# SUPER-RESOLUTION

**Pradeep Gaidhani**

## 1. INTRODUCTION

The central aim of Super-Resolution (SR) is to generate a higher resolution image from lower resolution images. High resolution image offers a high pixel density and thereby more details about the original scene. The need for high resolution is common in computer vision applications for better performance in pattern recognition and analysis of images. High resolution is of importance in medical imaging for diagnosis. Many applications require zooming of a specific area of interest in the image wherein high resolution becomes essential, e.g. surveillance, forensic and satellite imaging applications.

However, high resolution images are not always available. This is since the setup for high resolution imaging proves expensive and also it may not always be feasible due to the inherent limitations of the sensor, optics manufacturing technology. These problems can be overcome through the use of image processing algorithms, which are relatively inexpensive, giving rise to concept of super-resolution. It provides an advantage as it may cost less and the existing low resolution imaging systems can still be utilized.

## 2. SUPER-RESOLUTION

Super-resolution is based on the idea that a combination of low resolution (noisy) sequence of images of a scene can be used to generate a high resolution image or image sequence. Thus it attempts to reconstruct the original scene image with high resolution given a set of observed images at lower resolution.

The general approach considers the low resolution images as resulting from resampling of a high resolution image. The goal is then to recover the high resolution image which when resampled based on the input images and the imaging model, will produce the low resolution observed images. Thus the accuracy of imaging model is vital for super-resolution and an incorrect modeling, say of motion, can actually degrade the image further.

The observed images could be taken from one or multiple cameras or could be frames of a video sequence. These images need to be mapped to a common reference frame. This process is registration. The super-resolution procedure can then be applied to a region of interest in the aligned composite image. The key to successful super-resolution consists of accurate alignment i.e. registration and formulation of an appropriate forward image model. The figure 1 below shows the stages in super-resolution process.

