: IMM-PHD-2008-204
Main Research Area: Technical/natural sciences
Electronic versions:
phd204.pdf
Source: orbit
Source-ID: 222732
Publication: Research › Ph.D. thesis – Annual report year: 2009

4D Lung Reconstruction with Phase Optimization
This paper investigates and demonstrates a 4D lung CT reconstruction/registration method which results in a complete volumetric model of the lung that deforms according to a respiratory motion field. The motion field is estimated iteratively between all available slice samples and a reference volume which is updated on the fly. The method is two part and the second part of the method aims to correct wrong phase information by employing another iterative optimizer. This two part iterative optimization allows for complete reconstruction at any phase and it will be demonstrated that it is better than using an optimization which does not correct for phase errors. Knowing how the lung and any tumors located within the lung deforms is relevant in planning the treatment of lung cancer.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Image Analysis and Computer Graphics, Odense University Hospital
Authors: Lyksborg, M. (Intern), Paulsen, R. (Intern), Brink, C. (Ekstern), Larsen, R. (Intern)
Pages: 2227-2230
Publication date: 2009

Host publication information
Title of host publication: IFMBE Proceedings
Volume: 25/4
Place of publication: Munich
Publisher: Springer Berlin Heidelberg
Main Research Area: Technical/natural sciences
Conference: World Congress on Medical Physics and Biomedical Engineering, Munich, Germany, 07/09/2009 - 07/09/2009
Motion correction, 4D Lung CT
DOIs:
10.1007/978-3-642-03882-2
Source: orbit
Source-ID: 256161
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Analysis of gait using a treadmill and a Time-of-flight camera
We present a system that analyzes human gait using a treadmill and a Time-of-flight camera. The camera provides spatial data with local intensity measures of the scene, and data are collected over several gait cycles. These data are then used to model and analyze the gait. For each frame the spatial data and the intensity image are used to fit an articulated model to the data using a Markov random field. To solve occlusion issues the model movement is smoothened providing the missing data for the occluded parts. The created model is then cut into cycles, which are matched and through Fourier fitting a cyclic model is created. The output data are: Speed, Cadence, Step length and Range-of-motion. The described output parameters are computed with no user interaction using a setup with no requirements to neither background nor subject clothing.
Analyzing Gait Using a Time-of-Flight Camera

An algorithm is created, which performs human gait analysis using spatial data and amplitude images from a Time-of-flight camera. For each frame in a sequence the camera supplies cartesian coordinates in space for every pixel. By using an articulated model the subject pose is estimated in the depth map in each frame. The pose estimation is based on likelihood, contrast in the amplitude image, smoothness and a shape prior used to solve a Markov random field. Based on the pose estimates, and the prior that movement is locally smooth, a sequential model is created, and a gait analysis is done on this model. The output data are: Speed, Cadence (steps per minute), Step length, Stride length (stride being two consecutive steps also known as a gait cycle), and Range of motion (angles of joints). The created system produces good output data of the described output parameters and requires no user interaction.
Automatic Assessment of Craniofacial Growth in a Mouse Model of Crouzon Syndrome

BACKGROUND & PURPOSE: Crouzon syndrome is characterized by growth disturbances caused by premature craniosynostosis. A mouse model with mutation Fgfr2C342Y, equivalent to the most common Crouzon syndrome mutation (henceforth called the Crouzon mouse model), has a phenotype showing many parallels to the human counterpart. Quantifying growth in the Crouzon mouse model could test hypotheses of the relationship between craniosynostosis and dysmorphology, leading to better understanding of the causes of Crouzon syndrome as well as providing knowledge relevant for surgery planning.

METHODS: Automatic non-rigid volumetric image registration was applied to micro-CT scans of ten 4-week and twenty 6-week euthanized mice for growth modeling. Each age group consisted of 50% normal and 50% Crouzon mice. Four 3D mean shapes, one for each mouse-type and age group were created. Extracting a dense field of growth vectors for each mouse-type; growth models were created using linear interpolation and visualized as 3D animations. Spatial regions of significantly different growth were identified using the local False Discovery Rate method, estimating the expected percentage of false predictions in a set of predictions. For all image registrations, the Image Registration Toolkit was used under Licence from Ixico Ltd. RESULTS: Investigation proved growth in the Crouzon group to be inhibited, especially in the nasal and posterior regions of the skull compared to the growth in the normal group, and showed an expansion vertically and laterally in the middle and anterior part of the calvaria. Image registration was used to automatically obtain landmarks, thus, different skull measures could be performed e.g. length, width, height. The registrations were quantitatively validated using expert-placed landmarks. CONCLUSIONS: Image registrations made it possible to automatically quantify and visualize average craniofacial growth in normal and Crouzon mouse models, and significantly different growth patterns were found between the two. The methodology generalizes to quantification of shape and growth in other mouse models, and provides a tool for spatially detailed automatic phenotyping.

