Final Research Report of the Project NKFIH K112998 - „Discrete Tomography from Incomplete and Uncertain Data: Modelling, Algorithms, and Applications"

Research year 2015

In the first research year we mainly investigated theoretical questions regarding shape descriptors to be used in discrete tomography.

Convexity

We presented a measure of directional convexity of binary images combining various properties of the configuration of 0s and 1s in the binary image. The measure can be supported by proper theory, is easy to compute, and as shown in our experiments, behaves intuitively. The measure can be useful in numerous applications of digital image processing and pattern recognition, and especially in binary tomography. We showed in detail an application of this latter one, by providing a novel reconstruction algorithm for almost hv-convex binary images [A1].

Switching components

One of the most essential patterns in binary images are the so called switching components. One way to measure the effect of these subpatterns in a binary matrix representing the image is to count the number of 0-s which have to be replaced with 1-s in order to eliminate the switching components. Finding the minimal number of 0-1 flips is generally an NP-complete problem. We presented two novel-type heuristics for the above problem and showed via experiments that they outperform the formerly proposed ones, both in optimality and in running time. We also showed how to use those heuristics for determining the so-called nestedness level of a matrix, and how to use the flips for binary image compression [A2].

Thinning, reduction

Thinning is a frequently applied technique for extracting centerlines from 2D and 3D binary objects. Parallel thinning algorithms can remove a set of object points simultaneously, while sequential algorithms traverse the boundary of objects, and consider the actually visited single point for possible removal. Two thinning algorithms are called equivalent if they produce the same result for each input picture. We presented pairs of equivalent sequential and parallel thinning algorithms for both 2D and 3D binary shapes. These algorithms can be implemented directly on a conventional sequential computer or on a parallel computing device like a GPU [A3,A4].

Discrete Tomography

Extending a former result we studied the effects of filtering in the Discrete Algebraic Reconstruction Technique in the multivalued case. We created a new test phantom set with different intensity levels and performed a comprehensive experimental study. We generalized the Relative Mean Error to multivalued discrete phantoms, and used a ranking system to evaluate our numerical results [A5].

Further achievements

Based on their work in the project, *N. Hantos* and *P. Bodnár* prepared their doctoral dissertation [A6,A7]. Furthermore, *G. Petrovszki* won a II. prize on the Local Scientific Students' Associations Conference with his work on the „320kV 3D Tyre CT scanner" [A8]. The entire software infrastructure of this instrument was formerly designed and implemented by the participants of the current project, and for the next two years of the project we set up the goal of developing this software tool to be suitable for the aims of the OTKA project, especially to design and analyse discrete tomographic reconstruction methods.

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Research year 2016

In the second research year we continued to investigate shape descriptors and developed image feature-based reconstruction algorithms to be used in discrete tomography.

Convexity

The directional convexity measure developed in [A1] turned out to be hard to aggregate for 2 dimensions. As an extension of this result, we succeeded to develop a direct 2-dimensional convexity measure based on the concept of Q-convexity [B1].

Thinning, reduction

Bertrand gave sufficient conditions for topology preserving parallel reduction using "P-simple" sets. Palágyi indroduced the "general-simple" deletion rules which provide equivalent sequential and parallel reductions. In [B2] we proved that every deletion rule deleting a P-simple set is also general-simple, and points deleted by reductions with general-simple deletion rules define P-simple sets. Furthermore, we gave sufficient conditions for equivalent pairs of sequential and parallel thinning algorithms and also constructed such algorithms which can be implemented both on conventional sequential computers and on parallel processing units like GPUs [B3].

Discrete Tomography

In tomographical non-destructive testing the approximate shape of the investigated object is often known in advance. We showed that exploiting this prior information can speed up the reconstruction process and/or provide results of better quality. [B4]. As another image prior we investigated the shape orientation descriptor, and found that it can improve the quality of the reconstructed image, especially in case of very few (sometimes even just one) projections [B5,B6]. This prior, again, might be useful in nondestructive testing.

Further achievements

We began to study how the LBP (Local Binary Pattern) texture prior can facilitate the reconstruction. Analysing the observations *J. Szűcs* won a III. prize on the Local Scientific Students' Associations Conference [B7].

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Research year 2017

The aim of the third research year was to extend the results of the first two years to higher dimensions and to multivalued scenarios, and to investigate application-motivated problems.