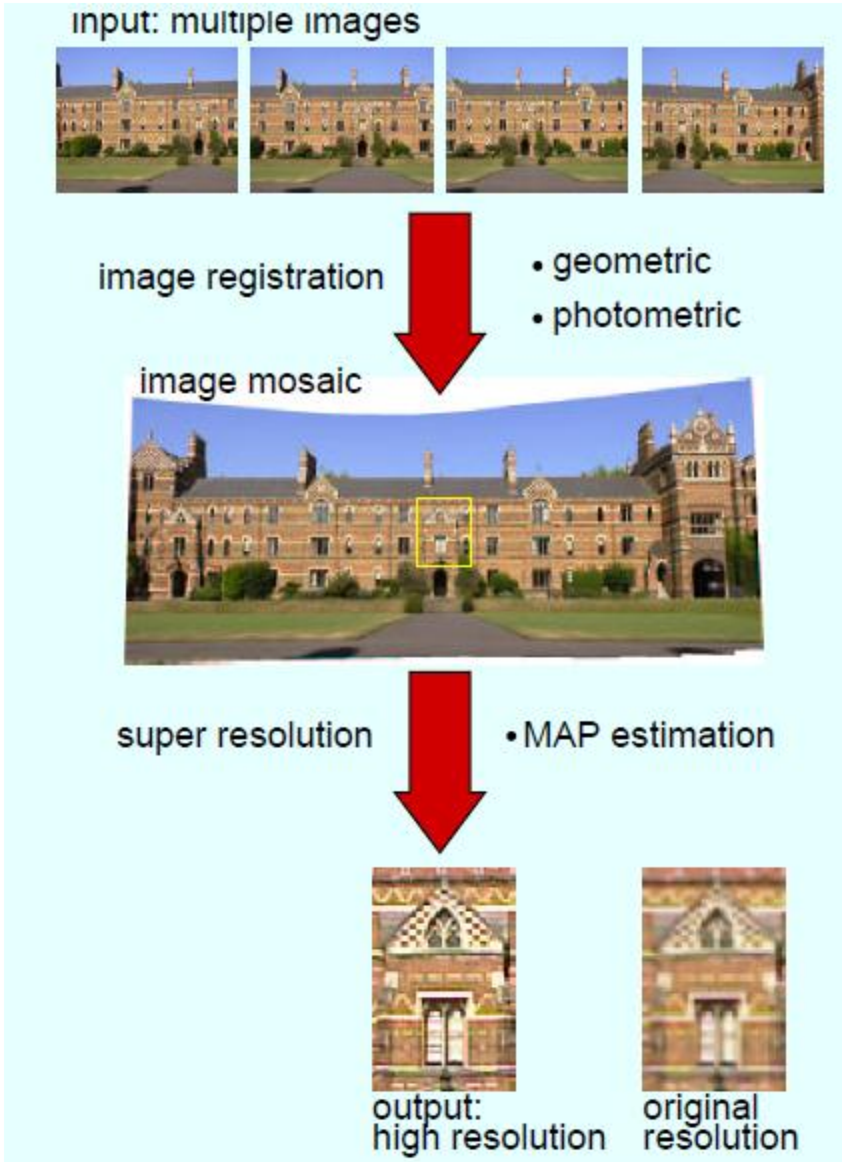



**Figure 1**: Stages in super-resolution (fig taken from [1])

### 2.1 Image Registration

The multiple low resolution images can represent different view-points of the same scene and image registration deals with mapping corresponding points in these images to the actual points in original scene and transforming data into one coordinate system. Several types of transformations could be required for registration of images like affine transformations, biquadratic transformations or planar homographic transformations. This alignment involves geometric component as well as photometric component.

#### 2.1.1 Geometric Registration

Let us consider homographic or planar projective transformation. This is illustrated in figure 2 for two situations, i) images of a plane from different camera positions and ii) images of a scene from a panning or zooming camera. The points x and x′ correspond to actual point X in the original scene.