Main Objectives of Presentation: We will present a 3D growth model of normal and Crouzon mice, and differences will be statistically and visually compared.

Hierarchical Markov Random Fields Applied to Model Soft Tissue Deformations on Graphic Hardware

General Information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, University of Bern
Authors: Seiler, C. (Ekstern), Büchler, P. (Ekstern), Nolte, L. (Ekstern), Reyes, M. (Ekstern), Paulsen, R. R. (Intern), Hermann, N. V. (Ekstern), Larsen, P. (Ekstern), Perlyn, C. A. (Ekstern), Kreiborg, S. (Ekstern)
Pages: 133-148
Publication date: 2009

Host Publication Information
Title of host publication: Recent Advances in the 3D Physiological Human
Publisher: Springer
Editor: Magnenat-Thalmann, N.
ISBN (Print): 978-1-84882-564-2
Regularisation of 3D Signed Distance Fields

Signed 3D distance fields are used in a variety of domains. From shape modelling to surface registration. They are typically computed based on sampled point sets. If the input point set contains holes, the behaviour of the zero-level surface of the distance field is not well defined. In this paper, a novel regularisation approach is described. It is based on energy formulation, where both local smoothness and data fidelity are included. The minimisation of the global energy is shown to be the solution of a large set of linear equations. The solution to the linear system is found by sparse Cholesky factorisation. It is demonstrated that the zero-level surface will act as a membrane after the proposed regularisation. This effectively closes holes in a predictable way. Finally, the performance of the method is tested with a set of synthetic point clouds of increasing complexity.

Analysis of Surfaces Using Constrained Regression Models

Analysis of Surfaces Using Constrained Regression Models
Analysis of Deformation of the Human Ear and Canal Caused by Mandibular Movement

Many hearing aid users experience physical discomfort when wearing their device. The main contributor to this problem is believed to be deformation of the ear and ear canal caused by movement of the mandible. Physical discomfort results from added pressure on soft tissue areas in the ear. Identifying features that can predict potential deformation is therefore important for identifying problematic cases in advance. A study on the physical deformation of the human ear and canal due to movement of the mandible is presented. The study is based on laser scanings of 30 pairs of ear impressions from 9 female and 21 male subjects. Two impressions have been taken from each subject, one with open mouth, and one with the mouth closed. All impressions are registered using non-rigid surface registration and a shape model is built. From each pair of impressions a deformation field is generated and propagated to the shape model, enabling the building of a deformation model in the reference frame of the shape model. A relationship between the two models is established, showing that the shape variation can explain approximately 50% of the variation in the deformation model. An hypothesis test for significance of the deformations for each deformation field reveals that all subjects have significant deformation at Tragus and in the canal. Furthermore, a relation between the magnitude of the deformation and the gender of the subject is demonstrated. The results are successfully validated by comparing the outcome to the anatomy by using a single set of high resolution histological sectionings of the region of interest.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Darkner, S. (Intern), Paulsen, R. R. (Intern), Larsen, R. (Intern)
Pages: 801-808
Publication date: 2007

Automated 3D Rigid Registration of Open 2D Manifolds

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling
Authors: Darkner, S. (Intern), Vester-Christensen, M. (Intern), Larsen, R. (Intern), Nielsen, C. (Ekstern), Paulsen, R. R. (Intern)
Pages: 19-22
Publication date: 2006

Statistical Shape Analysis of the Human Ear Canal with Application to In-the-Ear Hearing Aid Design

