Visualizing Parametric Density through Three-dimensional Amplitude Spectrum Slopes in Urban Canyons

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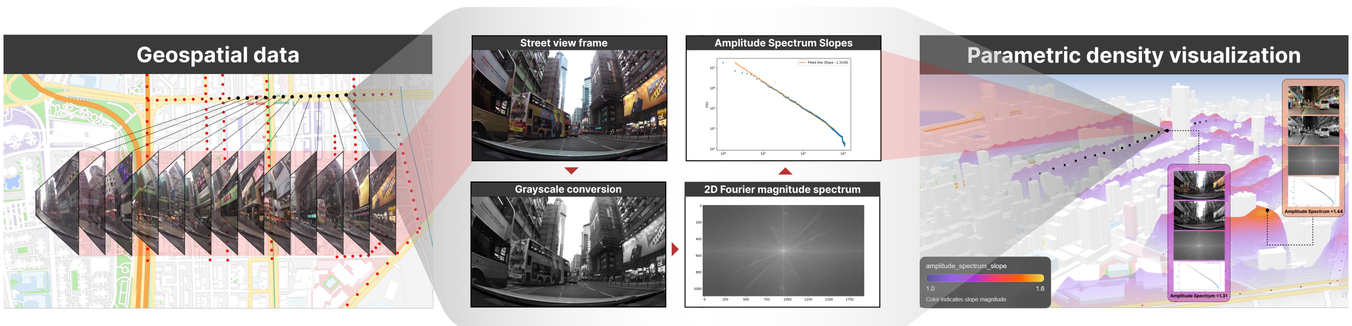

Figure 1: Pipeline for visualizing Parametric Density through 3D amplitude spectrum slopes in urban canyons. From geospatial data, each street view frame is processed by grayscale conversion and 2D FFT. Radial averaging and log fitting estimate the amplitude spectrum slope ($-\alpha$), and then map back to the city as a 3D parametric density visualization.

Abstract

We present a visualization system that computes amplitude spectrum slopes from street-level imagery and visualizes their variation, allowing users to perceive parametric density in urban canyons. The system provides a pipeline for spatial analysis via three-dimensional heatmap rendering. Giving street-view image samples as input, it extracts a sequence of spectral slopes, mapping these values back onto geographical coordinates using AMap (Gaode). In the visualization, the height and color of three-dimensional meshes jointly encode the slope values of the amplitude spectrum, which have been associated with visual perception and comfort in prior work. This system helps users quickly interpret how the slopes of amplitude spectra vary across streets at the city scale, providing an interpretable proxy to support exploratory assessment in urban analytics and design.

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CCS Concepts

• **Human-centered computing** → *Human computer interaction (HCI)*; **Geographic visualization**.

Keywords

Amplitude Spectrum Slopes, Street Canyons, Environmental Visualization, Parametric Density, Urban Analytics

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1 Introduction

Urban environmental exposures are associated with affective and stress-related outcomes [2]. However, existing tools often rely on experience-sampling methods or supervised perceptual labels, with limited support for interpretable, location-based visual analytics [1, 6]. We present a system that allows the visualization of a new parameter in urban analytics that could impact the future of our urban environments as an additional tools to consider human perceptions within urban design. The system visualizes what we define here as parametric density, a computation of spectral statistics from street-level imagery (e.g., the amplitude-spectrum slope as an interpretable proxy), and visualizes their variation along urban canyons to enable exploratory analysis [7].

2 Amplitude Spectrum Slope

Amplitude spectrum slope, denoted as $-\alpha$, is a low-level visual statistic that characterizes an image's scale structure by summarizing how Fourier amplitude decreases as spatial frequency increases. A robust finding in natural image statistics is that the radially averaged amplitude spectrum of many natural scenes is approximately scale-invariant and can be described by an inverse power law $A(f) \propto 1/f^{\alpha}$, with α often close to 1 for amplitude spectra, depending on the dataset and the fitted frequency band [4, 9]. This near $1/f$ behavior is frequently discussed as a reference regime for efficient visual coding, and it provides an interpretable baseline for comparing images in terms of the relative dominance of coarse, low-frequency structure versus fine, high-frequency detail [4].

