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Escuela Superior de Ingeniería

Multifractal Analysis of Thermal Images of Electronic Devices in Different Colour Profiles

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Marina Díaz-Jiménez, a graduated in Industrial Desing and Product Development in Engineering, is currently studying for a Master’s degree in Manufacturing Engineering at the University of Cádiz.

She embarked on her research career by focusing on the microgeometric characterization of porous images using fractal and multifractal geometry.

Currently, she is working as a researcher at the University of Cádiz, with her research centered on the characterization of one-dimensional signals (consumption signals) through the application of fractal and multifractal geometry.

Marina Díaz-Jiménez

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Contents

1. Introduction

Images in different colour formats

RGB, CMYK, HSV and HSI

Thermal images of electronic device

In order to make a first approach towards the characterization of electronic devices based on heat dissipation

Multifractal geometry

Suitable candidate for characterizing complex geometric shapes

Box-counting method and Method of Moments

They allow to extract the main multifractal parameters: Dimension Function, $D(q)$, and the Degree of Multifractality, $\Delta D(q)$.

2. Aims and contributions

To make a methodology using multifractal approach to characterise images in different colour formats

To make a preliminary study for the accurate characterization of electronic devices in terms of heat dissipation using multifractal analysis.

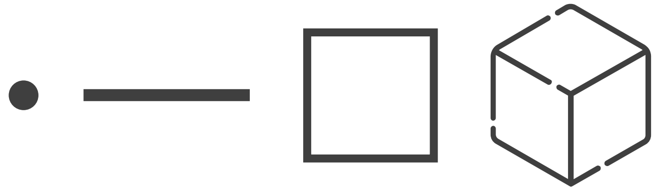
3. Theoretical Foundations

EUCLIDEAN GEOMETRY

- Objects composed of **points**, **curves**, **surfaces** and **volumes**
- Topological integer dimensions (0, 1, 2 and 3)
- The **measurement** of an object is **independent** of the scaling measure

$$L = N \cdot \delta$$

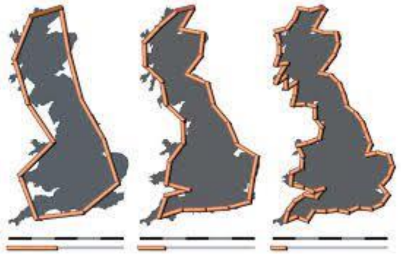
Point Line Plane Volume



FRACTAL GEOMETRY

- Objects with **irregular**, **rough** and **disordered shapes** and contours
- Objects with self-similarity property
- The **measurement** of an object is **dependent** of the scaling measure

$$L(\delta) = N(\delta) \cdot \delta$$



3. Theoretical Foundations

MULTIFRACTAL STRUCTURE

Superposition of subsets of monofractal structures interwoven through a hierarchy of scaling exponents characterizing local variability and heterogeneity

MULTIFRACTAL ANALYSIS

Description of complex structures exhibiting sets of regions with different fractal properties, providing a relatively more specific characterization

BOX-COUNTING METHOD AND METHOD OF MOMENTS

They allow to extract the main multifractal parameters

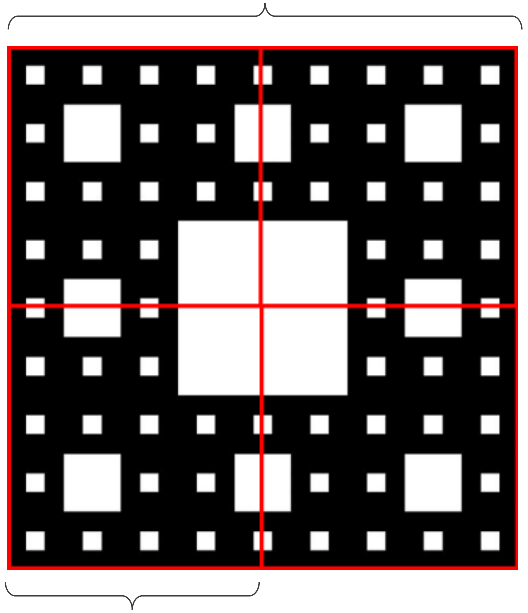
MULTIFRACTAL PARAMETERS

- Generalized dimensions function, $D(q)$
- Degree of Multifractality, $\Delta D(q)$