This thesis is about the statistical shape analysis of the human ear canal with application to the mechanical design of in-the-ear hearing aids. Initially, it is described how a statistical shape model of the human ear canal is built based on a training set of laser-scanned ear impressions. A thin plate spline based approach creates a dense correspondence
between the shapes in training set. In addition, a new flexible, non-rigid registration framework is proposed and used to optimise the correspondence field. The framework is based on Markov Random Field regularisation and is motivated by prior work on image restoration. It is shown how the method significantly improves the shape model. In the second part of the thesis, the shape model is used in software tools that mimic the skills of the expert hearing aid makers. The first result is that it is possible to learn an algorithm to cut an ear canal in order to produce an optimal in-the-ear hearing aid. Secondly, a framework for component placement using a coupling of stochastic optimisation and the results from the shape model is proposed. It is successfully used to place the so-called faceplate with associated component on in-the-ear hearing aids. In addition, the idea of one-size-fits-most shells is explored. In Danish: Denne afhandling beskriver brugen af statistisk formanalyse af den menneskelige hørekanal i det mekaniske design af i-øret høreapparater. Først beskrives det hvordan en statistisk formmodel af den menneskelige øre- kanal er lavet på baggrund af et træningsæt af laser-skannede øre aftryk. En Thin Plate Spline baseret metode genererer en kompakt korrespondance mellem formerne i træningsættet. Endvidere er en fleksibel, ikke-rigid registrerings metode foreslået og anvendt til at optimere korrespondance feltet. Metoden er baseret på Markov Random Field regulering og er motivert af tidligere arbejde vedrørende billede opretning. Det er vist hvordan metoden signifikant forbedrer formmodellen. I den anden del af afhandlingen, bruges formmodellen i programmer, der efterligner evnerne hos de bedste af dem der laver høreapparater. Det første resultat er, at det er muligt at lære en algoritme at skære en ørekanal for at producere et optimalt i-øret høreapparat. Dernæst, foreslås en metode til placering af komponenter. Metoden bruger en kombination af stokastisk optimering og resultater fra formmodellen. Den er succesfuldt brugt til at placere den såkaldte faceplate med komponenter på i-øret høreapparater. Derudover er ideen om en skal af en størrelse og form, som passer de fleste forfulgt.

Markov Random Field Restoration of Point Correspondences for Active Shape Modelling

In this paper it is described how to build a statistical shape model using a training set with a sparse of landmarks. A well defined model mesh is selected and fitted to all shapes in the training set using thin plate spline warping. This is followed by a projection of the points of the warped model mesh to the target shapes. When this is done by a nearest neighbour projection it can result in folds and inhomogeneities in the correspondence vector field. The novelty in this paper is the use and extension of a Markov random field regularisation of the correspondence field. The correspondence field is regarded as a collection of random variables, and using the Hammersley-Clifford theorem it is proved that it can be treated as a Markov Random Field. The problem of finding the optimal correspondence field is cast into a Bayesian framework for Markov Random Field restoration, where the prior distribution is a smoothness term and the observation model is the curvature of the shapes. The Markov Random Field is optimised using a combination of Gibbs sampling and the Metropolis-Hasting algorithm. The parameters of the model is found using a leave-one-out approach. The method leads to a generative model that produces highly homogeneous polygonised shapes with improved reconstruction capabilities of the training data. Furthermore, the method leads to an overall reduction in the total variance of the resulting point distribution model. The method is demonstrated on a set of human ear canals extracted from 3D-laser scans.
Using a Shape Model in the Design of Hearing Aids

Today the design of custom completely-in-the-canal hearing aids is a manual process and therefore there is a variation in the quality of the finished hearing aids. Especially the placement of the so-called faceplate on the hearing aid strongly influences the size and shape of the hearing aid. Since the future hearing aid production will be less manual there is a need for algorithms that mimic the craftsmanship of skilled operators. In this paper it is described how a statistical shape model of the ear canal can be used to predict the placement of the faceplate on a hearing aid made for a given ear canal.

