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Super Resolution Imaging Needs Better Registration for Better Quality Results

Patil V H[1], Kharate G K[2], Kamlapur S M[3]
[1,2,3]Professor, University of Pune, India
e-mail: varsha.patil@gmail.com[1]

Abstract

In this paper, trade-off between effect of registration error and number of images used in the process of super resolution image reconstruction is studied. Super Resolution image reconstruction is three phases process, which registration is at most importance. Super resolution image reconstruction uses set of low resolution images to reconstruct high resolution image during registration. The study demonstrates the effects of registration error and benefit of more number of low resolution images on the quality of reconstructed image. Study reveals that the registration error degrades the reconstructed image and without better registration methodology, a better super resolution method is still not of any use. It is noticed that without further improvement in the registration technique, it can be achieved by increasing number of input low resolution images.

1. Introduction

In today's modern era, multimedia has tremendous impact on human lives. It becomes inseparable part of our day-to-day activities. Image is one of the most important media contributing to multimedia. The significant feature of all image processing applications is good quality of image. The resolution of image is the principal factor in determining the quality of an image. The resolution is nothing but number of pixels per unit area. With the development of image processing applications, there is a big demand for high resolution (HR) images. The high resolution images not only give users a pleasing picture but also offer minute additional details that may be important for the analysis of image in many applications. Initial technology to obtain high resolution images mainly depends on sensor manufacturing technology. Sensor manufacturing technology has its own limitations. The cost for high precision optics and sensors may not be affordable for general purpose commercial applications such sensor networks. Super Resolution is a process to increase the resolution of an image beyond the resolving power of the imaging system [1].

The super resolution process reconstructs the high resolution image using low resolution images of same scene or low resolution images of similar scenes or a low resolution image. The generalized block diagram of super resolution process is shown in figure 2.3. Multiframe super resolution image reconstruction methods consist of three basic components [6]. There are: i) motion compensation (registration), ii) interpolation, and iii) blur and noise removal, if any (restoration).

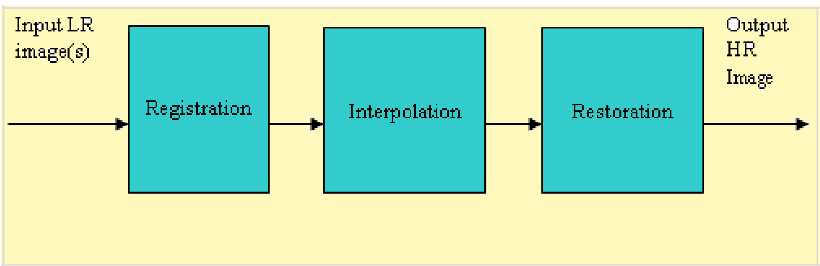

Figure 1. Super resolution Process

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Registration is basically preprocessing of the input information. Image registration is to align the different images as precisely as possible by estimating the motion between them. All the frames in the low-resolution observed image sequence are geometrically registered to a fixed reference frame, resulting in a composite image of non-uniformly-spaced samples. These nonuniformly spaced sample points are then interpolated and resampled on a regularly spaced high resolution sampling lattice. Restoration is used to remove noise and blur, if exists in the resultant image.

In this paper, we present study report of existing multiframe super resolution approaches, especially about registration phases and related problems.

2. Super Resolution- A Review of Existing Approaches

Tsai and Huang [2] are the first proposed the super-resolution idea in year 1984. They first derived a system equation that describes the relationship between low resolution images and a desired high resolution image by using the relative motion between low resolution images. They used the frequency domain approach to demonstrate the ability of reconstructing a single improved resolution image from several down-sampled noise-free versions of it. Several extensions to the basic Tsai-Huang method have been proposed in literature. However, contrary to the naive frequency domain description of this early work, it is seen that, in general, super resolution is a computationally complex and numerically ill-posed problem [8].

The technical report by S. Borman and R.L. Stevenson in [3] provides a comprehensive and complete overview on the super resolution image reconstruction algorithms until around 1998. They have defined Super-resolution as recovery of spatial frequency information beyond the diffraction limit of the optical system as well as removal of blur caused by the imaging system, such as out of focus blur, motion blur, non-ideal sampling, etc. Authors claim that there are two approaches, frequency domain and spatial domain approaches. Frequency domain approaches are, to a greater or lesser extent, unable to accommodate general scene observation models including spatially varying degradations, non-global relative camera/scene motion, general a-priori constraints or general noise models. Whereas spatial domain formulations can accommodate all these and provide enormous flexibility in the range of degradations and observation models which may be represented and thus are the methods of choice. Spatial domain observation models facilitate inclusion of additional data in the observation equation with the effect of reducing the feasible solution space.