4. Methodology

Multifractal Analysis: Box-counting method and the Method of Moments

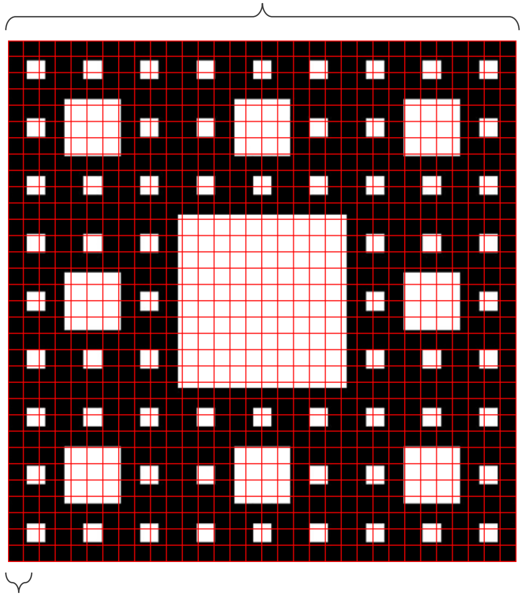
Side (L) = 2^9 = 512 pixels



δ = 2^8 = 256 pixels

n = 4

Side (L) = 2^9 = 512 pixels



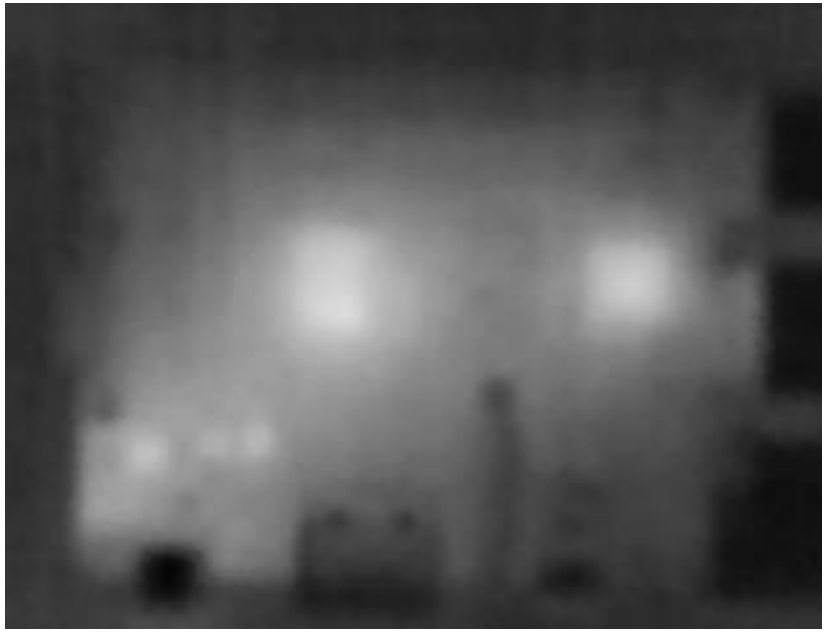
δ = 2^4 = 16 pixels

n = 1024

- Estimation of the generalized dimensions function, $D(q)$
- n = number of boxes to cover the image
- δ = side length
- $n(\delta)$ → number of boxes depends on the side length

- $\delta = \{L/1,\ L/2,\ L/4, L/8, \ldots\}$
- q varies between $-\infty$ and $+\infty$

4. Methodology – Experimental Setup



Pi3 Raspian Desktop board

Experimental setup

- Image capture time: 1 hour (3,600 seconds) → From t_0 = 0 s, when the board is off, to a t_1 = 3,600s, when the board is on
- Total images: 31,970 images
- Capture rate: 8-9 images per second
- Images obtained: images of 320x240 pixels

Images of different areas of the board

Image area 1

Image area 2

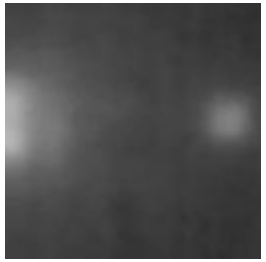


Image area 3

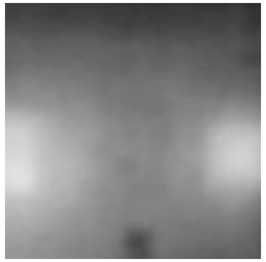
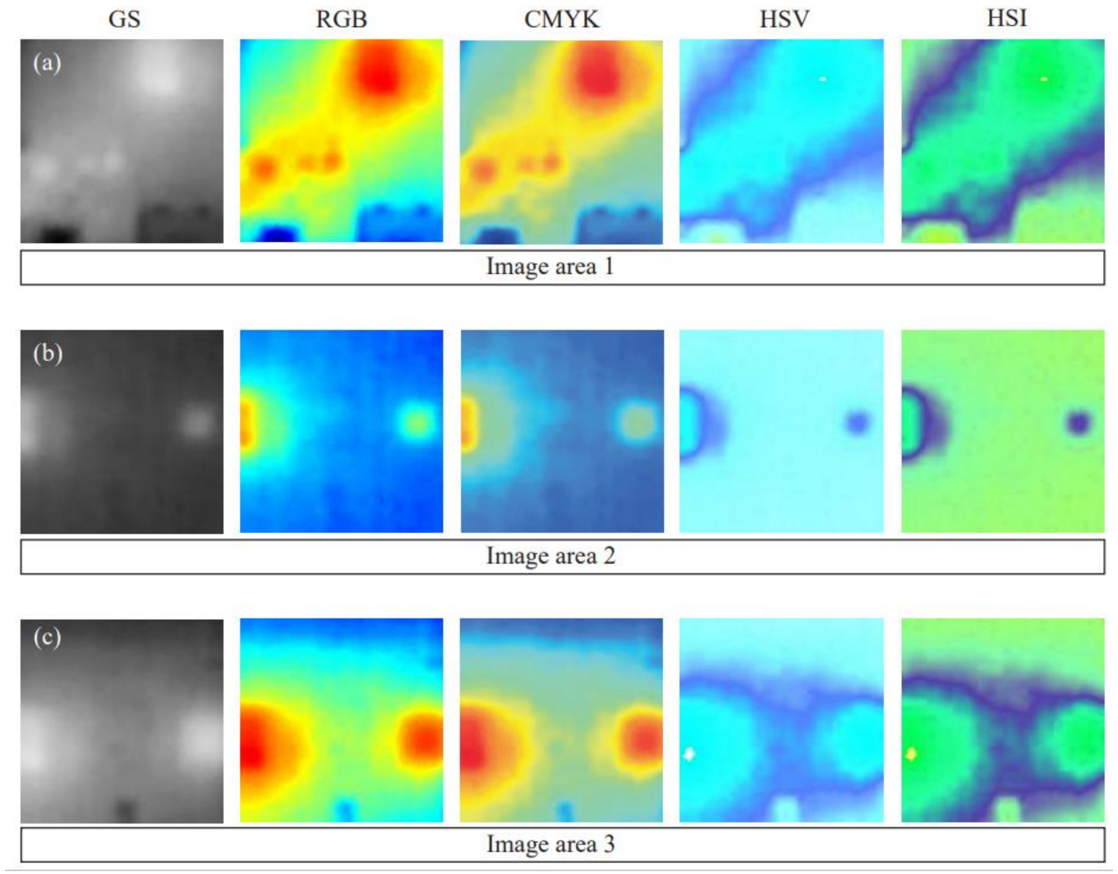


