Analysis of variance in statistical image processing

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PREFACE

The philosophical approaches pursued in this book can be divided into two groups: imaging problems involving relatively high signal-to-noise ratio (SNR) environments and problems associated with environments in which the images are corrupted by severe, usually non-Gaussian noise. The former class of problems led to the development of numerous approaches involving the so-called experimental design techniques.[2–5] The latter class of problems was addressed using techniques based on partition tests (Kurz,[72] chapter III, Kersten and Kurz[73]). The material in this book is based on experimental design techniques; it represents a graduate course offered by the senior author. The book considers the basic notions involving experimental design techniques. It is hoped that, in addition to being a text for a graduate course, the book will generate interest among imaging engineers and scientists, resulting in further development of algorithms and techniques for solving imaging problems.

The basic problems addressed in the book are line and edge detection, object detection, and image segmentation. The class of test statistics used is mainly based on various forms of the linear model involving analysis of variance (ANOVA) techniques in the framework of experimental designs. Though the statistical model is linear, the actual operations involving imaging data are nonlinear. It has been shown by Scheffe (Chapter10)[2] that statistical tests based on ANOVA are relatively insensitive to the variations in underlying distributions. This is particularly true in processing of imaging data if the corruption of the Gaussian noise background does not exceed ten percent. For higher rates of contamination and for other significant deviations from the Gaussian model, one can robustize the procedure along the lines suggested by Hampel et al.[84] The latter approach is cumbersome and computationally inefficient. A more practical approach to robustizing the ANOVA procedure is to use stochastic approximation algorithms as presented in Chapter 8.

The F-statistic, which is fundamental to the use of techniques based on the ANOVA model, is obtained from the ratio of two chi-square random variables. For the case of testing a null hypothesis against alternatives for a Gaussian noise distribution of unknown and/or variable variance, it is optimum. Namely, the same test maximizes the power of the test (probability of detection) for all alternatives and among all invariant tests with respect to shifting, scaling, and orthogonal transformation of the data resulting in a uniformly most powerful test if the underlying noise is Gaussian (Lehman,[1] p. 67).

Since in processing large images the noise variance or SNR can change significantly over various regions of the image, this situation leads to an automatic thresholding scheme that takes into account the histogram taken from the entire image yielding a constant false alarm rate.To ensure the practicality of the procedures, the image needs to be scanned by a localized mask. The mask must be large to yield enough power of the test, yet it must be sufficiently small to ensure the detection of small features or yield good resolution of image details. From many years of experience with imaging data, the authors know that the mask must consider at least 20 pixels (samples) of observable data. This determines the size of the mask and its geometry, which suggests 5×5 and 3×7 for most applications.

The standard ANOVA theory (independent sampling) is relatively insensitive to the departure from the Gaussian distribution of noise and to the departure from the assumption of equal variance. This insensitivity does not extend to the dependent noise model (Scheffe,[2] p. 364). As a matter of fact, when using modern image processing techniques, the assumption of independent sampling is invalid. Neglecting the statistical dependence of data results in total breakdown of the processing scheme. To bypass this difficulty, the theory of ANOVA is extended to include dependent data. In the latter situation, if the contamination of noise is severe, the robustizing of the procedures using techniques suggested by Hampel et al. is no longer viable. Yet the modifications of the imaging data extraction process based on the stochastic approximation algorithm (Chapter 8) are practicable. Alternatively, one can use procedures based on partition tests.[74, 77]

It is hoped that this book will stimulate a wider acceptance of the methodology of image processing suggested here. Based on many years of experience, the authors are confident that image processing techniques based on the experimental design model will become a significant tool in solving many imaging problems.

The authors are particularly indebted to the senior author's doctoral students. Without their important contributions, this book could not become a reality. The list of references lets the reader become familiar with additional aspects of the approach to imaging problems based on the experimental design model and provides

an opportunity to develop additional techniques to solve various problems in the field.

It is understood that the reader is familiar with basic aspects of probability and statistics. The authors decided that including simple problems and exercises would be counterproductive. In teaching the course, specific image processing problems based on the software developed over the years were assigned.