Most of authors have put forth three critical factors affecting super-resolution restoration. First, the reliable subpixel motion information is essential. Poor motion estimates are more detrimental to restoration than a lack of motion information. Second, the observation models must accurately describe the imaging system and its degradations. Third, the restoration methods must provide the maximum potential for inclusion of a prior information.

In super resolution image reconstruction process, registration is the first and the most important step. The accuracy of registration is based on motion estimation, and hence accurate knowledge of relative scene locations sensed by each pixel in observed images is necessary for super resolution. Irani and Peleg [4] suggested an Iterative Back Propagation (IBP) super resolution reconstruction approach for improving the resolution. The high resolution image is estimated by back propagating the error (difference) between simulated low resolution images. Initially, the high resolution image is guessed, and low resolution images are constructed from it. Further, these are compared with low resolution images constructed from input image. The difference is calculated and used to improve initial guess by back projecting each value in difference image into its respective field in original guess image. This process is repeatedly used to minimize error function. The authors have concluded that given technique original high resolution frequencies are not fully restored because the blurring function is low pass filter that filters out the high frequency information.

Authors [4] further put forth, that this problem can be avoided with use of, more than one, high resolution images by giving the same low resolution images after imaging process. However, this leads to several possible solutions and algorithm may converge to one of them or may oscillate among some of them. Choice of initial guess does not influence the performance of algorithm. A good choice of initial guess is average of low resolution images. Average image is constructed by registering the low resolution images over fixed finer grid.

Researchers M. Irani and S. Peleg, [5] have described methods for enhancing image sequences using the motion information computed by a multiple motions analysis method. The multiple moving objects are first detected and tracked using both a large spatial region and a large temporal region without assuming any temporal motion constancy. This paper has discussed in brief the approaches used for segmenting the image plane into different moving objects, computing their motion and tracking them throughout image sequence. Authors have described algorithm for image enhancement using the computed motion information. The techniques for improving resolution of tracked objects, occluded segments of tracked objects and transparent moving objects are presented as well. It is concluded that quality of high resolution image is a function of good motion estimation and segmentation of tracked objects.

S. Park, M. Park and M. Kang [6] have presented concepts of super resolution technology along with review of super resolution algorithms until around 2003 and issued to improve performance of super resolution algorithms. Further few issues in super resolution are presented by authors: registration error, blind super resolution image reconstruction, computational efficiency, color super resolution and compression issue.

Patrick Vandewalle, Sabine Susstrunk and Martin Vetterli [12] have proposed a frequency domain technique to reconstruct high resolution image from set of aliased images. Authors have defined high resolution image as image with more resolving power. Adding high frequency, typically based on known specific image model, can increase the resolving power of image. Authors have mentioned that for super resolution imaging two major challenges are to be handled. First, the difference between low resolution images is to be known precisely. This difference can have many origins: camera motion, change of focus or the combination of those. The camera motion can be calculated by using process of motion estimation. However, in high resolution, it is difficult to find the effect of change of focus. Author strongly claimed that an error in motion estimation translates most directly into degradation of resulting high resolution image. Further, authors claim that the result obtained by interpolating one of the low resolution images is better solution than high resolution image obtained from set of low resolution images using incorrect motion estimation. The artifacts due to bad motion estimation are visually very noticeable. The second challenge is to apply information obtained from different registered images to reconstruction of sharp high resolution image.

Authors have discussed image registration algorithm in frequency domain method. In algorithm, authors have used four low resolution images that are necessarily under-sampled. Otherwise, the algorithm is not able to reconstruct better image. For the registration, authors have discussed plain motion estimation algorithm. Authors claimed that their algorithm estimate shift and rotation parameter better than other methods in particular when strong directionality is present in image. It is observed that most of the natural image has strong frequency directionality. If directions are not present, the registration performance decreases and results are slightly worst.

One of the important limitations of algorithm discussed while concluding is that the proposed algorithm works properly if captured images possess aliasing. Nowadays, most of the digital camera manufacturers design optical system of their cameras to remove the aliasing. Optical low pass filter is applied to image before it's captured to ensure that aliasing cannot occur. Hence, the algorithm presented can not perform better than regular interpolations which use single image.

