SUPER RESOLUTION METHODS

1. INTRODUCTION

Camera technology is improving day by day. The features and resolution value that were not included in a digital camera in the past are now available even in smartphones that we carry in our pockets. While the camera resolution was 0.3megapixel in the past, cameras with a resolution of over 100 megapixels have been produced according to the latest technology today. The number of pixels in an image is the resolution of that image. Super resolution rendering is the process of taking several different (low resolution) images of the same scene and combining them into a single high resolution image. For example, a photographer might take four images with his four-megapixel camera, then combine them to create a sixteen-megapixel image. Papoulis first used the term Super Resolution in 1968. He showed that high frequency pixel information can be calculated using features such as Limited bandwidth and Size in images, and he called it Super Resolution. Tsai and Huang made the first super resolution algorithm using multiple low resolution images for the first time. In their study, they increased the resolution of satellite images by using different images and using the frequency domain method. Again in their studies, it has been shown that the bandwidth of the signal created in small deviations from the best values is larger. Thus, the FFT coefficients of the high-resolution image can be calculated effectively with FFT-based algorithmsSuper Resolution algorithms have 2 bad sides. The first is to align the Images on the same frame. The second is to create a better quality picture by using the pictures on the same frame. If either of these two cases is done poorly, the resulting picture will not be of the desired quality.

2. SUPER-RESOLUTIONS

Optical resolution is a measure of how sensitive digital cameras are, showing the details of an image. Image resolution is a measure of the amount of detail that can be seen in an image.

Low resolution images are needed to create a super resolution image. These pictures must be photos of the same scene taken from different angles. Since these pictures are taken from different angles, there is a pixel shift between the images. These low resolution images are subjected to different algorithms and then passed through several filters to obtain a higher resolution image. In these subpixel shifts extra information is available to create the new high resolution image. Taking the same picture from different places or taking the same picture with different cameras Figure 2.1. is also shown. This is how to view the picture from different angles.

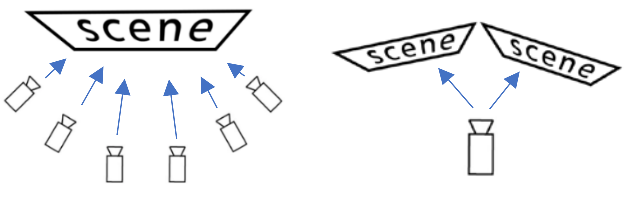


Figure 1.1 Obtaining Super resolution from different angles

By using different Low Resolution images, high resolution image is obtained, this is super resolution processing technique. There may be minor variations in these low resolution images. Often these differences are due to minor camera movements. One of the low-resolution photos is selected by taking as a referance. Other photos assume half pixel shift in Diagonal, Vertical and Horizontal directions. The pixels of the first image is separated from the pixels of the other three images with a gap in between, resulting in an image whose resolution is doubled in both directions. This situation is shown in Figure 2.2.

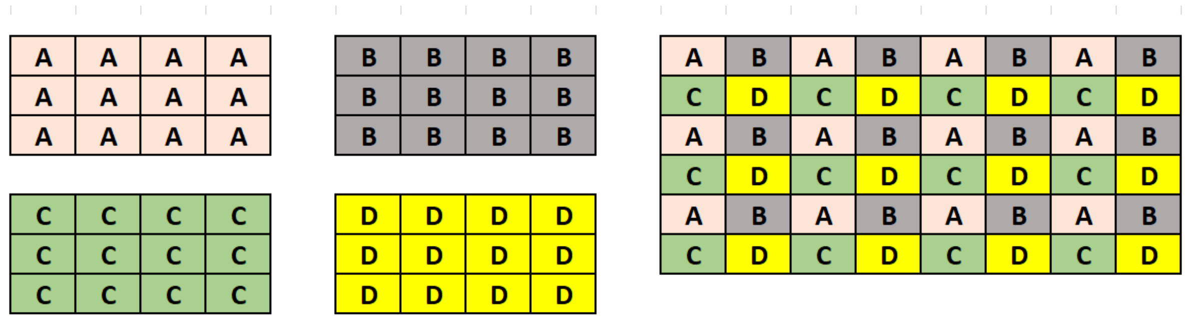


Figure 2.2: Ideal Super Resolution Rendering Technique

However, the amount of shift between images is usually not half the size of a pixel and can take arbitrary values. However, in many applications this motion information is not known, so it has to be calculated first.

