
**ISSN Print:** 2394-7500
**ISSN Online:** 2394-5869
**Impact Factor:** 5.2
IJAR 2016; 2(9): 08-12
www.allresearchjournal.com
Received: 02-07-2016
Accepted: 03-08-2016

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# Random motion of image sensor based super-resolution technique

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**Abstract**
This paper is about new method of image resolution enhancement that is a new method of Super-resolution. Super-Resolution is the word given to the techniques that generate high resolution image from a set of low resolution images. The paper describes about a new Super-resolution technique based on random motion of image sensor. However the term Super-resolution is usually used to describe methods that differ on mathematical aspects and do not involve any hardware change. But this time the change in hardware is simple and does not involve much complexity. So it will serve as an inexpensive technique to acquire high resolution images. The required low resolution images that contains sub-pixel information for the generation of high resolution image is acquired by the image sensor which is free to move on its horizontal and vertical axes but only in sub-pixel range. This motion of the image sensor is the result of vibration of piezoelectric material on the edges of the image sensor. The generation of high resolution image from the acquired set of low resolution images is based on Maximum-a-posteriori method of Super-resolution.

**Keywords:** Interpolation, sub-pixel, image sensor, piezoelectric, MAP, PSF

## 1. Introduction

This paper is about Image enhancement techniques, known as Super-Resolution of images. A set of images are taken into consideration and then sub-pixel information is gathered from them and then recombination is done to form a new Image. The resulting images are enhanced resolution images known as Super-Resolved images. Or simply high resolution images (HR images) [1, 2]. Here the technique is to acquire multiple images from a camera which has the image sensor chip a little modified. The modification done is just addition of a layer of piezoelectric material at its edges. These piezoelectric material is supplied a square wave voltage. This alternating voltage will cause oscillations in piezoelectric material at the edges due to inverse piezoelectric effect. This will result in vibration of the image sensor in both the vertical and horizontal axes. This motion is not determined accurately so is called random. And the camera captures several images. The motion of the image sensor is in sub-pixel range because the oscillations of the piezoelectric material at the edges is in micrometer range (< 1-2 micro meters) [3, 4].

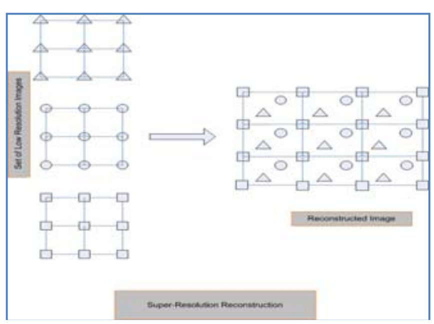



**Fig 1:** Super-Resolution Technique of creating a High resolution image from multiple low resolution images.

## 2. Background
Super-Resolution techniques can be classified as shown in the following tree:

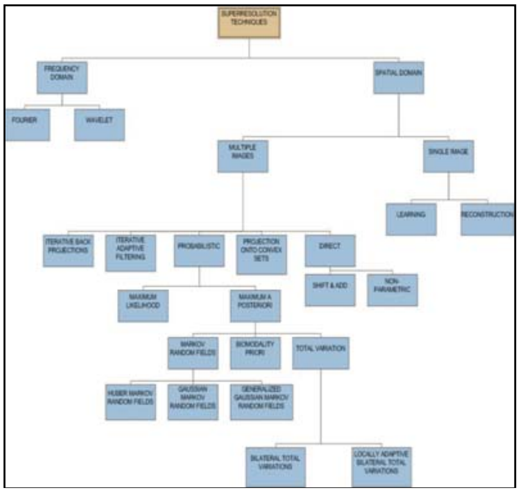



**Fig 2:** Tree classification of Super-Resolution Techniques.

We are using Maximum-A-Posteriori method here so a brief introduction is as follows.

### 2.1 Statistical Approaches
Statistical approaches reconstruct the SR image stochastically. The HR image and motions in the input LR images are taken as stochastic variable. [5] These are of following types:

a) Maximum Likelihood
b) Maximum a Posteriori
c) Joint Map Restoration
d) Bayesian Treatments

### a. Maximum Likelihood
In maximum likelihood estimation the desired HR image $\underline{X}$ is obtained by maximizing the conditional probability density function of the measurements (LR images) which is given by $P\{\underline{Y}/\underline{X}\}$. ML estimates are very sensitive to noise and errors in image registration. Assuming measurements additive noise is zero mean Gaussian random process with autocorrelation matrix $W^{-1}$.