One of the major issues regarding super resolution algorithms is their dependency on an accurate registration. If the displacement between images is inaccurately estimated, a super resolution algorithm may lead to image degradation instead of image improvement. This degradation is usually called registration error noise and it depends on the characteristic of both the registration algorithm and the images being processed. Recognizing is the importance of the registration errors to super resolution imaging, some recent works have proposed super resolution algorithms, which are designed for robustness to such errors [6]. Researchers, Guilherme Holsbach Costa and José Carlos Moreira [18], have proposed different registration algorithms for super resolution image reconstruction.

It is important to determine how sensitive a given super resolution algorithm, which is to the motion estimation errors caused by different registration algorithms. The work in this paper is a contribution to the quantification of the sensitivity of super resolution methods to error in the image registration process. The application of interest is the real-time super resolution algorithm of image sequences, for which fast and accurate registration tends to be more important for performance than in the case of images. A deterministic model for its stochastic behavior is proposed. The new model permits the determination of the mean square high-resolution estimation error for a given level of registration error.

Registration is being a very important step in ensuring success of super resolution, accurate motion estimation is the key factor. Many existing super resolution algorithms assume the displacement is known a priori image formation model or try to estimate the registration parameters by assuming a translational motion model or through an iterative two phases estimation procedure. Y. He, K. Yap, L. Chen & L. Chau [13] present a new algorithm to integrate image registration into super resolution by fusing multiple blurred low resolution images to render a high resolution image. The registration and high resolution reconstruction is handled jointly. It is an iterative scheme based on nonlinear least squares method to estimation of motion shift and high resolution image progressively. Unlike traditional two stage super resolution methods, the image registration estimated the high resolution image iteratively instead of low resolution images. Conventional Super resolution methods assume that the estimated motion errors by existing registration method are negligible or the displacement is known a priori. This assumption, however, is not practical as the performance of existing registration algorithms is still less than perfect. In this regard, the proposed framework for joint registration and reconstruction is beneficial. Results demonstrate that method is effective in performing image super resolution.

Dirk Robinson & Milanfar [14], have analyzed the performance bounds for super resolution algorithms combining set of low resolution images performing joint task of registering and fusing the low resolution data sets. This analysis measures the limit performance from statistical first principle using Cramer-Rao (CR) inequalities. The analysis offers insight into the fundamental super resolution performance bottlenecks as they relate to other associated problems such as registration, reconstruction and image restoration. The analysis shows that there is no single bound which applies to all super resolution operating scenario as others have done in the past. Instead, they have shown that super resolution performance depends on a complex relationship between measurement of SNR, the number of observed frames, set of relative motion between frames, image contents, and imaging systems PSF.

The authors instead have presented problem in the Fourier domain that facilitates numerical analysis of the CR bound. Authors have proved that degradation in super resolution performance can be substantial when image motion must be estimated from the data, as opposed to being known a priori. This degradation occurs most severely along edges within image. The analysis presented focus on the case of image sequences containing simple translational motion. It is showed when the motion vectors are uniformly random, the performance bounds exhibit a threshold number of frames, which reasonable performance may be expected with high probability.

S. Baker and T. Kanade [15], have presented limits on super resolution and techniques to break them. The paper is devided in some parts. In first half of paper, authors have showed the super resolution reconstruction constraints less provide and less useful information as magnification factor increases. The major cause is the spatial averaging over the photo sensitive area is non-zero. In order to be able to capture non-zero number of photo's light, authors have derived a sequence of analytical results to support these conclusions. It is claimed that any smoothness leads prior to overly smooth results with very little high frequency contents.

In second half, authors have proposed a super resolution algorithm which using a different kind of constraints, in additional to the reconstruction constraints the algorithm attempt to identify local features in low resolution images and then enhances the resolution appropriately. They have developed a super-resolution algorithm by modifying the prior term in cost to include the results of a set of recognition decision, and called it recognition-based super resolution or hallucination. They have introduced the notion of a recognition-based prior as a prior- is a function of a collection of recognition decision. The prior enforces the condition that the gradient in the super-resolved image should be equal to the gradient in the best match training image. The algorithm learns a recognition based prior to specific classes of objects, scenes or images. Algorithm has been applied to super resolution, both for faces and texts, claimed that it has obtained significantly better results both qualitatively and in terms of RMS pixel error than traditional reconstruction based on super resolution algorithms using standard smoothness priors. After investigating on how much, from where the information comes, and when the information is, authors put forth two conclusions: first, the information content is fundamentally limited by the dynamic range of images. Second, a strong class based priors can provide more information than the simple smoothness priors that are used in existing super resolution algorithm.

