Mathematical and Machine Learning Models and Techniques for Solving Complex Problems

Adrian Sergiu DARABANT

Department of Computer Science

Faculty of Mathematics and Computer Science
Babes Bolyai University

Habilitation Thesis

Babes Bolyai University 2021

Mathematical and Machine Learning Models and Techniques for Solving Complex Problems

Adrian Sergiu DARABANT

This habilitation thesis contains the most important research activities and results of the author in the past 7 years. Following the defense of the PhD thesis, the author continued to develop some of the methods and theoretical problems on data fragmentation and allocation using complex models. The focus changed then slowly from these topics to solving computer vision problems related to the human face and extraction of information from human face images. The computer vision topics are tackled from two perspectives: a classical one based on complex mathematical models and development of deep learning techniques. The entire post PhD research activity of the author consists of 56 papers, out of which 27 journal articles and 29 conference papers. Out of these 8 journal papers and 11 conference papers are of ranks A and B.

The first chapter presents a short introduction and the topics that will be covered throughout the thesis, together with the main results and the list of publications.

The second chapter presents two solutions to optimal data allocation in a distributed system under constraints. These are expressed as a Linear Programming Model and as a Network Flow compatible problem. The Linear Programming problem can be approached with any mathematical solver. For the Network Flow approach a backtracking algorithm is proposed. Alternatively, a Greedy algorithm that yields an approximate solution, but with a running time 550 times less is also described.

Third chapter presents a series of methods for extracting facial features from images using classical methods based on mathematical solutions. Two methods for eyeglasses extraction using either Fourier descriptors followed by a Monte Carlo method and a random walk of the solution space using Monte Carlo are presented. A third proposed approach is based on a Genetic Algorithm for eyeglasses localization. Results are compared with the latest state of the art works.

Eyes detection, position, shape description, iris radius, sclera shape and localization and tracking are another class of methods presented in this chapter. The first presented method is based on the Fast Radial Symmetry Transform to detect the iris and compute its radius. The solution is extended to sclera shape segmentation by modeling the eyelids as parabolic curves. Compared to the state of the art, the presented methods obtain better accuracy or comparable accuracy, but with better execution time. The second presented problem is eye

tracking and its description using a particle filter based method.

The end of this chapter handles the problem of detecting and recognizing micro-expressions. One proposed solution is based on a discrete motion magnitude descriptor coupled with a 3D Gaussian fitting method. The second method is based on dense optical flows. All results are compared with the state of the art and show comparable or better results.

Chapter four presents the research on 3D reconstruction and camera calibration. Two presented methods are targeted at reconstructing frontal faces from multiple images in order to obtain a frontal 3D model where one can measure morphological features and ratios. The second approach also brings the forehead into the 3D model (up to the hair). The obtained results are compared with similar works in the literature and show better average reconstruction errors. A camera calibration optimization method based on a genetic algorithm is also proposed. Compared to state of the art, the obtained accuracy is increased by several orders of magnitude.

Fifth chapter covers a different perspective on facial features analysis using convolutional neural networks and deep learning methods and a new class of problems: *neural architecture search.*

The facial analysis part deals with automatic gender extraction from facial images. Compared to classical methods this is a problem where CNNs really outshine classical approaches. Automatic skin tone extraction, face and hair segmentation, baldness detection and hair color extraction are covered. New techniques for accurate hair and face segmentation are proposed. The results are numerically compared to those of the state of the art.

Race and ethnicity is also presented with a method for determining these features from facial images. A number of well-known network architectures are studied to observe the properties that makes them more or less accurate to determining the race. The semantic and behavior of these networks is also studied to see what triggers certain responses from the network.

A final tackled problem is a new research direction: neural architecture search. An automatic problem-specific neural architecture search method is presented, has its results analyzed and compared to some other studies.

The last chapter draws some conclusions and presents the envisioned future research activities of the author, as well as the professional and academic development plan.