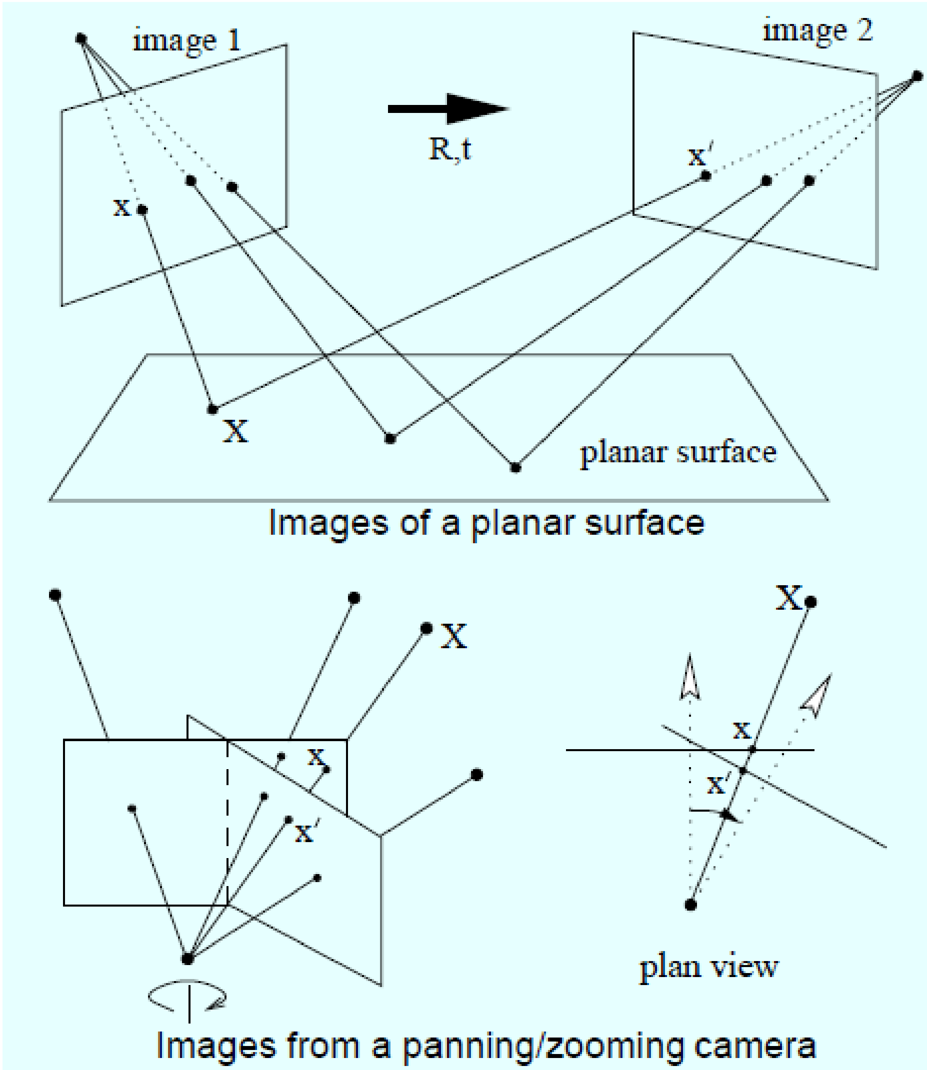



**Figure 2**: Two scenarios for planar homography (fig taken from [1])

### A. Feature-based Registration:

It deals with automatic detection and analysis of corresponding features in inputs images to use for geometric transformation. The corresponding features in the images are mapped together based on similarity, geometric closeness or by algorithms like Harris feature detector (Harris and Stephens, 1988). Similarity metric like normalized correlation can be used to identify correspondences which can be refined using search algorithms like RANSAC. Thereafter these correspondences can be used in a non-linear estimator which returns an accurate estimate of the projective transformation. A Maximum Likelihood method can be applied to estimate the registration parameters [1].

### B. Maximum Likelihood Registration:

The error in detected feature points can be modeled as Gaussian distribution with mean as zero and standard deviation as σ. Let $\underline{x}$ be a noise free projection of original scene point X, the probability density of corresponding observed point can be given as [1],

$$P(x \mid \underline{x}) = \frac{1}{2\pi\sigma^2} \exp\left( - \frac{(x - \underline{x})^2 + (y - \underline{y})^2}{2\sigma^2} \right)$$

Assuming the measurements are independent and error is uncorrelated between images, the probability density of set of observed correspondences between x, x′ given as

$$P(x, x') = \prod_i P(x_i \mid \underline{x}_i)\, P(x'_i \mid \underline{x'}_i)$$

The negative log likelihood of the set of all correspondences,

$$L = \sum_i \left((x_i - \underline{x}_i)^2 + (y_i - \underline{y}_i)^2 + (x'_i - \underline{x'}_i)^2 + (y'_i - \underline{y'}_i)^2\right)$$

Here, $\underline{x}$, $\underline{x}'$ and $\underline{y}$, $\underline{y}'$ are true (noise free) projections and so replacing it with estimated positions $\hat{x}$, $\hat{x}'$ and $\hat{y}$, $\hat{y}'$

$$L = \sum_i \left((x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (x_i - \hat{x}_i')^2 + (y'_i - \hat{y}_i')^2\right)$$

Imposing the constraint that $\hat{x}$ maps to $\hat{x}'$ under a homography and thus $\hat{x}' = H\hat{x}$.
Thus, estimation of homography and pre-image points $\hat{x}$ is required for minimizing L.

### 2.1.2 Photometric Registration

Along with geometric transformations, there could be photometric changes in the images. Photometric registration deals with estimating these photometric transformations due to changes in illumination, intensity etc. A simple parametric model of these effects can be used and the parameters can then be estimated using the available images. Figure 3 shows an example using a model that allows for affine transformation (contrast and brightness) per RGB channel [1].