Recently, researchers have started using wavelet for super resolution image reconstruction. Though researchers have used wavelet in either registration phase or for interpolation, they have used wavelet popularly for noise removal in multiframe based super resolution imaging. Wavelet has also been used widely in single frame super resolution algorithms. In these algorithms, the assumption is low resolution, low pass filter output of wavelet transform of original high resolution scene.

In a paper titled “A Second-Generation Wavelet Framework for Super-Resolution with Noise Filtering” [16], authors N. K. Bose, Mahesh B. Chappalli, have presented use of Second Generation Wavelets (SGW) to attend super resolution with noise filtering for captured sequence of low resolution frames without any assumption on grid structure. Authors have discussed in brief the First Generation Wavelets (FGW) & SGW and the importance of SGW properties, and use it in signal processing. In this paper, the super resolution algorithm using SGW with hard and soft thresholding is discussed in details. Image sequence super-resolution (high resolution) can be viewed in the conversion of the high-resolution non- uniformly sampled raster (irregular grid or non uniform sampling lattice) context generated from an acquired sequence of low-resolution frames to the desired uniformly sampled high resolution grid. Second-generation wavelets (SGWs) can not only deal with bounded domains and arbitrary boundary conditions, but also irregular sampling intervals, which at the heart of a sequence of low-resolution images from which image super-resolution is desired.

Authors claimed that due lifting technique used for implementation of wavelet, the algorithm is computationally efficient. SGW surface has been defined on irregularly sampled reconstruction grid. In proposed algorithm, the detail coefficient values are point on high resolution grid can be computed either by ignoring the irregularity of the grid and assigning value of closed irregular print or by resampling the wavelet and simultaneously for the noise reduction the thresholding of a coefficient is implemented. The simulated results are presented with PSNR as measuring parameter and comparison is made with interpolation techniques. Authors claimed that the choice of mother wavelet and scaling function which makes the SGW super resolution potentially more suitable in multimedia applications.

The process of image registration with respect to a reference frame results in a grid with irregularly spaced sampling points. Hence, the super resolution algorithm needs to handle irregular sampling most algorithms employ some means of approximating the irregularly sampled grid with a regularly sampled one. This induces some error in the process of super resolution which is reflected in the output image quality. The ability of second generation wavelets to adapt irregular sampling intervals rendered them an ideal for use in super resolution algorithms. The additional property of handling arbitrary boundaries eliminates the need to assume and to impose assumptions like the zero, periodic and Neumann boundary conditions and enhances the probability for obtaining better results from a super resolution algorithm based on second generation wavelets. The possibility of achieving simultaneous noise reduction by the use of wavelet coefficient thresholding provided an added incentive to delve deeper in this direction.

Second generation wavelet based super resolution algorithms is presented in paper [17] by M. El-Sayed Wahed titled “Image enhancement using second generation wavelet super resolution”. A framework for achieving image sequence super resolution simultaneously with noise filtering has been developed based on SGWs coupled with wavelet coefficient thresholding. The main advantages of the developed procedures are the adaptation to non-uniform sampling lattices, the absence of a priori assumptions on boundary conditions, independence from proper choice of mother wavelets and scaling functions, and the speed of implementation provided by the lifting technique. These advantages coupled with the improved performance in terms of visual quality of the reconstructed high resolution images make SGWSR algorithms potentially natural and suitable choices for multimedia applications.

A wavelet based super resolution algorithm has been presented in [18] a paper titled “A New Super resolution Reconstruction Algorithm Based on Wavelet Fusion” by S.E. Khamy, Hadhaud, Dessouky, Salam, and Abd El-Samie. The super resolution ill-posed problem has been solved in four consecutive steps: a registration step, a multi channel maximum entropy restoration step, a wavelet based image fusion step and finally a maximum entropy image interpolation step. The technique uses wavelet for image fusion. The wavelet packet decomposition is calculated for each observation to obtain the multi-resolution level of the images to be fused. In transformed domain, the coefficients in all resolution levels, whose absolute values are larger, are chosen between the available observations. This is maximum frequency rule. The maximum entropy interpolation gives high resolution image. The algorithm achieves good PSNR and computationally fast.

Authors in [19] have studied effects of image alignment error on vehicle license image reconstruction using the non-uniform interpolation method. The non-uniform interpolation method used a series of low resolution images to reconstruct high resolution image. It is important to know the position differences between these images before the reconstructing process. The study demonstrated the effects of misalignment on the reconstructed image. As expected that the increase in measurement error degrades the reconstructed image.