Image dimensions: 128 x 128 pixels

4. Methodology



Grey-scale (GS) images as a reference → They are considered to represent the most faithful and realistic situation to the raw files captured by the camera

5. Results

Multifractal Analysis of Grey-scale images

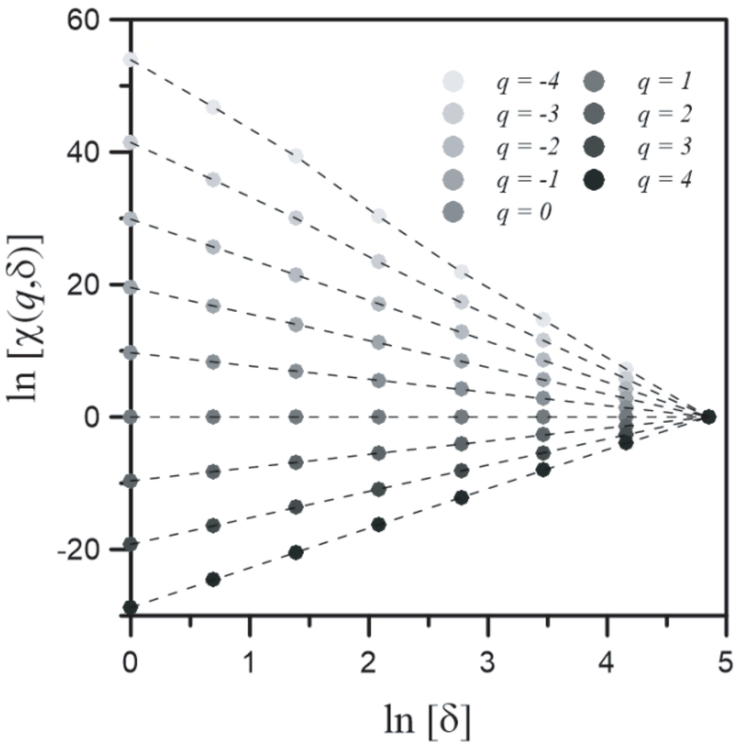
For images of 128 x 128 pixels:

- Scale range: δ = 1 to δ = 128
- *q* moments from -4 to 4

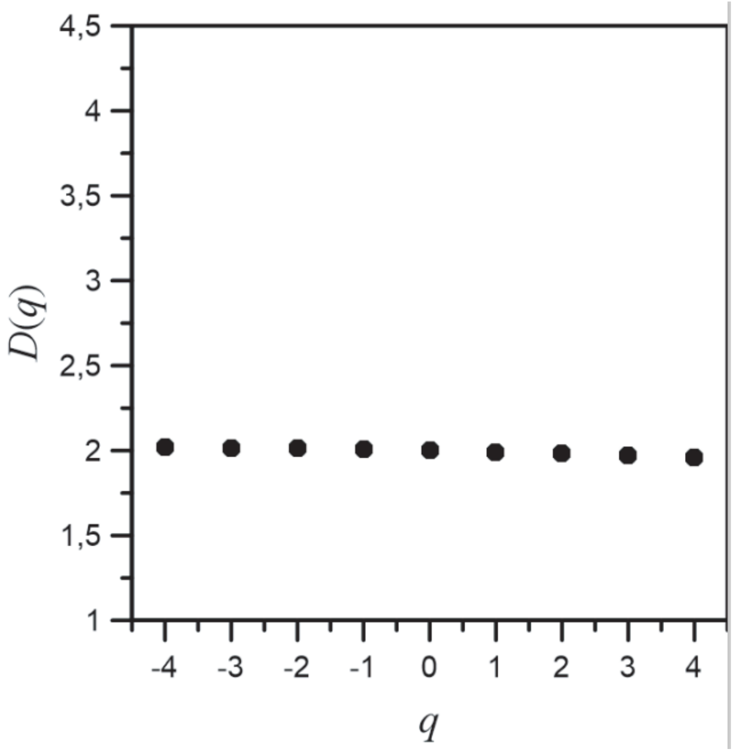
Degree of multifractality, $\Delta D(q)$		
	Image area 1	0.279
	Image area 2	0.059
	Image area 3	0.074