The shape model is a point distribution model built using a training set of shapes with manually placed landmarks. An interpolation method is used to generate dense landmark correspondence over the training set prior to building the shape model. Faceplates have also been placed on the training shapes by a skilled operator. These faceplate planes are aligned to the average shape from the shape model and an average faceplate plane is calculated. Given a surface representation of a new ear canal, the shape model is fitted using a combination of the iterative closest point algorithm and the active shape model approach. The average faceplate from the training set can now be placed on the new ear canal using the position of the fitted shape model. A leave-one-out study shows that the algorithm is able to produce results comparable to a human operator.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Oticon A/S
Authors: Paulsen, R. R. (Intern), Nielsen, C. (Ekstern), Laugesen, S. (Ekstern), Larsen, R. (Intern)
Publication date: 2004

Host publication information
Title of host publication: SPIE - Medical Imaging
Main Research Area: Technical/natural sciences
Conference: SPIE - Medical Imaging, San Diego, United States, 12/02/2005 - 12/02/2005
Links:
Source: orbit
Source-ID: 154656
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Shape Modelling Using Markov Random Field Restoration of Point Correspondences

A method for building statistical point distribution models is proposed. The novelty in this paper is the adaption of Markov random field regularization of the correspondence field over the set of shapes. The new approach leads to a generative model that produces highly homogeneous polygonized shapes and improves the capability of reconstruction of the training data. Furthermore, the method leads to an overall reduction in the total variance of the point distribution model. Thus, it finds correspondence between semilandmarks that are highly correlated in the shape tangent space. The method is demonstrated on a set of human ear canals extracted from 3D-laser scans.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Authors: Paulsen, R. R. (Intern), Hilger, K. B. (Intern)
Pages: 1-12
Publication date: 2003

Host publication information
Title of host publication: Information Processing in Medical Imaging
Main Research Area: Technical/natural sciences
Conference: Information Processing in Medical Imaging, 01/01/2003
Electronic versions: imm2375.pdf
Links:
Source: orbit
Source-ID: 58551
Publication: Research - peer-review › Article in proceedings – Annual report year: 2003
Some Issues of Biological Shape Modelling with Applications

This paper illustrates current research at Informatics and Mathematical Modelling at the Technical University of Denmark within biological shape modelling. We illustrate a series of generalizations to, modifications to, and applications of the elements of constructing models of shape or appearance. These elements are correspondence analysis, analysis and decomposition of variability, alignment, and visualisation.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling
Pages: 509-519
Publication date: 2003

Building and Testing a Statistical Shape Model of the Human Ear Canal

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Oticon A/S
Authors: Paulsen, R. R. (Intern), Larsen, R. (Intern), Laugesen, S. (Intern), Nielsen, C. (Ekstern), Ersbøll, B. K. (Intern)
Publication date: 2002

Testing for Gender Related Size and Shape Differences of the Human Ear canal using Statistical methods

This work deals with the analysis of the shape of the human ear canal. It is described how a dense surface point distribution model of the human ear canal is built based on a training set of laser scanned ear impressions and a sparse set of anatomical landmarks placed by an expert. The dense surface models are built by using the anatomical landmarks to warp a template mesh onto all shapes in the training set. Testing the gender related differences is done by initially reducing the dimensionality using principal component analysis of the vertices of the warped meshes. The number of components to retain is chosen using Horn’s parallel analysis. Finally a multivariate analysis of variance is performed on these components.

General information
State: Published
Organisations: Image Analysis and Computer Graphics, Department of Informatics and Mathematical Modeling, Technical University of Denmark
Authors: Paulsen, R. R. (Intern), Larsen, R. (Intern), Ersbøll, B. K. (Intern), Nielsen, C. (Ekstern), Laugesen, S. (Intern), Conradsen, K. (ed.) (Ekstern)
Projects:

Deep Learning Methods for Cardiac CT analysis
Department of Applied Mathematics and Computer Science
Period: 01/08/2018 → 31/07/2021
Number of participants: 5
Phd Student:
Juhl, Kristine Aavild (Intern)
Supervisor:
Camara, Oscar (Ekstern)
De Backer, Ole (Ekstern)
Kofoed, Klaus F. (Ekstern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)

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

Designing a Real-time Tracking and Feedback System to use During Endoscopic Procedures
Technical University of Denmark
Period: 01/03/2016 → 31/03/2018
Number of participants: 4
Phd Student:
Norsk, David (Intern)
Supervisor:
Clemmensen, Line Katrine Harder (Intern)
Svendsen, Lars Bo (Ekstern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)

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

Image Base Tracking and 3D Content Generation
Department of Mathematics
Period: 01/11/2014 → 15/08/2018
Number of participants: 6
Phd Student:
Stets, Jonathan Dyssel (Intern)
Supervisor:
Larsen, Rasmus (Intern)
Computerised Quantification of Motions Associated with Psychiatric Disorders