When saving a digital image, resolution loss occurs due to the following factors:

Captured images may have problems such as optical defects or blurred photos or noise in pictures because they were taken in motion. Image restoration techniques are applied to correct imperfections before these images achieve super resolution.

The repair problem to be used in super resolution rendering technique is well defined in image processing applications. The purpose of image repair operations is to remove effects such as noise and blur from the image (improvement of the image). But in these techniques, there is no change in the dimensions of the image. In fact, image restoration and super-resolution image acquisition techniques are theoretically similar. But in the super resolution technique, the dimensions of the image are enlarged. With this feature, the super-resolution image creation technique can be called the second generation problem of the image repair technique.

One of the techniques used to create super-resolution images is to increase the size of the image by interpolation. Although there are well-known interpolation techniques, the quality of the image obtained using a low-resolution image is limited. High-frequency components lost when acquiring low-resolution images or overlapping effects resulting from sampling cannot be eliminated by interpolation techniques alone. Therefore, interpolation 16 techniques alone cannot be considered as super-resolution rendering techniques. In the super-resolution rendering technique, Higher resolution pictures of the same scene can be created with the information obtained using different pictures.

2.1. Alignment of Images

Image alignment is the superimposition of different photographic images of the same scene. But these photos were taken from different angles, different sensors, different cameras and at different times. It is not possible to develop a single method that can be applied to all alignment operations because the images to be aligned vary widely and the image defects that may be encountered can be very different. Each method must consider the geometrical distortions between images, as well as radiometric distortions and the effects of noise. The vast majority of alignment techniques involve four steps. These steps are also shown in Figure 2.3:

a) **Determination of Attributes:** The features that distinguish the attributes from each other are determined automatically. These differences are Perimeter, Corners, Crossing Lines, borders, etc. factors. Going a step further, these features can be represented in the literature by points called control points (CP). These points are usually center of gravity, endpoints for lines, easily distinguishable points, etc. as selected.

b) Comparison of Features: In this step, the similarities between the specified features of the reference and observation images are determined. Many attribute descriptors are used for this.

c) Estimation of the Transformation Model: The type and parameters of the mapping function used to align the reference and observation images are determined. These parameters are calculated using the similarities between the attributes determined in the previous step.

d) Resampling the Image and Performing the Transformation: In this step, the observation image is moved to the new coordinate values (transformed) using the mapping function. Overlapping images are completed by interpolating values that do not correspond in the coordinate axis.