Monofractal behaviour is considered in all three cases

Partition Function



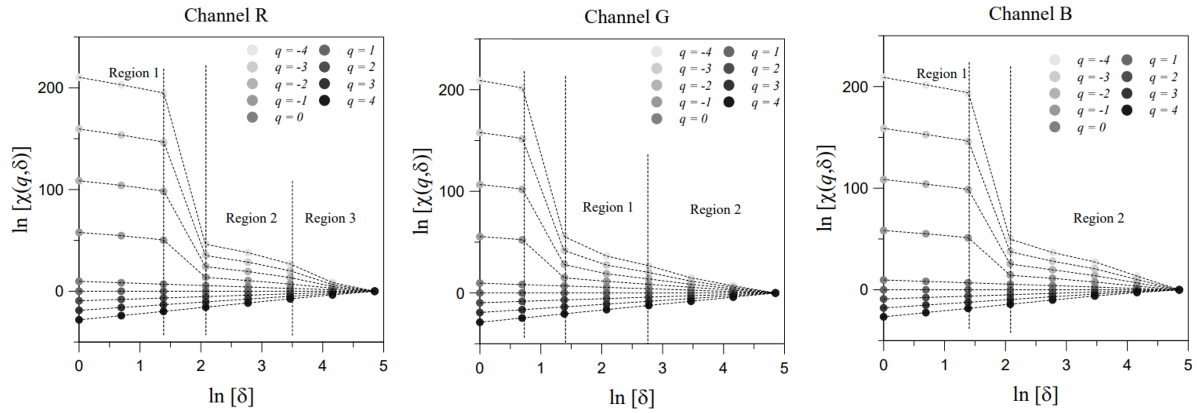
Generalized dimensions function, $D(q)$



5. Results

Multifractal Analysis of RGB images

Partition Functions



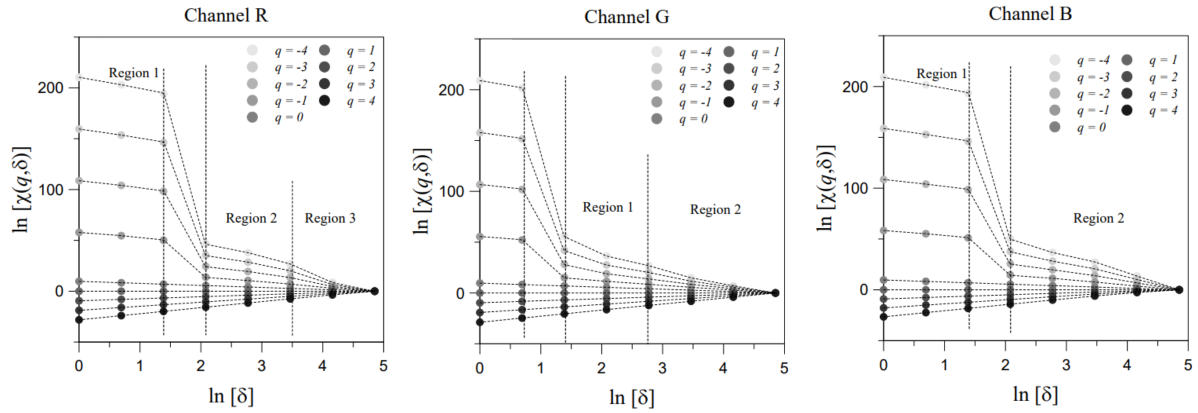
Channel R		SB[a]	ΔD(q)	$\sum x^2$
ΔD(q) Image 1	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	-	-	-
	Region 3. δ = 32 - 128	✓	2.051	6.363
ΔD(q) Image 2	Region 1. δ = 1 - 8	-	-	-
	Region 2. δ = 16 - 128	✓	2.400	8.150
ΔD(q) Image 3	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	-	-	-
Channel G		**SB[a]**	**ΔD(q)**	$\sum x^2$
ΔD(q) Image 1	Region 1. δ = 4 - 16	✓	2.224	9.179
	Region 2. δ = 16 - 128	✓	0.588	0.165
ΔD(q) Image 2	Region 1. δ = 1 - 128	✓	0.072	0.001
ΔD(q) Image 3	Region 1. δ = 4 - 16	✓	3.112	21.062
	Region 2. δ = 16 - 128	✓	0.436	0.186
Channel B		**SB[a]**	**ΔD(q)**	$\sum x^2$
ΔD(q) Image 1	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 128	✓	1.862	4.937
ΔD(q) Image 2	Region 1. δ = 4 - 16	✓	1.980	8.251
	Region 2. δ = 16 - 128	✓	0.315	0.116
ΔD(q) Image 3	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	✓	0.622	0.774

