

Group Theoretical Invariants in Color Image Processing

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Abstract

Many image formation processes are complex interactions of several sub-processes and the analysis of the resulting images requires often to separate the influence of these sub-processes. An example is the formation of a color image which depends on the illumination, the properties of the camera and the objects in the scene, the imaging geometry and many other factors. Color constancy algorithms try to separate the influence of the illumination and the remaining factors and are thus typical examples of the general strategy. An important tool used by these methods are invariants i.e. features that do not depend on the state of one (or several) of the sub-processes involved. Illumination invariants are thus features that are independent of illumination changes and depend only on the remaining factors such as material and camera properties.

We introduce transformation groups as the descriptors of the sub-processes mentioned above. We then show how they can be used to calculate the number of independent invariants for a given class of transformations. We also show that the theory is constructive in the sense that there are symbolic mathematics packages that can find the invariants as solutions to systems of partial-differential equations.

We illustrate the general theory with applications from color computer vision. We will describe the construction of invariants from the dichromatic and the Kubelka-Munk reflection models in detail. Space does not permit us to describe the detailed derivation of illumination invariants from PCA models of illumination spectra but it can be shown that the construction of the invariants follows the same mathematical procedure.

1. Introduction

Many pattern recognition models assume that the available measurements are the result of a number of different interacting processes. A standard model for color image formation assumes, for example, that the final color image depends on the characteristics of the illumination, the scene geometry, the properties of the materials in the scene

and the characteristics of the camera. In typical applications we are only interested in one or a few of these factors while the others should be ignored. This is the basic idea of invariants in pattern recognition. In the color image processing example mentioned above we may want to ignore the influence of the illumination source or the geometric relations between the camera and the scene. Invariance based mechanisms are highly successful in biological systems and we apply them all the time without even being aware of them. They are obviously one important tool to stabilize our perception of the world and to simplify our interpretation of it. Typical examples from human perception are:

Color Constancy: We routinely ignore the effect of variations of the spectral characteristics of the illuminants.

Orientation Invariance: We can compensate to a certain extent the influence of changes of viewing directions on the perceived image.

Shape Changes: A typical, and very important example, of this type of invariance is face perception. We can recognize a persons face independent of large variations of its shape, often connected to emotions like joy, sadness etc.

Permutation Invariance: Often we can recognize a collection of items independent of the order in which they are arranged.

Without conditional constraints it is very difficult to solve such invariance problems since without such constraints we would need something like a table that collects all the different cases that we would like to ignore. The solution to this problem is that invariance problems can be more easily solved if there is a law or a rule describing it. This law or rule can often be described in the framework of group theory and mathematical theories developed in the last 100 years provide the tools to investigate and solve these problems. Some of the first attempts to apply group theoretical tools to investigate properties of biological systems (and especially perceptual invariants) go back, at

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Table of Contents Group Theoretical Methods In Image Processing

1. Understanding the eBook Group Theoretical Methods In Image Processing
 - The Rise of Digital Reading Group Theoretical Methods In Image Processing
 - Advantages of eBooks Over Traditional Books
2. Identifying Group Theoretical Methods In Image Processing
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Group Theoretical Methods In Image Processing
 - User-Friendly Interface
4. Exploring eBook Recommendations from Group Theoretical Methods In Image Processing
 - Personalized Recommendations
 - Group Theoretical Methods In Image Processing User Reviews and Ratings
 - Group Theoretical Methods In Image Processing and Bestseller Lists

5. Accessing Group Theoretical Methods In Image Processing Free and Paid eBooks
 - Group Theoretical Methods In Image Processing Public Domain eBooks
 - Group Theoretical Methods In Image Processing eBook Subscription Services
 - Group Theoretical Methods In Image Processing Budget-Friendly Options
6. Navigating Group Theoretical Methods In Image Processing eBook Formats
 - ePub, PDF, MOBI, and More
 - Group Theoretical Methods In Image Processing Compatibility with Devices
 - Group Theoretical Methods In Image Processing Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Group Theoretical Methods In Image Processing
 - Highlighting and Note-Taking Group Theoretical Methods In Image Processing
 - Interactive Elements Group Theoretical Methods In Image Processing
8. Staying Engaged with Group Theoretical Methods In Image Processing
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Group Theoretical Methods In Image Processing
9. Balancing eBooks and Physical Books Group Theoretical Methods In Image Processing
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Group Theoretical Methods In Image Processing
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Group Theoretical Methods In Image Processing
 - Setting Reading Goals Group Theoretical Methods In Image Processing
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Group Theoretical Methods In Image Processing
 - Fact-Checking eBook Content of Group Theoretical Methods In Image Processing
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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