3. Summary-The Key Observations

A number of super resolution techniques have been suggested over the years. Since its conception in 1984 by Tsai and Haung, the topic has received huge interest due to its potential to increase performance of existing camera system without the need of dedicated hardware. Literature survey reveals that proposed super resolution algorithms can be categorized into three major classes: Reconstruction based super resolution, Learning based super resolution, and Wavelet based super resolution. The super resolution process can be generalized into three important phases: the preprocessing, the reconstruction, and the post processing. Though a wide variety of super resolution approaches are proposed, most of them suffer from drawbacks.

In reconstruction based approach, set of shifted and/or rotated low resolution images are used to reconstruct the high resolution image. Three phases process involve registration as preprocessing, interpolation as reconstruction and the restoration as post processing. Registration is basically preprocessing of the input information. Image registration is to align the different images as precisely as possible by estimating the motion between them. All the frames in the low-resolution observed image sequence are geometrically registered to a fixed reference frame, resulting in a composite image of non-uniformly-spaced samples. These nonuniformly spaced sample points are then interpolated and resampled on a regularly spaced high resolution sampling lattice. Restoration is used to remove noise and blur, if exists in the resultant image.

The basic premise for increasing the spatial resolution in reconstruction approach is the availability of multiple low resolution images of the same scene. These low resolution images represent different looks of same scene. That is, images are sub sampled (aliased) as well as shifted with subpixel precision. If the low resolution images are shifted by integer units, then each image would contain the same information and there is no new information that can be used to reconstruct an HR image. However capturing images with subpixel shift is not easy task. Capturing images with subpixel shifts means sampling of scene uniformly, and the shifts are to be combined so that an image, that is effectively sampled at higher rate than the individual frame, is reconstructed.

For Further aim is to investigate the problem of how information contained in these multiple images. Those are overlapped in time and/or space can be combined to produce image of better quality. Information from these images is extracted by process of registration.

Registration is important step in super resolution image reconstruction, as accurate registration is necessary for success of super resolution process. If any error occurs during registration, it should be overcome in reconstruction phase.

Key challenge to be handled in reconstruction approach is registration error. Accurate motion estimation is important parameter for proper registration. Motion parameters should be known in prior, if not, accurate motion parameter estimation is important for successful registration. This is a challenge as an error in motion estimation translates most directly into degradation of resulting SR image. Inaccurate registration leads to artifacts that are visually very disturbing.

Registration phase is very complex and it consumes most of the super resolution process time. One more challenge involved in multiframe super resolution is to apply the information obtained from different registered images to the reconstruction of good quality high resolution image. Since observed data results from under sampled, spatially averaged areas, the reconstruction step, which typically assumes impulse sampling, is incapable of reconstructing significantly more frequency content then its present in a single low resolution frame. Some of the researchers have reconstructed super resolution image using motionless LR observations too.

Recently, researchers have begin to investigate the use of wavelets for super solution image reconstruction. Since 2000, first generation wavelets have been used to attain super resolution. Some of the researchers have proposed wavelet for preprocessing which is for registering the low resolution images, few of them have used wavelet in reconstruction phase for interpolation and most of them have used wavelet for noise reduction.

In wavelet based registration, the high frequency information contained in wavelet coefficient of low resolution frames are extracted and fused. This is accomplished by exploiting the spatial correlation among low resolution images. Combining non-redundant information of super resolution image is reconstructed.

The ability of second generation wavelet to adapt irregular sampling intervals has lead to their usage in super resolution imaging. After registration is done, wavelet is used to uniform sample on non-uniform samples to rectangular grid. Wavelet is used for computing detail coefficient values at the point on high resolution grid by resampling the approximate component of wavelet.

4. Conclusion

In this paper, the effect of registration error and number of images which used in the process of super resolution image reconstruction is studied. Super Resolution image reconstruction has three phases process, of which registration at most importance phase. Super resolution image reconstruction uses set of low resolution images to reconstruct high resolution image during registration. The study demonstrates the effect of registration error and the benefit of more number of low resolution images on the quality of reconstructed image. Study reveals that the registration error degrades the reconstructed image and without better registration methodology, a better super resolution method is still not of any use. It is noticed that without further improvement in the registration technique, not much improvement can be achieved by increasing number of input low resolution images.

It is found that errors are not avoidable when estimating the position and orientation differences between images, using more frames of image might make the reconstructed image more blur instead of more clear.

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