SB[a]: Scaling Behaviour

5. Results

Multifractal Analysis of RGB images

Partition Functions



Best approximation to reference images:

- Channel G
- Channel B

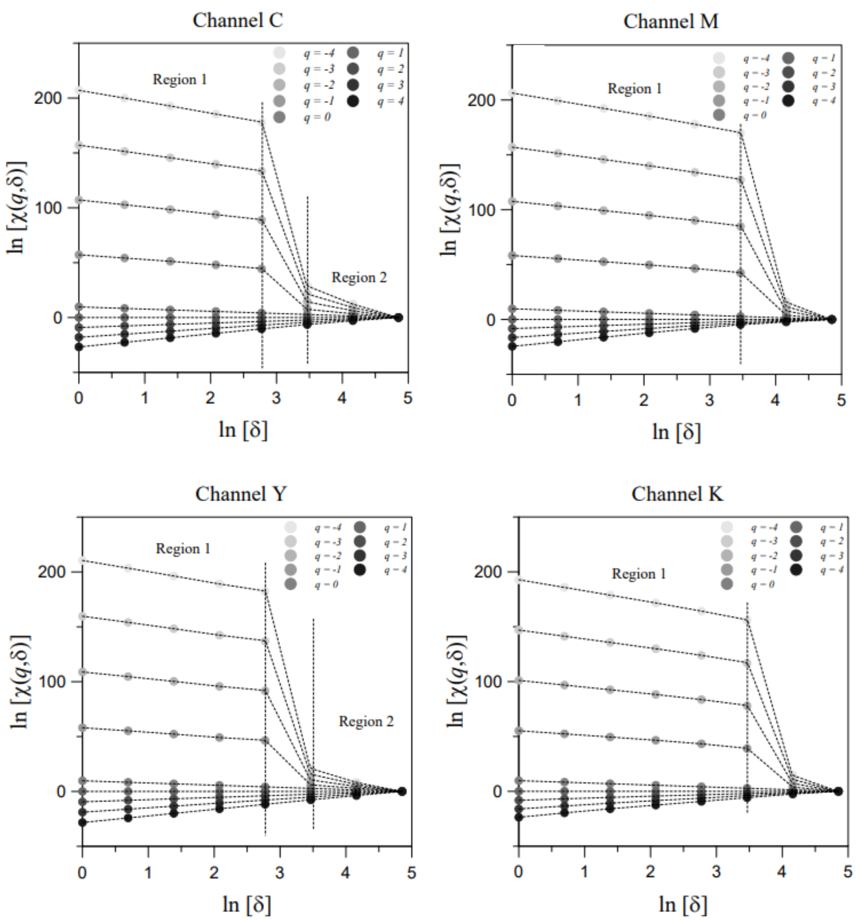
Channel R		SB[a]	$\Delta D(q)$	$\sum x^2$
$\Delta D(q)$ Image 1	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	-	-	-
	Region 3. δ = 32 - 128	✓	2.051	6.363
$\Delta D(q)$ Image 2	Region 1. δ = 1 - 8	-	-	-
	Region 2. δ = 16 - 128	✓	2.400	8.150
$\Delta D(q)$ Image 3	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	-	-	-
Channel G		**SB[a]**	$\Delta D(q)$	$\sum x^2$
$\Delta D(q)$ Image 1	Region 1. δ = 4 - 16	✓	2.224	9.179
	Region 2. δ = 16 - 128	✓	0.588	0.165
$\Delta D(q)$ Image 2	Region 1. δ = 1 - 128	✓	0.072	0.001
$\Delta D(q)$ Image 3	Region 1. δ = 4 - 16	✓	3.112	21.062
	Region 2. δ = 16 - 128	✓	0.436	0.186
Channel B		**SB[a]**	$\Delta D(q)$	$\sum x^2$
$\Delta D(q)$ Image 1	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 128	✓	1.862	4.937
$\Delta D(q)$ Image 2	Region 1. δ = 4 - 16	✓	1.980	8.251
	Region 2. δ = 16 - 128	✓	0.315	0.116
$\Delta D(q)$ Image 3	Region 1. δ = 1 - 4	-	-	-
	Region 2. δ = 8 - 32	✓	0.622	0.774