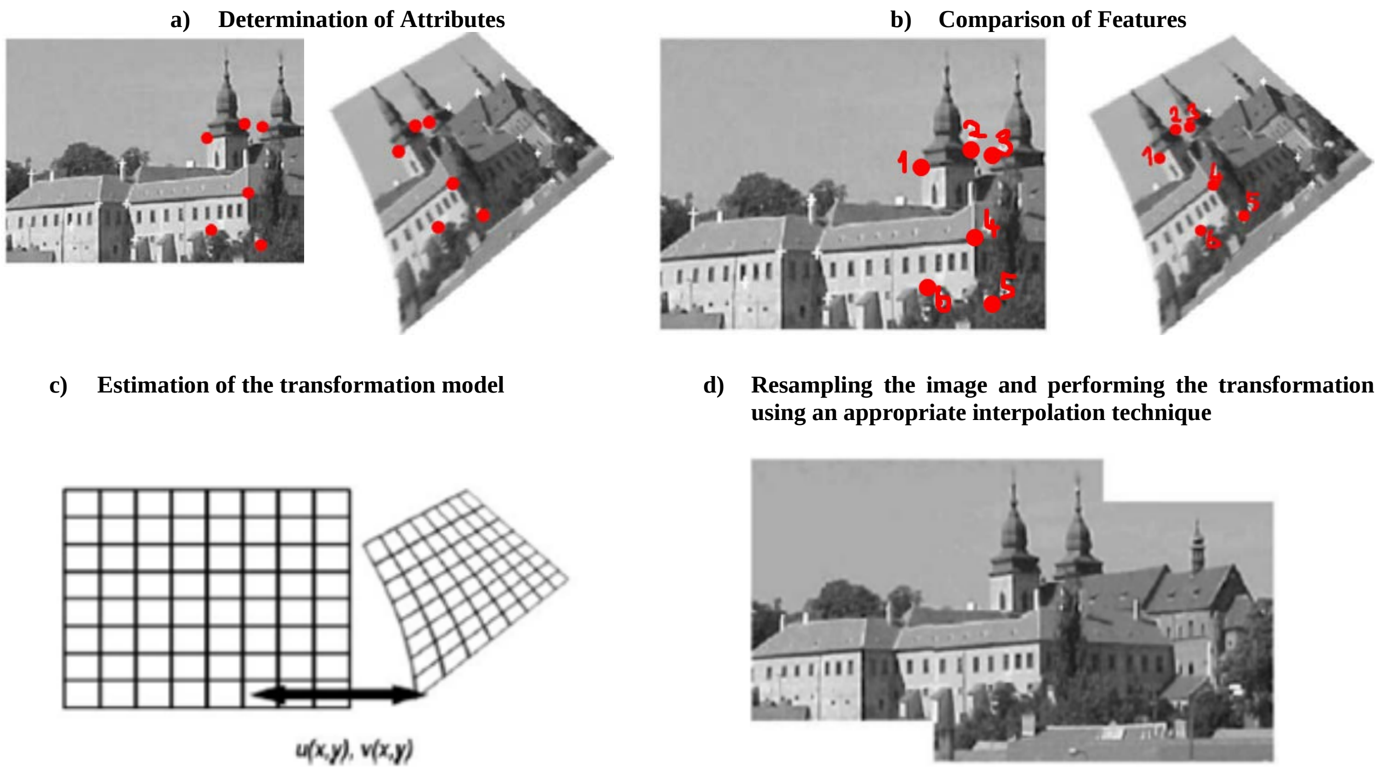


Figure 2.3: Alignment techniques

3. METHODS

The details of the use of super resolution methods are explained in this section.

3.1. Creating a Super Resolution Image

There are many proposed methods to create super resolution images in the literature. The main ones are:

- Non-Uniform İnterpolation Technique,
- Frequency Domain Approach,
- **Projection onto Convex Sets,**
- Deterministic And Stochastic Approaches,
- **Iterative Back Projection Technique,**
- Adaptive Filtering Approach

In this section, the advantages and disadvantages of the non-uniform interpolation technique, the Frequency domain approach then compare on pictures for Iterative Back Projection Technique and Projection onto Convex Sets are explained.

3.2. Non-uniform Interpolation Technique

One of the most intuitive Super Resolution methods is The non-uniform interpolation technique. It consists of three stages and these stages are shown in Figure 3.1:

i. Prediction of relative motion, e.g. alignment of images (if motion information between images is not clear)
ii. Generating a resolution-enhanced image with non-uniform interpolation
iii. Blur removal phase