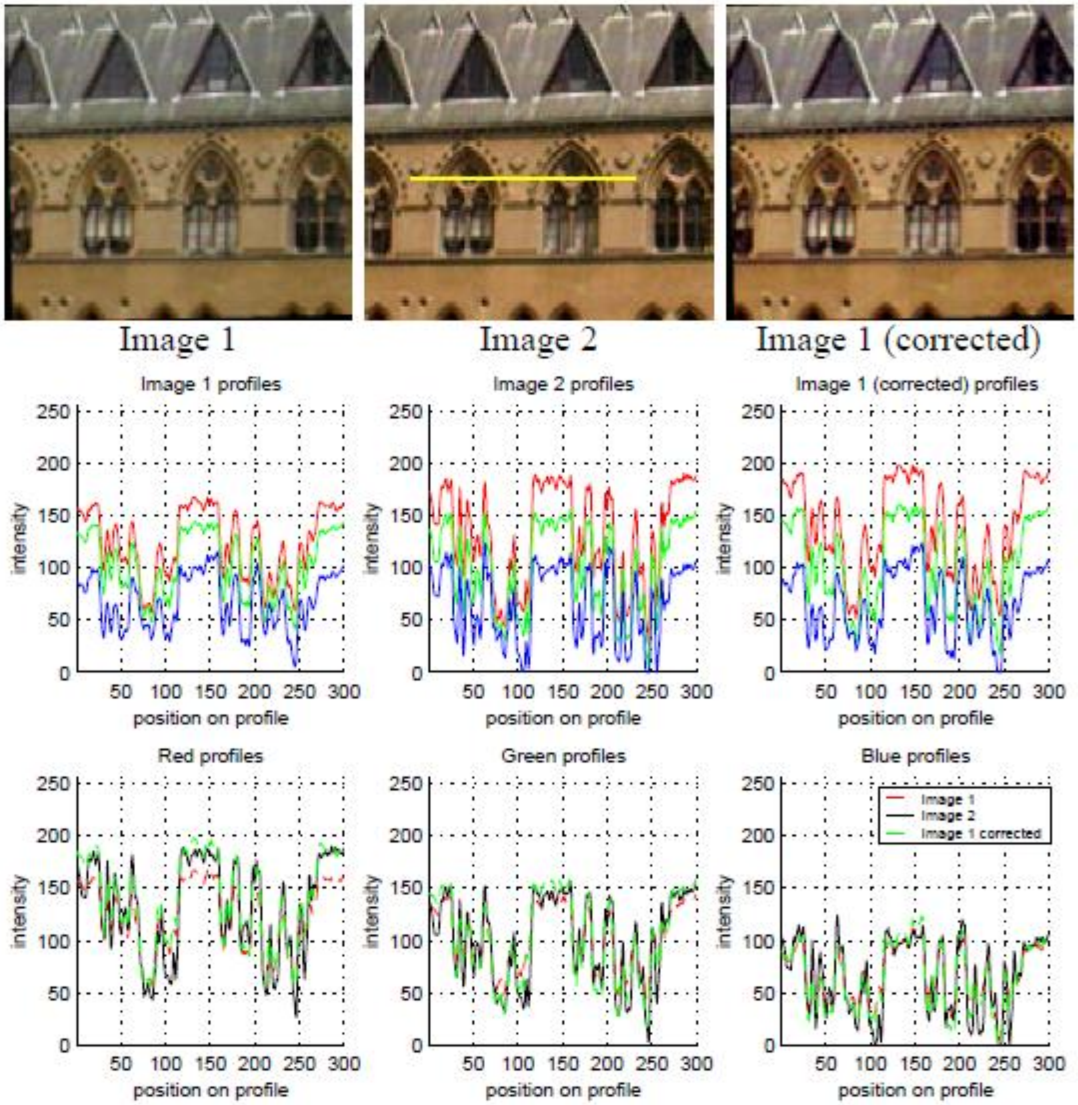



**Figure 3**: Correction of photometric variation in images (fig taken from [1])

### 2.2 Forward Imaging Model

One of the most vital aspects in super-resolution is good formulation of a model for the imaging and motion process. A forward model relates the original scene to the observed low resolution images.

Consider high resolution image of size $L_1N_1$ x $L_2N_2$. In lexicographical notation,
vector $x = [x_1, x_2, \ldots, x_N]^T$ ,
where $N = L_1N_1 \times L_2N_2$
Let parameters L1 and L2 be down sampling factors in the image model. Thus, the low resolution images are of size $N_1$ x $N_2$.
The $k^{th}$ low resolution image can be denoted as,
$y_k = [y_{k,1}, y_{k,2}, \ldots, y_{k,M}]^T$
$k = 1,2,\ldots,p$ and $M = N_1 \times N_2$

