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Partial iterates for symmetrizing non-parametric color correction

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ABSTRACT

Mosaic generation is a central tool in various fields ranging way beyond the scope of photogrammetry and requires the radiometry and color of the images to be corrected. Correction can either be done by a global parametric approach (looking for an optimal gain or gamma for each image of the mosaic), or by iteratively correcting image pairs with a non-parametric approach. Such non-parametric approaches allow for much finer correction but are asymmetric, i.e. they require the choice of a source image that will be corrected to match a target image. Thus the result on the whole mosaic will be very dependant on the order in which images are corrected. In this paper, we propose to use partial iterates to symmetrize non-parametric correction in order to solve this problem. Partial iterates formalize what partially applying a bijective function means and we explain how this can be done in both the continuous and discrete domain. This mechanism is applied to a simple non-parametric approach (histogram transfer of the luminance) to show its potential.

1. Introduction

1.1. Problem statement

The problem of image mosaicking (or stitching) is central for many applications:

- *Orthophoto generation*: The images rectified using a Digital Elevation Model need to be stitched together in order to create a large orthophoto.
- *Texturing*: When texturing a single geometric primitive with multiple images, the images should be rectified along this primitive then merged into an unique texture.
- *Mosaicking*: When creating a panorama, multiple images should be put in the same geometry (rectilinear, cylindrical, spherical, stereographic, etc.) before being blended.

It has thus received a lot of attention from the scientific community and this research has led to numerous operational tools (Hugin, Autostich, Autopano, Panorama Tools, Microsoft ICE (Image Composite Editor), Panorama maker, Photoshop Auto-Blend, etc.). Even if the exact implementation of most of these tools is not known, they rely on the following steps:

1. *Rectify the images in the same geometry*: This is usually done by finding tie points, and choosing a common geometry (rectilinear, cylindrical, spherical, stereographic, etc.) for all the images.
2. *Color correction*: modifying the color of each image in order to have a matching global radiometry. Failing to correct the color will generally lead to displeasing artifacts such as shown in Fig. 1.
3. *Blending*: This last step usually relies on defining seam lines avoiding discontinuities and blending the images in a multiband approach.

In this paper, we address the second step, that we formalize in the next section.

1.2. Formalization of mosaic correction

Let us call I_i the n images composing the mosaic, deformed to a common geometry (by the first step) such that each image is defined by $I_i : D_i \rightarrow R$ where D_i is the domain of definition (support, mask) in the common geometry, and R is the dynamic range, common to all images ($[0,255]$ for instance). We define the problem of mosaic correction as finding *transfer* functions f_i for each I_i that realize a compromise between two goals:

1. *Color transfer effectiveness*: Having the images $f_i(I_i)$ be as close as possible over their overlaps $D_{ij} = D_i \cap D_j$. This closeness between two images can be defined per pixel, or more generally by statistical properties of the images over their overlaps. In the latter, we prefer the second alternative that we consider more

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Fig. 1. Typical radiometric issue arising when texturing a building facade (bottom band is darker).

robust to outliers. It is however quite straightforward to make our proposed approaches work with a per pixel closeness criterion.

2. *Extendibility*: The transferred images $f_i(I_i)$ should be as close as possible to the original images I_i, which means that we want to preserve the content of the original images as much as possible.

We now use this formalism to detail the properties of color correction methods.

1.3. Properties of color correction

Color correction problems are generally classified based on the following distinctions:

1. *Parametric vs non-parametric*: In parametric approaches, the f_i are defined by a limited number of parameters, e.g. gain ($f_i(l) = g_i l$) and/or gamma ($f_i(l) = l^{\gamma_i}$) for instance (l is the luminance). In the non-parametric case (also called modeless) the f_i can be any monotonous functions (to avoid inverting levels).
2. *Global vs local*: In local approaches, the correction can be different in various parts of the image, while the transfer function is the same over the whole image in the global case. Local approaches often rely on applying global ones on various blocks of the image, so we concentrate on the latter in this paper.
3. *Empirical vs physically based approaches*:
   - In empirical approaches, the transfer functions f_i are searched in order to have a pleasing seamless visual mosaicking. In that case, color transfer effectiveness is often defined based on statistical considerations (for instance equalizing the mean and variance of the images). Most of the popular mosaicking software cited above rely such approaches.
   - Physically based approaches aim at correcting some precise physical effects such as BRDFs (for the correction of hotspots), atmospheric diffusion, etc. They are usually parametric (the parameters being those of the physical model used), and are mainly found in the context of orthophoto generation from aerial imagery.

In this paper, we propose an additional distinction: Symmetric vs Asymmetric. We call symmetric a correction method where all images play the same role (i.e. there is no distinction between a source and a target). The mosaic correction problem as we have formalized it is symmetrical. However, most of the literature adress the more simple asymmetric problem with only two images, a source I_s and a target I_t, and only one transfer functions f_s is looked for. Solving the mosaic correction problem then requires to iterate this process, with the result being highly dependant on the successive choices of sources and targets.

2. Related work

2.1. Empirical approaches

2.1.1. Parametric and symmetric

In the context of mosaicking, the problem is posed symmetrically, but because it is more difficult, the solutions are often limited to being parametric (which is simpler). The very complete PhD work of Brown (2000) covers all aspects of image mosaicking and resulted in the development of a popular mosaicking Software (Autostich). His color correction module, described in Brown and Lowe (2007) is global and relies on finding a gain correction for each image that minimizes the difference of image means over all their overlaps. Xiong and Pulli (2010) does the same thing but with a much more elaborate model combining linear and gamma corrections instead of a simple gain.