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Original

Exploring the use of two-dimensional piecewise-linear functions as an alternative model for representing and processing grayscale-images

Victor Manuel Jimenez-Fernandez [a,*], Héctor Vazquez-Leal [a], Uriel Antonio Filobello-Nino [a], Maribel Jimenez-Fernandez [b], Luis Javier Morales-Mendoza [c], Mario Gonzalez-Lee [c]

[a] *Universidad Veracruzana, Facultad de Instrumentación Electrónica, Circuito Gonzalo Aguirre Beltrán s/n, Zona Universitaria, CP. 91000, Xalapa, Veracruz, Mexico*

[b] *Instituto de Ciencias Básicas, Av. Luis Castelazo Ayala s/n, Col. Industrial Ánimas, CP. 91190, Xalapa, Veracruz, Mexico*

[c] *Facultad de Ingeniería en Electrónica y Comunicaciones, Venustiano Carranza s/n, Col. Revolución, CP. 93390, Poza Rica, Veracruz, Mexico*

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Abstract

Traditionally, a grayscale image is represented as a rectangular array whose internal values describe a discrete level of intensity or luminance denoted as pixel. Due to its structure and complete compatibility with matrix operators, this representation is the most widely used in image processing. Although the strong robustness of this standard is not in question, it is always enriching to have an alternative description format in order to provide not only a different image representation scheme but also an additional approach to image processing. Motivated by this fact, in this paper the viability of using continuous piecewise-linear functions of two spatial variables as an alternative model description of grayscale images is explored. Moreover, the possibility of applying this type of representation in image processing is also examined by using mapping variable transformations, here denominated as functional filters. Furthermore, it is also shown that such alternative image model can also be used in more complex tasks like tridimensional volume estimation. To verify this proposal, illustrative examples are reported, showing not only an inherent improvement in the visual perception of image, but also a practical image processing capability.

Keywords: Piecewise-linear; Grayscale-images; Alternative-representation

1. Introduction

In computer graphics literature, a graphical object is mainly defined by two fundamental characteristics: shape which refers to the geometry of the object, and attributes which is more related to intrinsic properties like color or texture (Gomes, Costa, Darsa, & Velho, 1996). Depending on the type of graphical object, one of these characteristics become more dominant, for example in digital images a description of attributes takes more relevance, while in geometric solids a shape representation is the imperative characteristic. Moreover, this difference is also observed in the kind of mathematical model used to represent such characteristic. While discrete models are preferred to image description, functional representations are typically used in geometric and solid modeling. However, due to grayscale images present the properties of a monochrome function (Velho, Frery, & Gomes, 2009), in this paper, this type of images emerge as the more suitable kind of graphical object with the capability of joining the two fundamental graphical characteristics through a continuous functional model, preserving not only a good approximation of the object geometry but also a precise description of graphical attributes. In our proposal, the color attribute (set of luminance or pixel intensity values) is used to construct a two-dimensional function which defines the height of the graph at each coordinate in the image spatial domain. At this point, the challenge consists in obtaining a suitable continuous function from the set of discrete pixel values. In this

* Corresponding author.
E-mail address: vicjimenez@uv.mx (V.M. Jimenez-Fernandez).
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regard, it is important to clarify that the numerical technique of fitting input sparse data points by a mathematical function is not a novel strategy used in graphical objects, in fact it can be found in a variety of visualization applications like image processing (Amat, Donat, Liandrat, & Trillo, 2006; Biancardi, Lombardi, & Pacaccio, 1997; Gao, Zhang, Zhang, & Zhou, 2008; Scharinger, 1997;), computer graphics (Feng, Nishita, Jin, & Peng, 2002; Mukundan, 2012), pattern recognition (Oden, Ercil, & Buke, 2003; Subrahmonia, Cooper, & Keren, 1996; Tashk, Helfroush, & Dehghani, 2010; Tarel & Cooper, 2000), and computer-aided geometric design (Heine & Berger, 2012; Park, 2001), among others. For example, in Wu, Wang, and Chiu (2015) a spline interpolation is proposed to image up-scaling with the aim of improving resolution and sharpness, in Ho and Zeng, (2012) a bi-cubic regression is used to achieve better resolution and reduction in border zigzag effects, in Zhang, Chan, Zhang, et al. (2009) a local polynomial regression is applied to high-resolution image reconstruction, and Zhang, Chan, and Zhu (2009) presents a method for image restoration by using least-squares in polynomial regression. Nevertheless, it is important to emphasize that in all of these cases, the interpolated function is always obtained with the main purpose of processing data instead of using it as a proper representation model. In contrast, in this paper, our particular interest is to explore the viability of using continuous interpolated functions as an alternative model description of grayscale images, furthermore, its possible application to image processing is also considered. In relation to this, it must be highlighted that although there are in literature many function estimation methods based on polynomial regressions and spline approximations, our interest centers on the so-called piecewise-linear approach which in recent references (Jiménez-Fernández, Cerecedo-Nuñez, Vazquez-Leal, Beltran-Parrazal, & Filobello-Nino, 2014; Jiménez-Fernández, Vazquez-Leal, et al., 2014), has been successfully used to represent two-dimensional image curves, specifically devoted to laser projection. Moreover, in Jiménez-Fernández, Cerecedo-Nuñez, et al. (2014) a comparative study exhibited a better curve fitting performance of piecewise-linear in comparison to their spline and polynomial counterparts. Among the most emblematic