Technical University of Denmark
Period: 15/08/2014 → 16/05/2018
Number of participants: 8
Phd Student:
Einarsson, Gudmundur (Intern)
Supervisor:
Clemmensen, Line Katrine Harder (Intern)
Fink-Jensen, Anders (Ekstern)
Pagsberg, Anne Katrine (Ekstern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)
Examiner:
Nielsen, Allan Aasbjerg (Intern)
Gudmundsson, Steinn (Ekstern)
Moeslund, Thomas B. (Ekstern)

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

Image Reconstruction under Non-Gaussian Noise

Technical University of Denmark
Period: 01/09/2013 → 26/10/2016
Number of participants: 6
Phd Student:
Sciacchitano, Federica (Intern)
Supervisor:
Hansen, Per Christian (Intern)
Main Supervisor:
Dong, Yiqiu (Intern)
Examiner:
Paulsen, Rasmus Reinhold (Intern)
Lauze, Francois Bernard (Ekstern)
Steidl, Gabriele (Ekstern)

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

Relations
Publications:
Sparse Classification - Methods & Applications
Project: PhD
Image reconstruction under non-Gaussian noise
Project: PhD

**Computing pseudo-CT from MR: Towards MR-only based radiation therapy**

Technical University of Denmark  
Period: 01/08/2013 → 12/12/2016  
Number of participants: 7  
Phd Student:  
Andreasen, Daniel (Intern)  
Supervisor:  
Edmund, Jens Morgenthaler (Intern)  
Larsen, Rasmus (Intern)  
Main Supervisor:  
Van Leemput, Koen (Intern)  
Examiner:  
Paulsen, Rasmus Reinhold (Intern)  
Cardoso, Jorge (Ekstern)  
Nyholm, Tufve (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.

**Relations**  
Publications:  
An Investigation of Methods for CT Synthesis in MR-only Radiotherapy  
Project: PhD

**Computational Analysis of Brain Images: Towards a Useful Tool in Clinical Practice**

Technical University of Denmark  
Period: 01/11/2012 → 24/02/2016  
Number of participants: 6  
Phd Student:  
Puonti, Oula (Intern)  
Supervisor:  
Larsen, Rasmus (Intern)  
Main Supervisor:  
Van Leemput, Koen (Intern)  
Examiner:  
Paulsen, Rasmus Reinhold (Intern)  
Ashburner, John (Ekstern)  
Maes, Frederik (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.

**Motion Tracking of Children in Risk of Cerebral Palsy**

Technical University of Denmark  
Period: 15/09/2012 → 24/02/2016  
Number of participants: 6  
Phd Student:  
Olsen, Mikkel Damgaard (Intern)  
Supervisor:  
Nielsen, Jens Bo (Intern)  
Main Supervisor: 
Computer Vision Assisted Motion Correction in Medical Imaging

Department of Mathematics
Period: 01/09/2012 → 31/03/2016
Number of participants: 7
Phd Student:
Wilm, Jakob (Intern)
Supervisor:
Hejgaard, Liselotte (Intern)
Paulsen, Rasmus Reinhold (Intern)
Main Supervisor:
Aanæs, Henrik (Intern)
Examiner:
Carstensen, Jens Michael (Intern)
Vogiatzis, George (Ekstern)
Åström, Kalle (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Statistical Shape Modelling of the Human Cochlear with Application to Cochlear Implant Surgical Procedures

Department of Mathematics
Period: 01/09/2012 → 30/09/2015
Number of participants: 5
Phd Student:
Kjer, Hans Martin (Intern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)
Examiner:
Dahl, Anders Bjorholm (Intern)
Darvann, Tron Andre (Intern)
Delingette, Hervé (Ekstern)

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

Image Analysis for X-ray Imaging of Food

Technical University of Denmark
Period: 01/06/2012 → 30/09/2016
Number of participants: 6
Phd Student:
Einarsdottir, Hildur (Intern)
Supervisor:
Larsen, Rasmus (Intern)
Main Supervisor: 
Ersbøll, Bjarne Kjær (Intern)
Examiner: 
Paulsen, Rasmus Reinhold (Intern)
Andersen, Kristinn (Ekstern)
Heyden, Anders (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering

