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Logarithmic Image Processing: Theory and Applications

MICHEL JOURLIN

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VOLUME ONE HUNDRED AND NINETY FIVE

ADVANCES IN IMAGING AND ELECTRON PHYSICS

Logarithmic Image Processing: Theory and Applications

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PREFACE

It is a pleasure to welcome Michel Jourlin back to these Advances. With his colleagues, he has already written extensively on the logarithmic image processing (LIP) model, which he originated. In this volume, he brings together both the theoretical background of the model and the motivation for using it, together with a host of applications in different subject areas. The book begins with an account of the origins of the model and the ways in which it has developed, which includes much useful advice for new generations of scientists and mathematicians embarking on such subjects. I say no more about this here, for I would merely be repeating his vividly written Foreword. He also presents the contents of each chapter there and draws attention to novel features.

I am confident that readers will appreciate this full and very lucid new account of the LIP model, and I am delighted to include it in these Advances.

Peter Hawkes

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ACKNOWLEDGMENTS

I want first to say that this book would never be written without the unfailing support and confidence of Dr. Peter Hawkes. Thus, I am deeply indebted to him, even if the last 3 months were entirely dedicated to the logarithmic imaging process (LIP), which became the obsession of my days and my nights. I hope that the achievement of this work will signify a return to normal life.

I also take this opportunity to express my gratitude to

- a number of my students for the pleasure it was to work with them: Pierre Guilbert, Victor Deshayes, Bassam Abdallah, Joris Corvo, Enguerrand Couka, Josselin Breugnot, Maxime Carré, Frédéric Itthirad, and earlier Freddy Darsonville, Pascal Michoud, Nathalie Montard, among others.
- my colleagues whose honesty and open minds made the collaboration both enjoyable and fruitful: Jean-Marie Becker, Marie-José Labouré, Isabelle Fillère—with whom we animated a working group focused on geometry, metrics, and shapes—Thierry Fournel, Guillaume Noyel, Guy Courbebaisse, Laurent Navarro, and earlier to Richard Grisel.
- the researchers who shared my passion of image processing: Dominique Jeulin, Françoise Préteux, Jacques Demongeot, Isabelle Magnin, among others who always accepted my invitations to PhD juries, Congresses, etc.
- and those who contributed to the LIP developments, including the teams of Prof. Cahill, Buzuloiu, and Agaian.

Writing all these names, I am very aware how truly lucky I was to meet these people.

Michel Jourlin

FOREWORD: SHORT HISTORY OF THE LIP MODEL

1. JUSTIFICATION OF THE MODEL

The first question we will answer is: *Why the logarithmic image processing (LIP) model?*

In fact, when we consider preexisting logarithmic look-up tables (LUT) we should ask what novel logarithmic tools can really bring to image processing. Moreover, when we analyze the content of the many papers dedicated to the LIP framework, we notice that their contribution directly relies on the model's nonlinearity. Particularly, most of them point out the ability of LIP tools to enhance or process dark images or dark regions inside an image. In fact, such tools are now well known to be practically insensitive to lighting variations or lighting drift.

In this book, a number of applications we will expose also rely on these capabilities of the LIP model. Nevertheless, using the strong mathematical and physical properties of the model, we will try to understand and justify the power of logarithmic operators. This way of reasoning permitted us to propose many novel tools and results. For example, we invite the readers to focus their attention on these sections:

Chapter II

- The physical meaning of the logarithmic additive contrast and its link with the classical Michelson contrast
- The logarithmic multiplicative contrast and its strong sensitivity in bright regins

Chapter III:

- The metrics associated with logarithmic contrasts
- Novel notions: the various Asplünd's metrics and particularly the additive Asplünd's metric, whose insensitivity to exposure time and, at a lesser level, to diaphragm aperture variations offers a new way of processing low-light images as well as images acquired under variable lighting.

Chapter IV:

- Based on the mathematical vector space structure valid on the space of images (Chapter "Gray-Level LIP Model. Notations, Recalls and First Applications"), the use of negative gray levels as light intensifiers permits the enhancement of very low-light images.

We have also taken care to:
- illustrate the main results with plenty of biomedical and industrial applications, and
- highlight the places where new research developments are required.

2. ORIGIN OF THE MODEL

In 1983, I attended a training week dedicated to image analysis at the "Ecole des Mines de Fontainebleau." I already worked in collaboration with this team, called the "Fontainebleau School," and understood the principles and tools of "mathematical morphology." Nevertheless, this training was an opportunity for me to enter the formulation of the main tools of mathematical morphology in depth, and I focused my attention on the gray-level mathematical morphology. Since my initial education was purely mathematics, I was particularly interested in the set of theoretical results developed by the Fontainebleau School on the basis of the Minkowski's addition $A \oplus B$ of two binary shapes A and B. I remarked that for dilation (resp. erosion) operator, noted $A \oplus B$ (resp. $A \ominus B$), the structuring element B and the studied shape A were of same nature (binary shapes). However, when transferred to functions, they produce dilation/erosion operators $f \oplus B$ and $f \ominus B$ where the structuring element B remains binary.