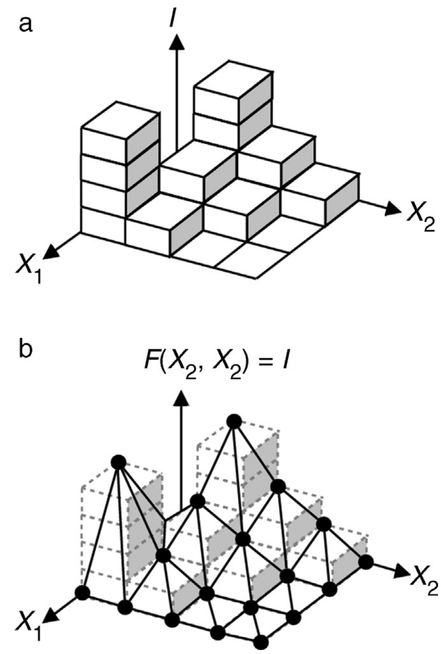

Fig. 1. Grayscale image representation. (a) Discrete pixel array. (b) Continous piecewise-linear function.

piecewise-linear models reported in literature (Chua & Deng, 1986, 1988; Chua & Kang, 1977; Guzelis & Goknar, 1991; Kahlert & Chua, 1990; Van Bokhoven, 1998), the simplicial representation of Pedro-Julian (Julian, Desages, & Agamennoni, 1999) is taken as reference in our exploratory study. The main reasons for adopting this model are: its superior performance due to its capability to represent n-dimensional functions, and the direct programmability of the function construction methodology which is widely reported in literature (Julian, Desages, & Agamennoni, 1998; Julián, Desages, & D'Amico, 2000; Julián, 2003). The content of this paper is organized as follows. In Section 2, the basic idea of the use of continuous piecewise-linear functions to represent grayscale images is exposed. Section 3 is devoted to describe the piecewise-linear simplicial algorithm for constructing a continuous two-dimensional function. Examples

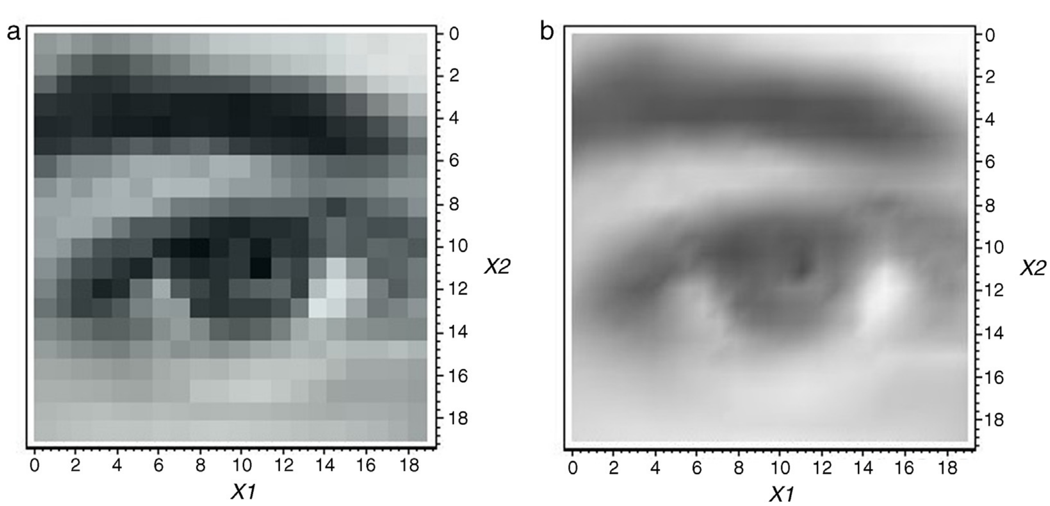

Fig. 2. (20 × 20)-resolution grayscale image. (a) In a pixel format. (b) In a piecewise-linear functional format.

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