SB[a]: Scaling Behaviour

5. Results

Multifractal Analysis of CMYK images

Partition Functions



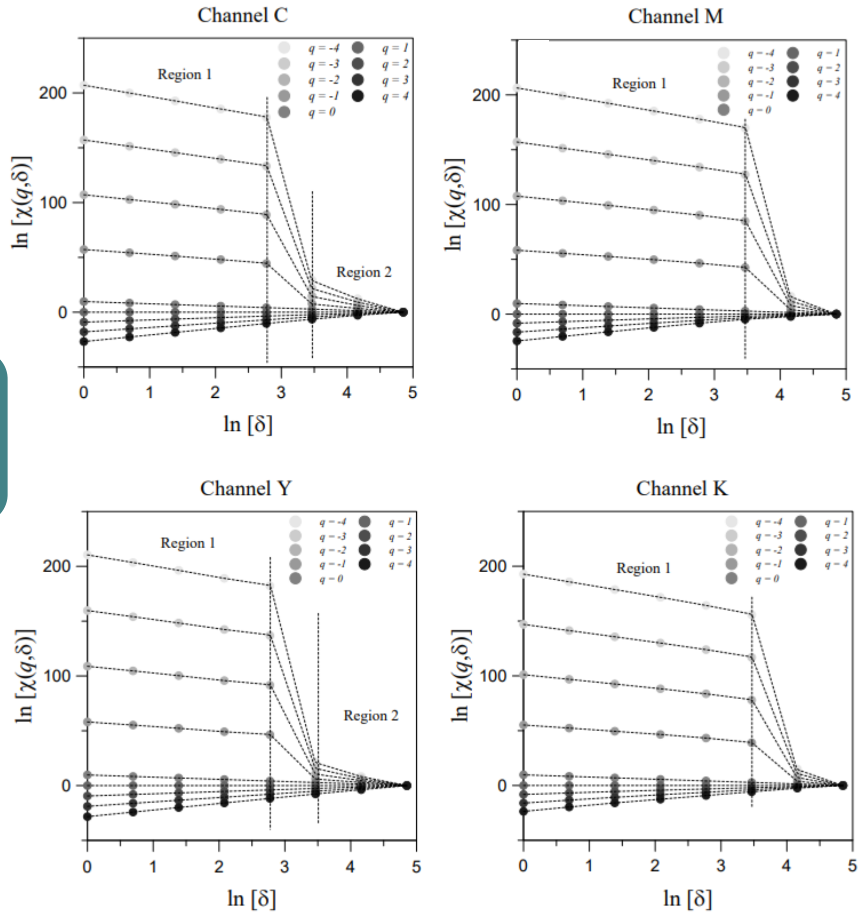
Scaling Behaviour

Channel C	
$\Delta D(q)$ Image 1	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 - 8
	Region 2. δ = 16 - 128
$\Delta D(q)$ Image 3	-
Channel M	
$\Delta D(q)$ Image 1	-
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-
Channel Y	
$\Delta D(q)$ Image 1	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-
Channel K	
$\Delta D(q)$ Image 1	-
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-

5. Results

Multifractal Analysis of CMYK images

Partition Functions



CMYK colour profile does not provide proper results

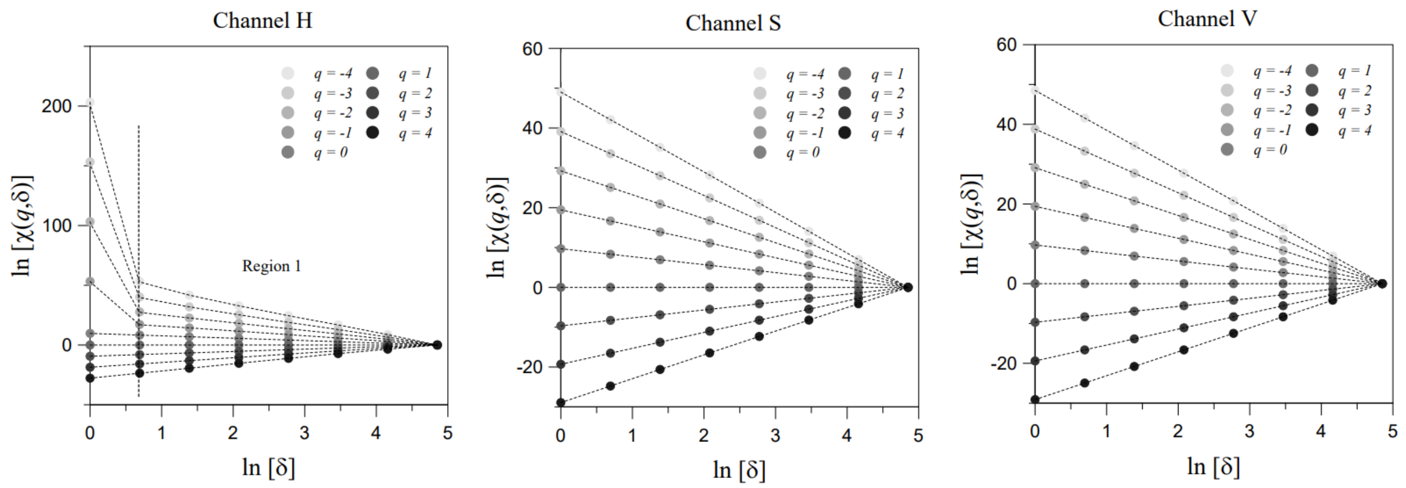
Scaling Behaviour

Channel C	
$\Delta D(q)$ Image 1	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 - 8
	Region 2. δ = 16 - 128
$\Delta D(q)$ Image 3	-
Channel M	
$\Delta D(q)$ Image 1	-
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-
Channel Y	
$\Delta D(q)$ Image 1	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-
Channel K	
$\Delta D(q)$ Image 1	-
$\Delta D(q)$ Image 2	Region 2. δ = 32 - 128
$\Delta D(q)$ Image 3	-