Thus, I thought that it would likely be interesting (at least intellectually) to imagine new operators $f\,''\!\oplus''\,g$ and $f\,''\!\ominus''\,g$ where g could play the role of a functional structuring element, ie, could be chosen as a simplified function dedicated to the study of an image f, as it is commonly done for binary shapes. Moreover, as a former mathematician converted to image processing, I had in mind that the laws $''\oplus''$ and $''\ominus''$ would not be limited to a mathematical formulation, but would possess a tangible usefulness. This is the reason why my first concern was to think about a realistic situation in image processing where the sum of two images could have a physical meaning. This reflection directed me toward images acquired in transmission (microscopy, tomography, scanner, etc.) where the observed object appears often as the superimposition of various components. For example, the simple observation with a microscope of the nucleolus of a cell consists of the stacking of the cell cytoplasm, of the nucleus and the nucleolus. The resulting image is then nothing but the addition, in transmission, of the images corresponding separately to each component.

In such conditions, I decided to define first the law $''\oplus''$ in the context of transmitted signal (images acquired in transmission), ie, when the observed object is located between the source and the sensor. I finally noted this addition law with the symbol $\triangle\!\!\!\!\!+$ so as not to lead to confusion with the standard morphological operators.

The first research on this subject permitted me to effectively introduce an internal addition law $\triangle\!\!\!\!\!+$ on the space $I(D, [0, M[)$ of images defined on the same spatial support D and with values in the same gray scale $[0, M[$. Such a law is the well-known transmittance law expressed in terms of gray levels (cf. following Chapter "Gray-Level LIP Model. Notations, Recalls and First Applications"). A classical reflex for a mathematician when he disposes of an addition law is to deduct a scalar multiplication $\triangle\!\!\!\!\!\times$ by stacking n times the object corresponding to the image *f*: $f \triangle\!\!\!\!\!+ f \triangle\!\!\!\!\!+ \cdots \triangle\!\!\!\!\!+ f = n \triangle\!\!\!\!\!\times f$. Once established for integers, this law is then extended to every real number λ. At this moment, we dispose of two laws, one permitting to add two images ($f \triangle\!\!\!\!\!+ g$), the other to multiply an image by a real number ($\lambda \triangle\!\!\!\!\!\times f$). Having done this "physical" reasoning based on the transmittance law, I returned to a mathematical point of view, which consisted of asking what the properties of these laws are in terms of associativity, neutral element, opposite, commutativity, distributiveness, etc.

All these properties are satisfied when the space $I(D, [0, M[)$ of images is extended to the space $F(D,]-\infty, M[)$ of functions defined on the same domain D with values in $]-\infty, M[$. In fact, the introduction of possible negative values allows us to define the opposite $\triangle\!\!\!\!\!- f$ of an image *f*, representing the function, which results in the neutral element 0 when added to the image $f : f \triangle\!\!\!\!\!+ (\triangle\!\!\!\!\!- f) = 0$.

The set of these properties structures $F(D,]-\infty, M[), \triangle\!\!\!\!\!+, \triangle\!\!\!\!\!\times)$ as a vector space, allowing the use of the numerous tools available in such spaces, such as interpolation, gauges, norms, scalar products, etc.

In conclusion, we dispose of a strong physical and mathematical framework to perform image processing in good conditions.

I do not know if the reader is unfamiliar with the LIP model considered at this step, or whether it is interesting to pursue these first developments, but I will say that when I proposed this subject to my PhD students, no one was enthusiastic. I most strongly insisted until one of them, J.C. Pinoli, demonstrated some interest. I must admit that nobody, not even myself, had the least idea of the subject's extent at this period.

After I published the first results with J.C. Pinoli and R. Zeboudj (1985-89), I had some contact with researchers interested in the LIP model. I remember particularly the visit in Lyon of Professor Cahill (La Trobe

University, Australia) who had the courtesy to ask my agreement before beginning a PhD on the LIP subject with his student, Dennis Deng.

To refer to the most important milestones punctuating the LIP progresses, I must cite:

- In the biomedical domain, the collaboration I developed with Professor Jörg Schüpbach (University of Zurich) concerning the three-dimensional (3D) visualization of T4-lymphocytes cultured in presence of HIV virus. T4-lymphocytes were removed from the culture and fixed in an epoxy block before being cut into very thin slices (thickness: 40 nm) with an ultramicrotome. Each slice was then imaged with an electron microscope in transmission and the role of the LIP was to interpret some missing cuts (logarithmic interpolation) and to normalize the lighting changing observed on the cuts due to thickness variations. This research took place between 1985 and 1989 and resulted in a scientific prize (Plano Prize, Salzburg, 1989).
- In the research domain, I had a lasting collaboration with the team created and led by Professor Vasile Buzuloiu (Polytecnica, Bucaresti), including the works of V. Patrascu, E. Zaharescu, C. and L. Florea, C. Vertan, among others.
- In research-development and industrial applications, I am working with a start-up called NT2I, which has integrated the set of logarithmic tools and tests the final tools as we proceed in their creation. I have headed two PhD theses prepared by research engineers from NT2I and we work together daily.

2.1 Spirit and Goals of the Book

It's a pleasure for me to recall the long and fruitful collaboration I developed with Peter Hawkes: thanks to him, it was possible to publish extended papers dedicated to the LIP model. I had already the occasion to emphasize the particular role of AIEP Serial in the "jungle" of scientific journals, where it is customary today to publish papers mostly devoted to abstract, introduction, notations, recalls, conclusion, perspectives, and references, with very little space for research itself. On the contrary, AIEP Serial permits me to present extended papers that allow in-depth study of a subject. With Peter Hawkes agreement, I decided that this book's contents would not be the simple aggregation of previous papers. It seemed more interesting to summarize the main existing results (which remain accessible to the interested reader) and to highlight the novel ones, as well as application examples.