Relations
Publications:
Image Analysis for X-ray Imaging of Food
Project: PhD

Individualized directional microphone optimization in hearing aids based on reconstructing 3D geometry of the head and ear from 2D photos
Technical University of Denmark
Period: 15/03/2012 → 19/06/2015
Number of participants: 6
Phd Student: 
Harder, Stine (Intern)
Supervisor: 
Laugesen, Søren (Intern)
Main Supervisor: 
Paulsen, Rasmus Reinhold (Intern)
Examiner: 
Bærentzen, Jakob Andreas (Intern)
Ballester, Miguel A. G. (Ekstern)
Juhl, Peter Møller (Intern)

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

A Neuroimaging study: Consequences of physical exercise on regional brain structure and connectivity in AD
Technical University of Denmark
Period: 01/12/2011 → 21/01/2016
Number of participants: 6
Phd Student: 
Larsen, Christian Thode (Intern)
Supervisor: 
Garde, Ellen (Ekstern)
Main Supervisor: 
Van Leemput, Koen (Intern)
Examiner: 
Paulsen, Rasmus Reinhold (Intern)
Hendrikse, Jeroen (Ekstern)
Menze, Bjoern H. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering
Project: PhD
Facial recognition
Department of Informatics and Mathematical Modeling
Period: 01/09/2010 → 26/02/2014
Number of participants: 5
Phd Student:
Fagertun, Jens (Intern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)
Examiner:
Clemmensen, Line Katrine Harder (Intern)
Cootes, Timothy F. (Ekstern)
Hansen, Dan Witzner (Intern)

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

Anatomical surface reconstruction and optimization
Department of Informatics and Mathematical Modeling
Period: 15/04/2010 → 30/08/2013
Number of participants: 6
Phd Student:
Jensen, Rasmus Ramsbøl (Intern)
Supervisor:
Poel, Mike van der (Intern)
Main Supervisor:
Paulsen, Rasmus Reinhold (Intern)
Examiner:
Bærentzen, Jakob Andreas (Intern)
Olsen, Ole Fogh (Ekstern)
Reyes, Mauricio (Ekstern)

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

Determination of magnetic resonance imaging biomarkers for multiple sclerosis treatment effects
Department of Informatics and Mathematical Modeling
Period: 01/04/2010 → 17/06/2013
Number of participants: 7
Phd Student:
Lyksborg, Mark (Intern)
Supervisor:
Dyrby, Tim Bjørn (Intern)
Siebner, Hartwig R. (Ekstern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Paulsen, Rasmus Reinhold (Intern)
Jones, Derek K. (Ekstern)
Westin, Carl-Fredrik (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering
Project: PhD
Neuro-morphological Interpretation of Clinical Outcome

Technical University of Denmark
Period: 15/08/2009 → 31/03/2016
Number of participants: 5
Phd Student:
Jensen, Betina Vase (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Paulsen, Rasmus Reinhold (Intern)
Nielsen, Mads (Ekstern)
Niessen, Wiro (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Planning and evaluation of radio-therapeutic treatment of head-and-neck cancer using PET/CT scanning

Department of Informatics and Mathematical Modeling
Period: 01/08/2009 → 19/12/2012
Number of participants: 7
Phd Student:
Hollensen, Christian (Intern)
Supervisor:
Hejgaard, Liselotte (Intern)
Specht, Lena (Ekstern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Pauisen, Rasmus Reinhold (Intern)
Ballester, Miguel A. G. (Ekstern)
Visvikis, Dimitris (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Surface Reconstruction of Coherent Deformable 3D Scans with Topological Recovery

Department of Informatics and Mathematical Modeling
Period: 01/05/2009 → 31/10/2010
Number of participants: 4
Phd Student:
Giotis, Nikolaos (Intern)
Supervisor:
Bærentzen, Jakob Andreas (Intern)
Pauisen, Rasmus Reinhold (Intern)
Main Supervisor:
Antón Castro, Francesc/François (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD
Cranio-facial growth modelling
Department of Informatics and Mathematical Modeling
Period: 01/12/2008 → 24/05/2013
Number of participants: 9
Phd Student:
Thorup, Signe Strann (Intern)
Supervisor:
Darvann, Tron Andre (Intern)
Hermann, Nuno (Ekstern)
Kreiborg, Sven (Ekstern)
Paulsen, Rasmus Reinhold (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Ersbøll, Bjarne Kjær (Intern)
Rueckert, Daniel (Ekstern)
Østergaard, Lasse Riis (Ekstern)