5. Results

Multifractal Analysis of HSV images

Partition Functions



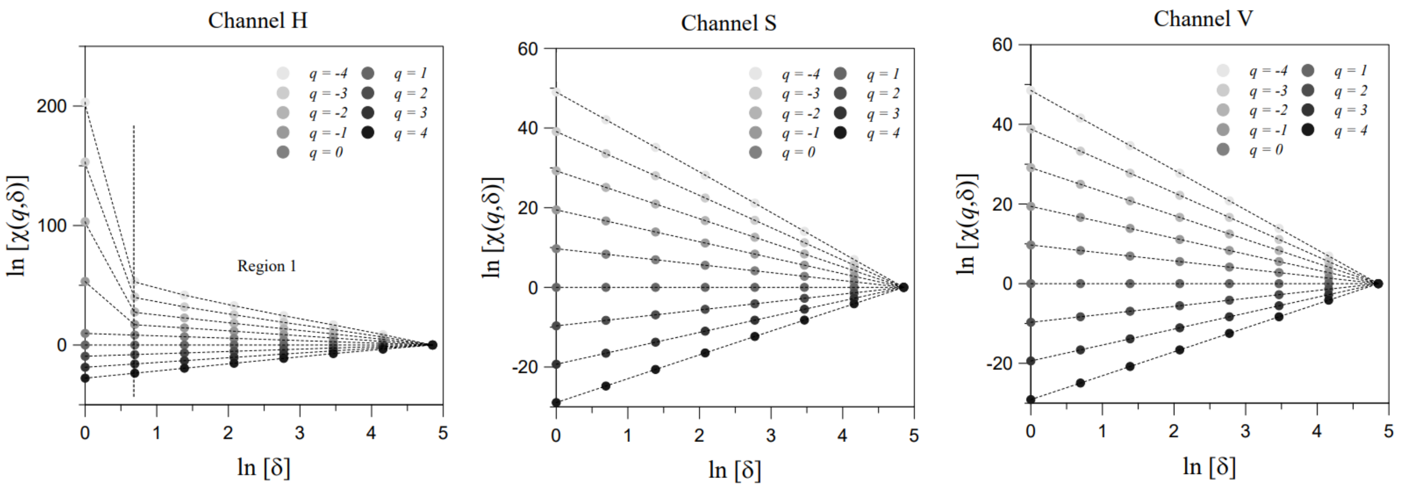
Scaling Behaviour

Channel H	
$\Delta D(q)$ Image 1	Region 1. δ = 2 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 2 – 128
Channel S	
$\Delta D(q)$ Image 1	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 1 – 128
Channel V	
$\Delta D(q)$ Image 1	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 1 – 128

5. Results

Multifractal Analysis of HSV images

Partition Functions



Scaling Behaviour

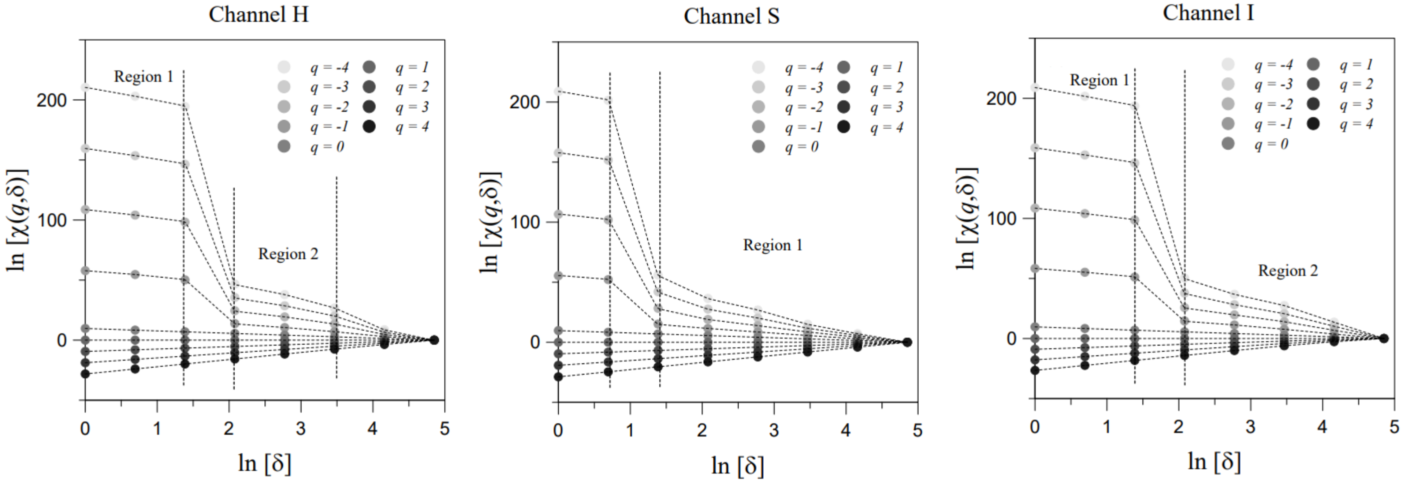
Channel H	
$\Delta D(q)$ Image 1	Region 1. δ = 2 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 2 – 128
Channel S	
$\Delta D(q)$ Image 1	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 1 – 128
Channel V	
$\Delta D(q)$ Image 1	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 1 – 128

All 3 channels are capable of capturing the scaling behaviour of the reference images