Convexity

We provided an improvement of the 1D convexity measure published in [A1] making it to follow better the intuitive concept of geometric convexity [C1] and also extended it to two dimensions [C2]. In [C3,C4] we developed several alternatives of the 2D Q-convexity measure published in [B1]. As a generalization, we suggested two approaches to measure convexity of grayscale images [C5,C6]. Finally, in [C7] we presented a Q-convexity vector descriptor that can be regarded as the extension of the scalar Q-convexity measures. The results reach far beyond the topic of the current project, as these measures – either solely or combined with other descriptors – can be used to a variety of pattern recognition and image classification problems. Some of them have been already studied in the recent project.

Thinning, reduction

In [C8,C9], we presented the first pair of equivalent sequential and fully parallel 3D surface-thinning algorithms. The proposed algorithms use the same deletion rule, and preserve topology for (26,6) pictures. Considering the studies of P-simple points, in [C10,C11], both formal and easily visualized characterizations of P-simple points in all the three types of regular 2D grids are reported. In [C12], we introduced the notion of a simplifier point, and we showed that simplifier points are line end points for both (8,4) and (4,8) pictures on the square grid. Our result makes efficient implementation of endpoint-based topology-preserving 2D thinning algorithms possible. In [C13], we gave two sufficient conditions for topology-preserving reductions working on the three possible 2D regular grids. The new conditions combined with parallel thinning strategies and geometrical constraints yield a single-step thinning scheme that deletes solely P-simple points.

Texture

We summarized our observations on using LBP (Local Binary Pattern) texture priors in binary image reconstruction in a journal paper [C14]. We introduced and investigated the problem of reconstructing binary matrices from their row and column sums when the number of strips (maximal sequences of consecutive ones) are additionally given in each row and column [C15,C16]. Such priors can also hold information on the texture of the image to be reconstructed. Investigation of further texture descriptors (e.g., GLCM matrices, Hu moments) are among our future plans.

Optical Coherence Tomography

We investigated how medically relevant features can be automatically extracted and biomarkers identified in optical coherence tomography images. We presented novel algorithms to localize subretinal fluid and cyst segments in OCT images and to extract quantitative measures thereof. Since, these algorithms are fully automated, medical experts do not need to perform time-consuming manual contouring and human inaccuracies can be also eliminated [C17,C18].

Discrete Tomography in Non-Destructive Testing

We designed and implemented a complete software framework for the „320kV 3D Tyre CT scanner" suitable to perform non-destructive X-ray testing, using continuous and discrete reconstruction techniques [C19,C20]. Many of the methods are implemented on GPUs. To enhance reconstruction quality we proposed a denoising model and tested its effect in the scanner [C21]. The calibration of the scanner is achieved by an optimization approach [C22]. As an application, we developed a method to detect steel cord discontinuities in tire tread x-ray images, using radiographs produced by the scanner [C23]. A special property of the scanner (and the reconstruction algorithms it is equipped with) is that it can work with arbitrary circular geometry, not just with the conventional equiangular one. This allows to obtain projections just from the informative angles, thus reducing acquisition time, energy consumption, and the amount of data processed. We developed several strategies to select the most informative projection angles, using blueprint images [C24,C25].

Further achievements

Including also his results in the current project, *A. Nagy* prepared his habilition thesis and received the degree [C26]. *J. Szűcs* won Special prize on the National Scientific Students' Associations Conference, the Best Poster Award 3rd Place at the WSPS 2017 conference [B6,C27]. *Cs. Olasz* won a III. prize on the Local Scientific Students' Associations Conference [C28]. With the GPU-based tomographic software solutions of the 3D Tyre CT Scanner *P. Balázs* and *L. Varga* won the Innovation Award of the University of Szeged, in 2017.

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Dissemination and international activity

The research results of the projects was published in 9 international journal articles, 17 international and 6 domestic conference papers, and 7 abstracts. During the project we established strong collaboration with the following internationally active professors: Sara Brunetti (University of Siena, Italy), Stanislav Harizanov (Bulgarian Academy of Sciences, Sofia, Bulgaria), Tibor Lukic (University of Novi Sad, Serbia), Rajmund Mosko (Laboratory MAX IV - Lund University, Sweden).