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

Motion Correction on High resolution Brain PET Imaging
Department of Informatics and Mathematical Modeling
Period: 15/11/2008 → 20/01/2012
Number of participants: 8
Phd Student:
Olesen, Oline Vinter (Intern)
Supervisor:
Højgaard, Liselotte (Intern)
Paulsen, Rasmus Reinhold (Intern)
Roed, Bjarne (Ekstern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Conradsen, Knut (Intern)
Bentzen, Søren Møller (Ekstern)
Reyes, Mauricio (Ekstern)

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

An open database of 3D scans of the human head, ear, and torso
The aim of this project is to generate a database of high-resolution 3D scans of the head and torso of humans. The data will be presented on a web-portal where software to view, manipulate and process the data is also available. The intended users of the data and tools are students and researchers working with acoustical modelling. Specifically, the data can for example be used to optimise spatial perception in hearing aids, boom design for headsets, and simulating individual head related transfer functions. Mathematical modelling of the sound field surrounding the head is an emerging discipline that has shown promise to alleviate some of the difficulties in for example designing and testing the performance of new hearing aid designs. However, current state-of-the arts methods are mostly based on synthetic data and the results are therefore somewhat misleading. The lack of data is mainly due to the difficulty in acquiring real 3D data of the human head and torso. Especially, the 3D geometry of the human ear is very difficult to obtain using traditional 3D acquisition techniques like CT, MR, and laser scanning. Recently, the 3D Laboratory at the school of dentistry at the University of Copenhagen obtained a 3dMD cranial scanner by a donation from the Oticon Foundation. This scanner can be used to capture high quality 3D scans of the head, ear (pinna and part of concha), and torso of humans. The aim of this project is to use the scanner at the 3D laboratory to capture the torso and head geometry of a group of test persons. Furthermore, ear impressions should be taken and scanned so the final and merged data is a precise 3D presentation of torso, head,
and the ear canal.

Department of Informatics and Mathematical Modeling
Period: 01/02/2008 → 01/03/2011
Number of participants: 1
Acronym: OpenHATS
Project Manager, organisational:
Paulsen, Rasmus Reinhold (Intern)

Financing sources
Source: Forsk. Private danske - Fonde
Name of research programme: Forsk. Private danske - Fonde
Amount: 1,000,000.00 Danish Kroner
Project

3D Shape Modelling using High Level Descriptors
Department of Informatics and Mathematical Modeling
Period: 01/06/2007 → 22/06/2011
Number of participants: 6
Phd Student:
Dahl, Vedrana Andersen (Intern)
Supervisor:
Baarentzen, Jakob Andreas (Intern)
Main Supervisor:
Aanæs, Henrik (Intern)
Examiner:
Paulsen, Rasmus Reinhold (Intern)
Solem, Jan Erik (Ekstern)
Sporring, Jon (Ekstern)

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

Advanced Methods for Biological Shape Analysis
Department of Informatics and Mathematical Modeling
Number of participants: 6
Phd Student:
Hansen, Michael Sass (Intern)
Supervisor:
Ersbøll, Bjarne Kjær (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Paulsen, Rasmus Reinhold (Intern)
Rueckert, Daniel (Ekstern)
Van Leemput, Koen (Intern)

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

Shape Analysis of the Dynamics of the Human Ear Canal
Department of Informatics and Mathematical Modeling
Period: 01/07/2005 → 30/01/2009
Number of participants: 7
Phd Student:
Darkner, Sune (Intern)
Supervisor:
Olsen, Ole Fogh (Ekstern)
Pualsen, Rasmus Reinhold (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Carstensen, Jens Michael (Intern)
Ahlberg, Jørgen (Ekstern)
Lorenz, Cristian (Ekstern)

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

Formanalyse af ørekanaler
Department of Informatics and Mathematical Modeling
Period: 01/06/2001 → …
Number of participants: 8
Phd Student:
Pualsen, Rasmus Reinhold (Intern)
Supervisor:
Conradsen, Knut (Intern)
Delingette, Hervé (Ekstern)
Laugesen, Søren (Intern)
Main Supervisor:
Larsen, Rasmus (Intern)
Examiner:
Carstensen, Jens Michael (Intern)
Cootes, Timothy F. (Ekstern)
Thodberg, Hans Henrik (Intern)

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