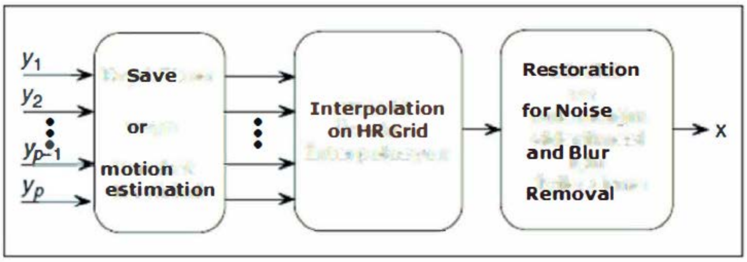
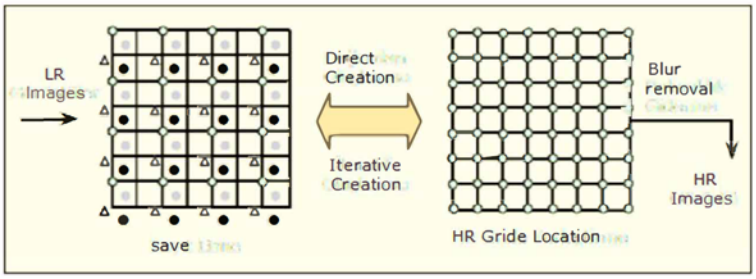


Figure 2.1: Super Resolution Rendering Diagram with Non-uniform Interpolation Technique

The sequential execution of these operations is shown in Figure 3.2:



3.2 Alignment, Interpolation, and Image Reconstruction Operations in Nonuniform Interpolation Technique

Pixels of the High resolution image calculated using the Relative Motion information are placed in the Grid with high resolution. At this stage, the distance between these points is not equal and they do not show a uniform distribution. Using direct or iterative reconstruction techniques, this non-uniformly spaced set of points is placed evenly on the high-resolution grid. After creating a high resolution image as a result of non-uniform interpolation, image enhancement techniques are used to remove blur effects and remove noise. Any deconvolution technique involving noise removal can be used to improve the image.

The result of a simulation performed using this technique is given in Figure 3.3. In the example below, 4 low-resolution images were created as a result of the 256 x 256 image, subsampling with vertical and horizontal directions.

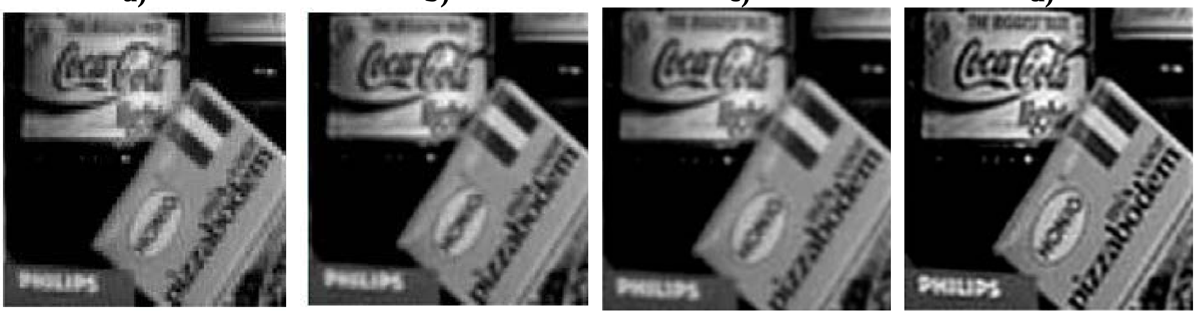
In Figure 3.3, The nearest neighbor interpolation applied to the low resolution image shows in (a).

The bilinear interpolation technique applied to the low resolution image is shown in (b).

The non-uniform interpolation of four low-resolution images is shown in (c).

The image obtained in (c) is blurred using the Wiener filter, shown in (d).

a) **b)** **c)** **d)**



3.3 Nonuniform Interpolation Super Resolution Rendering

The most important advantage of super-resolution image generation technique with non-uniform interpolation is its low processing complexity. Thus, this technique allows real-time applications to be implemented. However, in this model, it is assumed that all low-resolution images are subject to the same characteristic blur and noise. Also, there is no guarantee that this algorithm will give an optimal result. Because the image enhancement stage ignores the errors made in the interpolation stage and only offers improvement in terms of blur and noise.

