Iterative-Interpolation Super-Resolution Image Reconstruction

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Editor-in-Chief
Prof. Janusz Kacprzyk
Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6
01-447 Warsaw
Poland
E-mail: kacprzyk@ibspan.waw.pl

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A Computationally Efficient Technique

Springer

Dr. Vivek Bannore
SCT-Building
University of South Australia
Adelaide
Mawson Lakes Campus
South Australia, SA 5095
Australia
E-mail: Vivek.Bannore@gmail.com

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To my wife, Mitu

- Vivek Bannore

Preface

In many imaging systems, under-sampling and aliasing occurs frequently leading to degradation of image quality. Due to the limited number of sensors available on the digital cameras, the quality of images captured is also limited. Factors such as optical or atmospheric blur and sensor noise can also contribute further to the degradation of image quality. Super-Resolution is an image reconstruction technique that enhances a sequence of low-resolution images or video frames by increasing the spatial resolution of the images. Each of these low-resolution images contain only incomplete scene information and are geometrically warped, aliased, and under-sampled. Super-resolution technique intelligently fuses the incomplete scene information from several consecutive low-resolution frames to reconstruct a high-resolution representation of the original scene.

In the last decade, with the advent of new technologies in both civil and military domain, more computer vision applications are being developed with a demand for high-quality high-resolution images. In fact, the demand for higher-resolution images is exponentially increasing and the camera manufacturing technology is unable to cope up due to cost efficiency and other practical reasons. Therefore, for an imaging system, super-resolution overcomes the limitation in terms of image quality by enhancing the spatial resolution to generate high-resolution images of the original scene, without the need of any hardware enhancements. This is why most of the research into image resolution enhancement (or super-resolution) has been majorly directed towards developing techniques that deliver the highest possible fidelity of the reconstruction process. The computational efficiency issues and the feasibility of developing realistic applications based on super-resolution algorithms have attracted much less attention.

In the field of image processing, it is a widely known fact that, super-resolution is an inverse problem which is also ill-conditioned, making the estimation process highly computationally expensive. Also, the number of unknown variables to be estimated is equal to the number of pixels in the reconstructed high-resolution image, which is of the order of hundreds of thousands. Clearly, the fidelity of the reconstruction has to be traded-off by performance. It is, thus, desirable to develop algorithms that maintain the proper balance between computational performance and the fidelity of the reconstruction.

In this research, a novel and innovative, hybrid reconstruction scheme has been proposed for super-resolution reconstruction which addresses the issue of maintaining

an optimum balance between improving spatial resolution and keeping the computational time low. The proposed fast reconstruction scheme is referred to as ***Iterative-Interpolation Super-Resolution*** (**IISR**). It is based on interpolation and subsequent iterative improvements of the reconstructed image to generate a high-resolution image from a sequence of geometrically warped, aliased and under-sampled, low-resolution frames. A mathematical basis for the proposed scheme is also provided. The IISR technique utilizes a relatively small number of low-resolution images, as low as 10, to generate the high-resolution image and is relatively inexpensive computationally.

The common feature of inverse problems is their sensitivity to even small perturbations of the data that may introduce significant errors in the reconstruction process. Due to this many existing super-resolution techniques are based on the optimization approach where a regularization term is added so as to stabilize the inverse problem and generate a unique solution. In this research, the optimization approach to super-resolution is re-visited. The estimation problem of super-resolution is reformulated in terms of Tikhonov regularized optimization procedure and the conjugate gradient method is adopted for finding the minimum of the resulting objective function. Also, the significance and influence of the regularization term on the accuracy of super-resolution image reconstruction is reinvestigated. An added benefit of this reinvestigation helps in comparing the performance, in terms of effectiveness and accuracy, of the IISR method with the best possible regularized optimization technique.

It is also shown that by combining the IISR technique with the regularized optimization approach, the convergence rate of the reconstruction process in the optimization approach can be significantly improved. It is also validated that the proposed IISR reconstruction technique is accurate and the further improvement by the optimization procedure is relatively small, computationally expensive and therefore impractical.

Image registration forms a significant intermediate process in achieving accurate super- resolution from a sequence of aliased and under-sampled low-resolution frames. Even though image registration is not the primary subject of this research, the significance and advantages of implementing a computationally efficient and accurate hierarchical-based image registration technique is also discussed.

Two major software frameworks have been developed based on the research presented in this research. Both softwares serve the purpose of comparative experimental tools but can also be used as standalone super-resolution image reconstruction systems.

The research is accompanied by experimental simulations and numerical results generated on synthetic and real imagery.

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Vivek Bannore

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