ML is of the following weighted least squares (WLS) form:

$$\underline{\hat{X}}_{ML} = \underset{\underline{X}}{\arg\max}\ P[\underline{\bar{Y}}/\underline{X}]$$

$$= \underset{\underline{X}}{\arg\max}\ \{[\underline{Y} - H\underline{X}]^T W [\underline{Y} - H\underline{X}]\}$$

Differentiating with respect to $\underline{X}$ and equating to zero gives the result:-

$$R\underline{\hat{X}}_{ML} = \underline{P}$$

Where

$$R = H^T W H = \sum_{k=1}^{N} H_k^T\, W_k H_k$$
$$\underline{P} = H^T W \underline{Y} = \sum_{k=1}^{N} H_k^T\, W_k \underline{Y}_k$$

The ML estimation is not so useful when the image is noisy or information available is not sufficient.

### b. Maximum a Posteriori (MAP)
Here we use posterior i.e. instead of maximizing the likelihood function: $\text{Prob}\{\underline{Y}|\underline{X}\}$, we maximize the posterior probability function: $\text{Prob}\ \{\underline{X}|\underline{Y}\}$

The priors for the desired image commonly used are

a) Gaussian Markov Random Field.
b) Huber Markov Random Field.
c) Total variation.

### c. Joint Map Restoration
In the above techniques the process of LR images registration and estimation of HR image are considered as separate a process but in Joint Map Restoration motion estimates and image restoration are combining together.

### d. Bayesian Treatment
Bishop and Tipping proposed a Bayesian approach where the estimate of PSF and motion parameters is done by integrating unknown high resolution image. However, this integration is computationally heavy, so needs to be improved.

The aim of these methods is to upscale an image using other similar low resolution images (LR images) while maintaining the details in the image. HR image is desired because of the more information contained in it be it a just real world images from a consumer point of view got from a digital image product or in medical science image study where more detail in images mean better diagnosis.

## 3. Implementation
In order to combine the multiple images, super resolution algorithm based on Fusion of interpolated frames [6] has been used. This algorithm combined with the non-precision motion of the image sensor [7] gives better performance in terms of complexity as well as noise reduction in the final super-resolved image. The algorithm is based on Maximum-a-Posteriori technique of image enhancement using anisotropic diffusion method, which involves total variations regularizers [8].

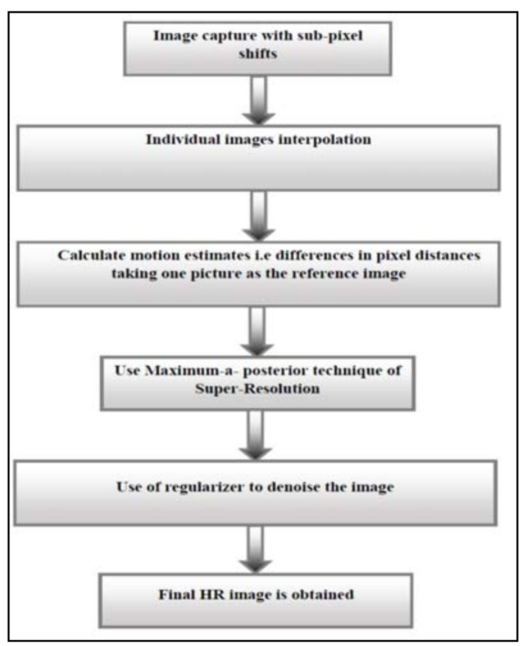



**Fig 3:** Flow chart of the proposed methodology.

## 3. Regularizers

The following regularizing term:

$$\frac{\partial u}{\partial t} = div\left(\frac{2+\frac{|\nabla u|}{\beta}}{\left(1+\left(\frac{|\nabla u|}{\beta}\right)^2\right)}\nabla u\right) + \lambda(u-f)$$

Where $\lambda$ is the weighing parameter for regularization?
$\beta$ is the shape defining tuning constant,
In homogeneous regions-

$$\frac{\partial u}{\partial t} = C\nabla u + \lambda(u-f)$$

The above equation is an isotropic linear diffusion equation i.e heat equation that reduces noise uniformly over the whole image region. It also protects edges and contours when the diffusivity becomes zero.

$$\frac{\partial u}{\partial t} = C\ div\left(\frac{\nabla u}{1+\left(\frac{|\nabla u|}{\beta}\right)^2}\right) + \beta\ div\left(\frac{\nabla u}{|\nabla u|}\right) + \beta\ div\left(\frac{-1}{|\nabla u|\left(1+\left(\frac{|\nabla u|}{\beta}\right)^2\right)}\nabla u\right) + \lambda(u-f)$$

where the terms (lexicographically) are as follows: first term is the Perona–Malik (PM) second is the nonlinear Total Variation (TV), third is the backward diffusion model that sharpen edges and contours and fourth is the fidelity term.