Amplitude spectrum slope has also been associated with perceptions and visual comfort. Images can induce visual discomfort even when semantic content is not the driver, and that discomfort can be associated with atypical spectral structure, including departures from naturalistic $1/f^{\alpha}$ statistics and disproportionate Fourier energy in perceptually sensitive spatial frequency ranges [3, 8]. Complementing behavioral evidence, neuro-imaging studies report systematic differences in early visual cortical responses to stimuli with different $1/f^{\alpha}$ amplitude-spectrum characteristics, supporting the view that spectral statistics such as α are interpretable proxy features linked to human visual processing [5]. Motivated by these findings, this work uses amplitude spectrum slopes as a compact and explainable proxy to transform street-level imagery into a comparable continuous signal for exploratory visual analysis of urban walking experiences.

3 Visualizing Parametric Density

We selected street-level images in Hong Kong and computed the amplitude spectrum slope for each image. As a proof-of-concept demonstration, these images were obtained from a publicly available street-level viewer (Mapillary) to illustrate the end-to-end pipeline and visual encoding.

For each image, we compute the amplitude spectrum slope, defined as $-\alpha$, as a compact quantifier of scale structure. The image is converted to a single-channel grayscale intensity signal and mean-centered to reduce the zero-frequency component. We then compute the 2D Fourier transform of the image and obtain the amplitude spectrum by shifting the zero-frequency component to the center and taking the magnitude. Next, we perform radial averaging by grouping frequency bins with the same radial distance from the spectrum center and averaging their amplitudes, yielding a one-dimensional radial profi $A(r)$. We estimate the amplitude spectrum slope by fitting a straight line in log–log space over a restricted mid-radius range that excludes the DC component and avoids the highest-frequency bins. Specifically, we fit

$$\log_{10} A(r) = -\alpha \log_{10} r + c \tag{1}$$

and report the fitted slope $-\alpha$ as the amplitude spectrum slope for that image. Finally, we built a web-based visual interface using the AMap (Gaode) Web JavaScript API and overlay data-driven layers with AMap Loca, the interactive interface is shown in figure 2 .

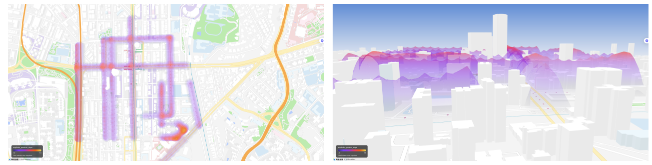

Figure 2: The parametric density visualization system interface.

Route samples are exported as GeoJSON with coordinates and the corresponding amplitude spectrum slope as a feature property, which is rendered as a heatmap. In our heatmap, the amplitude spectrum slope of each streetscape sample is rendered as a mesh, where larger values are shown with greater height and more saturated colors. Higher α indicates a stronger deviation from the natural 1/f pattern, for which $\alpha \approx 1$ [3, 8]. By mapping samples into a continuous surface representation, we connect street-level visual structure to potential visual comfort at the city scale.

This visualization maps amplitude spectrum slopes from street-level imagery back onto geographical coordinates, helping individuals understand how spectral slope varies across urban canyons. As these variations have been linked to visual comfort in prior work[3, 8], the system can support exploratory assessments of streetscape analytics. In practice, architects and urban designers can use this tool to identify segments that differ in low-level visual structure and to inform more human-centered urban design and planning decisions.

4 Limitation and Future Works

We present here the pipeline and the core concept of the parametric density visualization system; we thus used a limited set of street-view images. In practice, variations in viewing direction can influence the estimated amplitude spectrum slope. Future work will incorporate multi-view imagery at each location to produce more robust and comprehensive datasets. Beyond its exploratory role, the system could also help identify street segments that may benefit from spatial updates or interventions, and support comparisons between design alternatives to evaluate how changes in urban form influence perceptual experience.

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