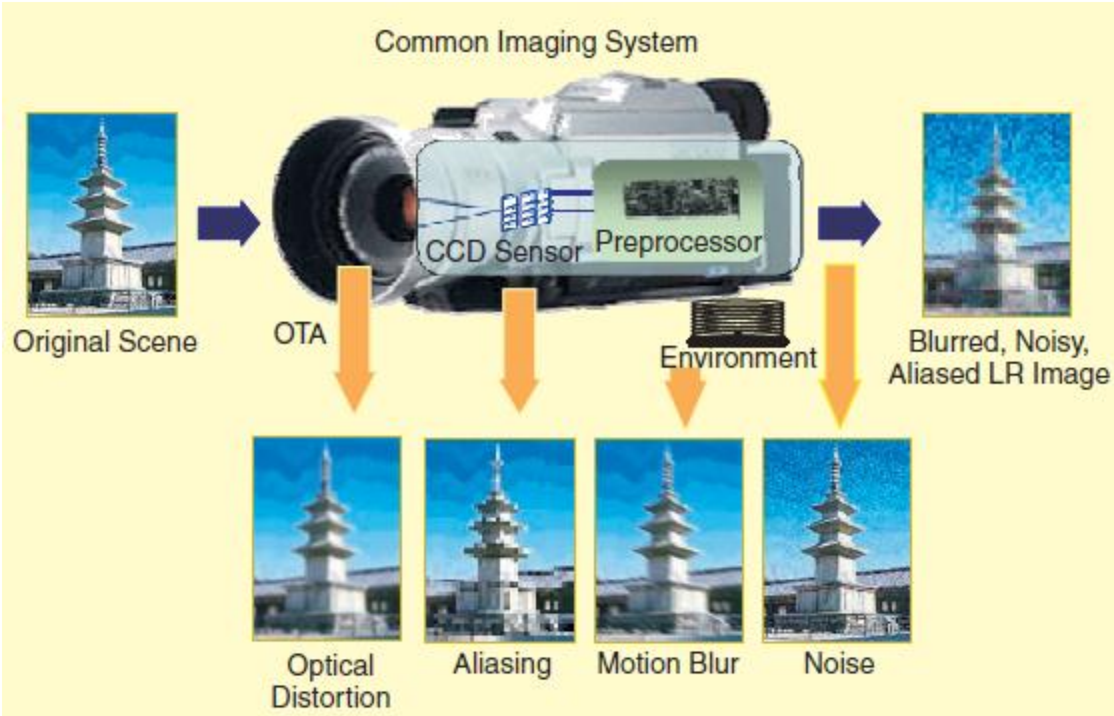



**Figure 4**: Common imaging system (fig taken from [2])

The observed low resolution images result from warping, blurring and subsampling performed on the high resolution image x. The forward image model can then be represented as [2],

$y_k = DB_kM_k x + n_k$ for $1 \leq k \leq p$

$M_k$ = warp matrix
$B_k$ = blur matrix
$D$ = subsampling matrix
$n_k$ = noise vector

A block diagram of the imaging process shown below:

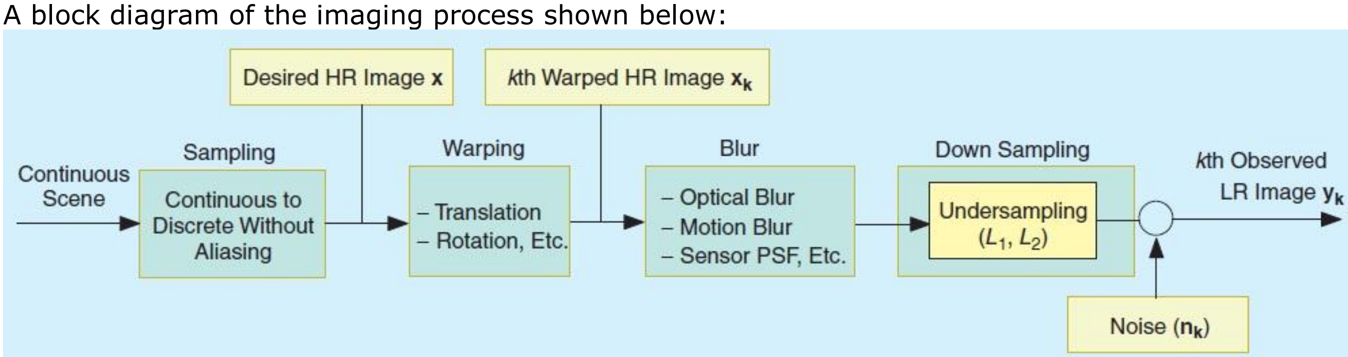
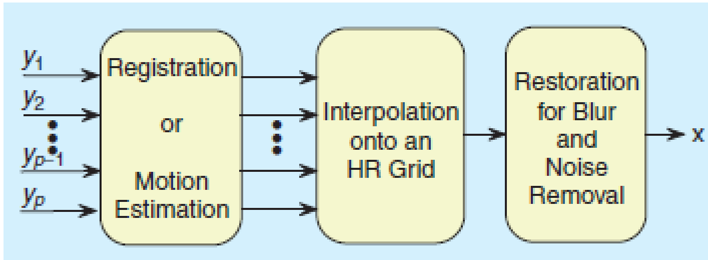



**Figure 5**: Forward imaging model (fig taken from [2])

## 3. SUPER-RESOLUTION IMAGE RECONSTRUCTION ALGORITHMS

### 3.1 Non-uniform Interpolation

This approach consists of three stages i) registration, ii) non-uniform interpolation and iii) de-blurring [2]