### 3.2 Image Sensor Modification

The following modifications are to be made in image sensor:

- Piezoelectric material at the border of image sensor to facilitate motion.
- Variable voltage supply to the piezoelectric material.
- External electric field Noise immunity for the image sensor by metal casing etc.
-

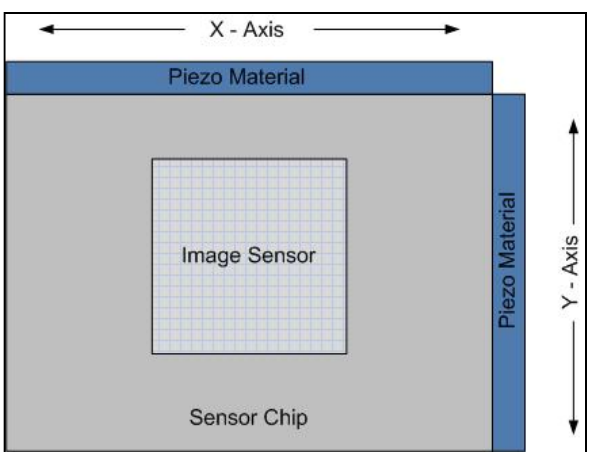



**Fig 4:** Image sensor modification.

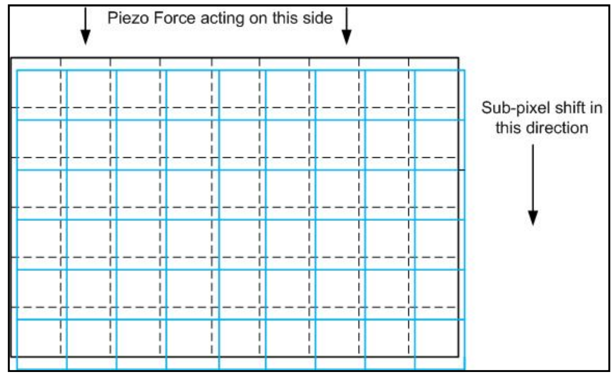



**Fig 5:** Motion of the image sensor.

The above modifications are necessary to support the random motion of the image sensor in sub-pixel range. The lens system over the sensor area should be kept intact because no modification is needed at that part of the imaging system.

### 3.3 Piezoelectric Effect

Piezo or Piezien is a Greek word which means to squeeze or press. Piezoelectricity was discovered by French physicists Jacques Pierre Curie in 1880.
It is the ability to generate an electric potential in response to the mechanical stress applied. This effect is due to the electro-mechanical interaction inside the crystalline material.
The reverse piezoelectric effect is also exhibited that is the generation of mechanical strain inside the material when an electric field is applied. It is the mechanical deformation or strain (expansion and contraction) of piezoelectric crystal under the influence of an electric field. Reverse piezoelectric effect is also called as inverse piezoelectric effect and also as indirect piezoelectric effect.

### 3.4 Graphical User Interface

The Graphical User interface for the camera images capture and super-resolution algorithm is as follows:

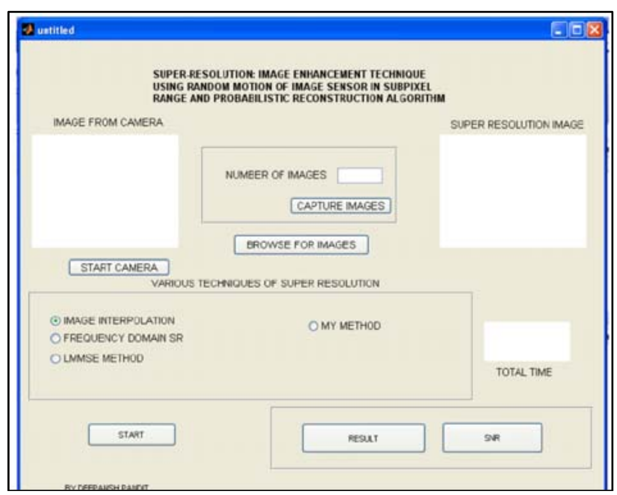
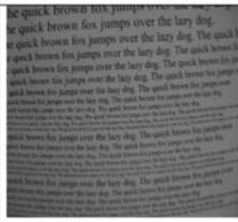
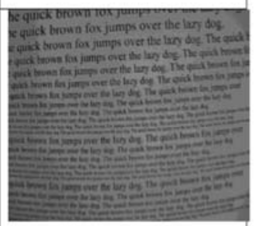
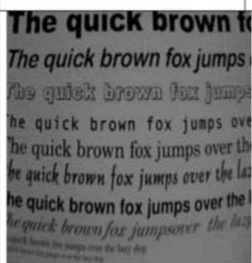
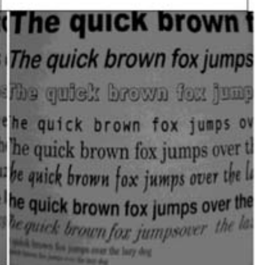


