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Efficient implementation of image interpolation as an inverse problem

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Abstract

This paper presents three computationally efficient solutions for the image interpolation problem which are developed in a general framework. This framework is based on dealing with the problem as an inverse problem. Based on the observation model, our objective is to obtain a high resolution image which is as close as possible to the original high resolution image subject to certain constraints. In the first solution, a linear minimum mean square error (LMMSE) approach is suggested. The necessary assumptions required to reduce the computational complexity of the LMMSE solution are presented. The sensitivity of the LMMSE solution to these assumptions is studied. In the second solution, the concept of entropy maximization of the required high resolution image a priori is used. The implementation of the suggested maximum entropy solution as a single sparse matrix inversion is presented. Finally, the well-known regularization technique used in iterative nature in image interpolation and image restoration is revisited. An efficient sectioned implementation of regularized image interpolation, which avoids the large number of iterations required in the interactive technique, is presented. In our suggested regularized solution, the computational time is linearly proportional to the dimensions of the image to be interpolated and a single matrix inversion of moderate dimensions is required. This property allows its implementation in interpolating images of any dimensions

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which is a great problem in iterative techniques. The effect of the choice of the regularization parameter on the suggested regularized image interpolation solution is studied. The performance of all the above-mentioned solutions is compared to traditional polynomial based interpolation techniques such as cubic O-MOMS and to iterative interpolation as well. The suitability of each solution to interpolating different images is also studied.
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1. Introduction

Image interpolation is the process by which a high resolution image can be obtained from a low resolution one. Image interpolation has a wide range of applications in numerous fields such as medical image processing, military applications, space imagery, image decompression, and digital HDTV. The efficiency of any image interpolation algorithm is determined by two major factors, the quality of the obtained high resolution image and the computational complexity required to obtain that image.

The image interpolation problem has been treated in the literature using different approaches. Conventional spline-based algorithms have been widely used in image interpolation [1–6]. These algorithms can be can be classified as signal synthesis or reconstruction from basis functions. The implementation of spline-based algorithms using the digital filtering approach has been widely used to reduce the computational complexity resulting from the spline basis functions being non-interpolating [1–6]. Another family of optimal basis functions with maximal order and minimal support (O-MOMS) is made of combinations of B-splines of the same order and their derivatives [7,8]. The implementation of O-MOMS in image interpolation has achieved a sampling gain over traditional spline basis functions [7,8]. The O-MOMS basis functions are still non-interpolating and thus the digital filtering approach is the best solution to this problem [7,8]. Some other interpolating basis functions such as the key's basis functions have been proposed [9,10].

All of the above-mentioned conventional algorithms are space invariant signal synthesis algorithms. Spatially adaptive variants of the above-mentioned algorithms have been developed as well. A simple warped distance approach, based on the adaptation of the distance among the pixels has been developed [10]. Some authors have proposed adaptive interpolation algorithms based on a fixed shift at each pixel to reduce the computational burden required in the adaptation [11,12]. Another adaptive approach based on the image local activity levels has been presented [13]. Recently, an adaptive pixel-by-pixel algorithm based on the minimization of the squared estimation error at each pixel has been proposed [14]. Although these adaptive algorithms improve the quality of the interpolated image especially near edges, they still do not take into consideration the mathematical model by which the image capturing devices operate. If this model is considered in the interpolation process, higher quality is expected.

In fact, most image capturing devices are composed of charge-coupled devices (CCDs). In CCD imaging, there is an interaction between the adjacent points in the object to be im-

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