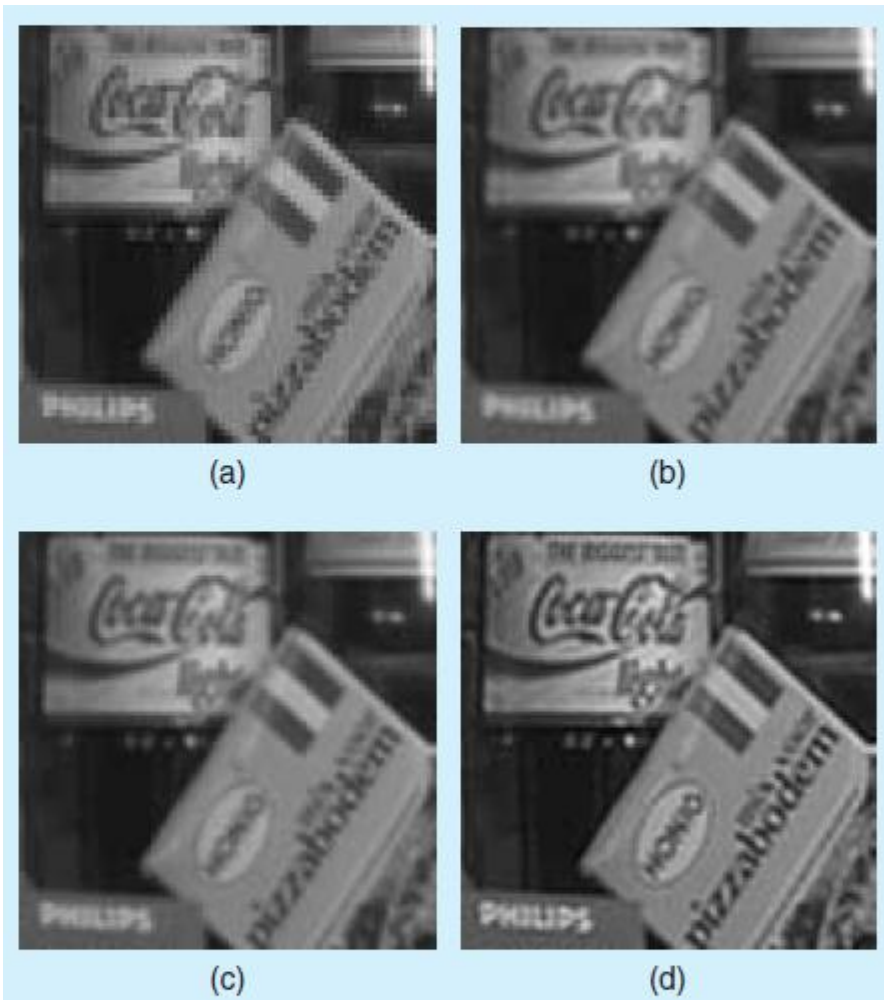




**Figure 6**: *Nonuniform interpolation SR reconstruction results by (a) nearest neighbor interpolation, (b) bilinear interpolation, (c) nonuniform interpolation using four LR images, and (d) debluring part (c)* (fig taken from [2])

With registration of input images, a composite image on non-uniformly spaced sampling points is obtained. In the second step, uniformly spaced sampling points are obtained by direct or iterative reconstruction procedure. After getting a high resolution image with non-uniform interpolation, restoration is carried out to remove blurring.

### 3.2 Frequency Domain Approach

This approach was proposed by Tsai and Huang [4] where aliasing in the low resolution images is used to reconstruct high resolution image. The relationship between low resolution images and the high resolution image is described by them using relative motion between the low resolution images. This approach is based on following three principles [2],

i) the shifting property of Fourier transform
ii) the aliasing relationship between the continuous Fourier transform (CFT) of an original HR image and the discrete Fourier transform (DFT) of observed LR images
iii) the assumption that an original HR image is band-limited

It is thus possible to formulate the system equation relating the aliased DFT coefficients of the observed low resolution images to a sample of the CFT of an unknown image.

### 3.3 Regularized Image Reconstruction Approach

The super-resolution image reconstruction approach can be an ill-posed problem because of an insufficient number of low resolution images and ill-conditioned blur operators. Regularization is the procedure adopted to stabilize the inversion of ill-posed problem [2]. This is achieved by imposing prior knowledge on the solution. There are two types of approaches, viz. i) deterministic approach ii) stochastic approach.