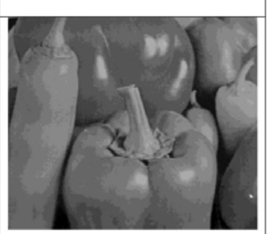

**Fig 6:** Graphical User Interface in Matlab.

## 4. Results

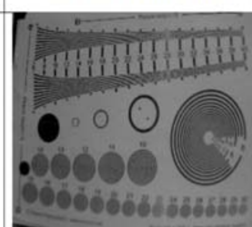
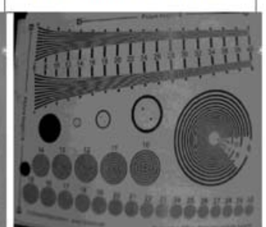
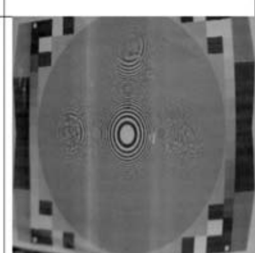
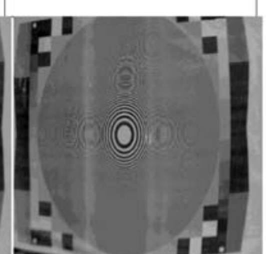
### 4.1 Images

The following set of images printed on plain paper were used in capturing images from the camera.

| Sr. No. | One of Low resolution Images | Resulting High resolution Image |
|---|---|---|
| Image 1 |  |  |
| Image 2 |  |  |
| Image 3 |  |  |

| Sr. No. | One of Low resolution Images | Resulting High resolution Image |
|---|---|---|
| Image 4 |  |  |
| Image 5 |  |  |
| Image 6 |  |  |

| Sr. No. | One of Low resolution Images | Resulting High resolution Image |
|---|---|---|
| Image 7 |  |  |
| Image 8 |  |  |
| Image 9 |  |  |

| | One of Low resolution Images | Resulting High resolution Image |
|---|---|---|
| Image 10 |  |  |
| Image 11 |  |  |
| Image 12 |  |  |

| TABLE OF COMPARISION OF VARIOUS ERRORS IN IMAGES | | | | | | | |
|---|---|---|---|---|---|---|---|
| SR.NO. | MSE | PSNR | NK | AD | SC | MD | NAE |
| IMAGE 1 | 7.9093 | 39.1494 | 0.9994 | 0.0293 | 1.0005 | 25 | 0.0198 |
| IMAGE 2 | 49.2188 | 31.2095 | 0.9934 | 0.1851 | 1.0092 | 102 | 0.043 |
| IMAGE 3 | 35.4744 | 32.6317 | 0.9961 | 0.0149 | 1.0048 | 55 | 0.0339 |
| IMAGE 4 | 15.549 | 36.2138 | 0.9992 | -0.0417 | 1.0003 | 47 | 0.0275 |
| IMAGE 5 | 6.4171 | 40.0574 | 0.9997 | -0.0069 | 1 | 29 | 0.0173 |
| IMAGE 6 | 5.4605 | 40.7585 | 0.9998 | -0.0096 | 0.9999 | 45 | 0.016 |
| IMAGE 7 | 30.731 | 33.255 | 0.997 | 0.0041 | 1.0033 | 44 | 0.0403 |
| IMAGE 8 | 20.8629 | 34.9371 | 0.9987 | -0.0418 | 1.0006 | 48 | 0.0322 |
| IMAGE 9 | 79.4613 | 29.1292 | 0.9908 | 0.0607 | 1.0121 | 113 | 0.0501 |
| IMAGE 10 | 11.9784 | 37.3468 | 0.9989 | 0.0095 | 1.0011 | 50 | 0.0227 |
| IMAGE 11 | 18.7601 | 35.3984 | 0.9987 | -0.0289 | 1.0011 | 37 | 0.0284 |
| IMAGE 12 | 62.5492 | 30.1686 | 0.9912 | 0.139 | 1.0119 | 98 | 0.0468 |

| |
|---|
| MSE = Mean Square Error |
| PSNR=Peak signal to Noise Ratio |
| NK= Normalized Cross-Correlation |
| AD= Average Difference |
| SC= Structural Content |
| MD=Maximum Difference |
| NAE= Normalized Absolute error |

**Fig 7:** Image set and table for comparision.

## 5. Conclusion

We can observe from the above results that the generated image is improved in resolution and thus the method of capturing images this way is an improvement and can be implemented in several domains.

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