5. Results

Multifractal Analysis of HSI images

Partition Functions



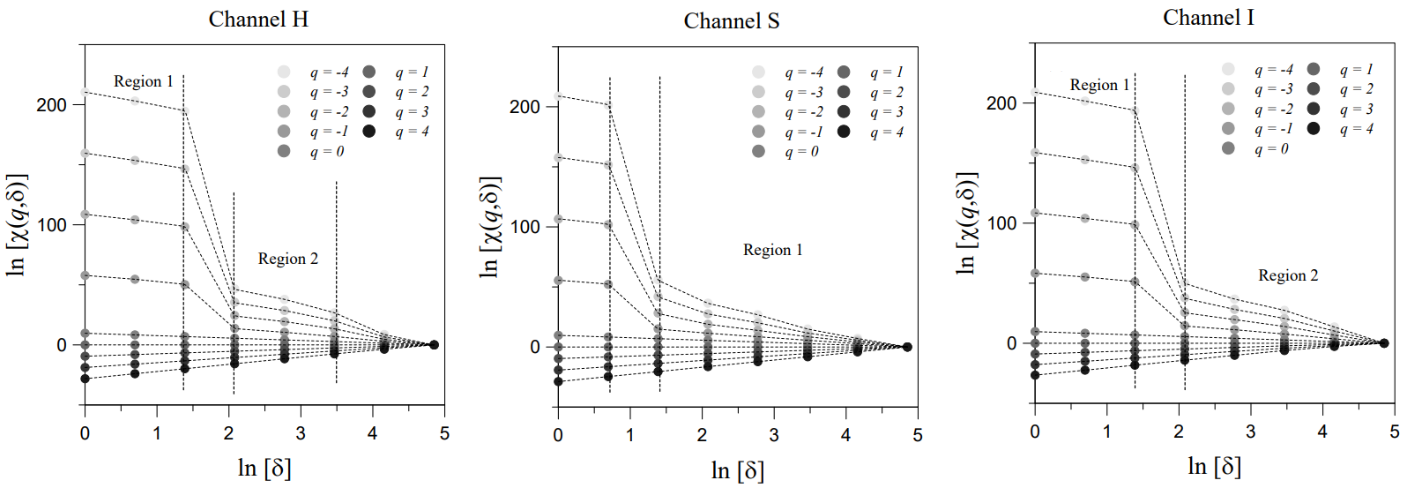
Scaling Behaviour

Channel H	
$\Delta D(q)$ Image 1	Region 2. δ = 8 - 32
$\Delta D(q)$ Image 2	Region 2. δ = 16 – 128
$\Delta D(q)$ Image 3	Region 2. δ = 8 - 32
Channel S	
$\Delta D(q)$ Image 1	Region 1. δ = 4 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 4 – 16
	Region 2. δ = 16 – 128
Channel I	
$\Delta D(q)$ Image 1	Region 2. δ = 8 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 4 – 16
	Region 2. δ = 16 – 128
$\Delta D(q)$ Image 3	Region 2. δ = 8 – 32

5. Results

Multifractal Analysis of HSI images

Partition Functions



Best approximation to reference images:

- Channel S
- Channel I

Scaling Behaviour

Channel H	
$\Delta D(q)$ Image 1	Region 2. δ = 8 - 32
$\Delta D(q)$ Image 2	Region 2. δ = 16 – 128
$\Delta D(q)$ Image 3	Region 2. δ = 8 - 32
Channel S	
$\Delta D(q)$ Image 1	Region 1. δ = 4 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 1 – 128
$\Delta D(q)$ Image 3	Region 1. δ = 4 – 16
	Region 2. δ = 16 – 128
Channel I	
$\Delta D(q)$ Image 1	Region 2. δ = 8 – 128
$\Delta D(q)$ Image 2	Region 1. δ = 4 – 16
	Region 2. δ = 16 – 128
$\Delta D(q)$ Image 3	Region 2. δ = 8 – 32

5. Results

Comparison between grey-scale images and colour formats

D(*q*) values of grey-scale images compared with *D*(*q*) values in each colour format → $\sum \boldsymbol{x}^2$

$$\sum x^2 \leq 0.2$$ ✓

HSV colour model provides proper results → But three out of the four colour formats studied fail to capture the reference monofractal behaviour

Colour profile		Approximation rate (%)
RGB	Channel R	0%
	Channel G	60%
	Channel B	25%
CMYK	Channel C	67%
	Channel M	0%
	Channel Y	0%
	Channel K	0%
HSV	Channel H	67%
	Channel S	100%
	Channel V	100%
HSI	Channel H	0%
	Channel S	50%
	Channel I	250%

6

Conclusions

Multifractal analysis

Varies depending on both the image format and the colour profile → Same image presents different multifractal behaviour depending on the colour format

Range of scales

The monofractal behaviour depends on the range of scales considered (δ)

A new methodology using multifractal approach to characterise images in different colour formats → A preliminary study for the accurate characterization of electronic devices in terms of heat dissipation using multifractal analysis

In-Depth study

On the multifractal features images in different colour formats using image analysis benchmarks from the literature is needed

Meta-model

In which different formats would consider their “understanding” of the image, while that meta-model would combine their “opinions”

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