## 4. SUPER-RESOLUTION FROM SINGLE IMAGE

In the recent years, example based super-resolution methods have been proposed with the aim to reconstruct a high resolution image given a single low resolution image. In this approach, the correlation between low resolution images and corresponding high resolution images is learnt from a database of known low and high resolution image pairs. This learning is then applied to a new low resolution image to obtain its most likely high resolution image. Higher factors of super-resolution have been obtained by repeated application of this process. In their paper [3], Glasner et al. have proposed an approach combining the classical multi-image super-resolution along with example-based approach and have shown how a super-resolution image can be reconstructed from a single input image.

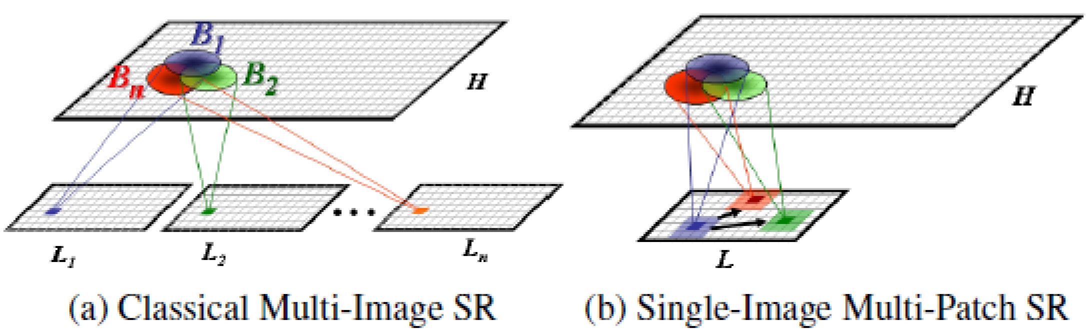



**Figure 7**: *Recurring patches within a single low-res image can be regarded as if extracted from multiple different low-res images of the same high resolution scene*
(fig taken from [3])

(a) Input image (scaled for display). (b) Bicubic interpolation (×2). (c) Within image repetitions (×2). (d) Unified single-image SR (×2).

**Figure 8**: A combined classical multi-image + example based approach for super-resolution from single image (fig taken from [3])

## 5. SUPER-RESOLUTION OF A VIDEO

The super-resolution techniques for image can be extended to a video sequence by simply shifting along the temporal line. The link below shows a real-time application of super-resolution to video.
Super-Resolution: Jitter Camera (http://www.youtube.com/watch?v=QdK5-gNf4Wg)

## 6. REFERENCES


[1] Capel, D.; Zisserman, A.; , "Computer vision applied to super resolution," *Signal Processing Magazine, IEEE* , vol.20, no.3, pp. 75- 86, May 2003
doi:10.1109/MSP.2003.1203211
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1203211&isnumber=27099

[2] Sung Cheol Park; Min Kyu Park; Moon Gi Kang; , "Super-resolution image reconstruction: a technical overview," *Signal Processing Magazine, IEEE* , vol.20, no.3, pp. 21- 36, May 2003
doi:10.1109/MSP.2003.1203207
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1203207&isnumber=2709

[3] Glasner, D.; Bagon, S.; Irani, M.; , "Super-Resolution from a Single Image", *12th International Conference on Computer Vision (ICCV), IEEE ,* pp. 349 – 356, 2009
URL: http://www.wisdom.weizmann.ac.il/~vision/SingleImageSR.html

[4] Tsai, R.; Huang T.; , "Multi-frame image restoration and registration", *Advances in Computer Vision and Image Processing*, vol. 1, no. 2, JAI Press Inc., Greenwich, CT, 1984, pp. 317–339


## 7. OTHER RESOURCES

1. List of Super-Resolution publications
   http://decsai.ugr.es/~jmd/superresolution/publications.html [Date accessed: 31/03/2011]

2. Super-resolution SD-to-HD up-converter super-resolution (Avarex.ru)
   http://www.youtube.com/watch?v=wxCleSGnji8 [Date accessed: 31/03/2011]

3. YUV Super Resolution vs plain static upscaling of video
   http://www.youtube.com/watch?v=181c6DxDs6k [Date accessed: 31/03/2011]

4. SR Overview (Visual Geometry Group)
   http://www.robots.ox.ac.uk/~vgg/research/SR/ [Date accessed: 31/03/2011]