3.3. Frequency Domain Approach

To obtain a high resolution image, overlap in Low resolution images is used in the Frequency domain approximation. Relative motion information between Low resolution images is used to establish a connection between a low resolution image and a high resolution image. The frequency domain approach is under three headings:

- The translation property of the Fourier transform,
- Overlapping relationship between the CFT and DFT of the high resolution image,
- High resolution image, limited band image,,

These features listed above allow the DFT coefficients (exposed to overlap) of the observation images to be correlated (with a system equation) with the CFT samples of the image that is trying to be obtained. In this study, a new perspective has been brought to the frequency domain approach, and in addition to the translation feature of the Fourier transform, the case where the observation images are rotated relative to each other is also examined. The estimation of the rotation angle is a more difficult process than the estimation of the translation amount, and different approaches have been presented in the literature for this process. In this study, a new approach is presented in calculating the rotation angle, and then its performance is analyzed on different images. Then, the performance analysis of this approach has been made and a new approach has been introduced that accelerates the algorithm. In addition, an examination was made for images that were exposed to the effect of overlapping, and super-resolution images were obtained from them (with certain constraints). Since these approaches are examined in detail in the study, the details of them are explained in the following sections.

3.4. Projection onto Convex Sets

The Projection onto Convex Sets method solves the problem of super-resolution by defining some limitations. These constraints should accommodate some candidate solutions. The Projection onto Convex Sets method aims to reach a solution that does not violate the boundaries of the observed low-resolution images. The Projection onto Convex Sets method finds alternative solutions for each pixel value that satisfies both convex sets, i.e. the observed low-resolution images. Stark and Oskui did a study on this. They used the proximity and convexity of the constraint sets to distribute the images among the clusters and achieved convergence. Tekalp, Özkan and Sezan developed a more powerful Projection onto Convex Sets method. The Projection onto Convex Sets method is a simple and effective method. In the solution area, the a priori constraint, which is the frame of reference, is determined first. The reference frame is included in the high-resolution copy, thus obtaining an initial estimate. After that, the iterative process starts and goes through every frame and pixel looking for the solution. The steps of the Projection onto Convex Sets method are as follows. First, the images are recorded and the coordinate values of each pixel are taken. Pixels should be thrown into the high-resolution area. To do this, the Gaussian function is applied to each pixel. This way we have a solution for each image in the array. In the next step, these solutions are joined by the intersection of the sequences. Each pixel has a value unique to that array found in the previous value. Existing estimates are then expanded to fit the solution sequence. With the completion of these operations, the first iteration is completed. The solutions are normalized to [0,255] and thus the newly obtained high resolution image is ready.

$$X^{n+1} = P_m P_{m-1} \ldots P_2 P_1 X^n$$

X^0 is the optional starting point and P_i is the initialization operator that assigns an optional x signal to closed convex arrays (Ci). Yk[m1, m2] for each pixel in low resolution images.

$$r^{(x)}[m_1,m_2] = y_k[m_1,m_2]$$

$$r^{(x)}[m_1,m_2] = y_k[m_1,m_2] \ {}_{n_1 n_2} x[n_1,n_2] \ Wk[m_1,m_{2;}\, n_1,n_2]$$

$$C_d^{k\,)}[m_1,m_2] = \{x[n_1,n_2]: | r^{(x)\,)}[m_1,m_2] \leq \delta_k [m_1,m_2]\}$$

3.5. Iterative Back Projection Technique

In this method, the difference between the low resolution images is reflected back to calculate the high resolution image and thus the high resolution image is calculated. This process is repeated until, for example, the error is minimized or the maximum allowed number of iterations is reached, that is, until the desired value is achieved.

Iterative Back Projection is an efficient, iterative method to reduce error. This method can be used to combine another constraint representing a desired property of the solution, or constraints such as smoothness. In the Iterative Back Projection method, the process first starts with the input low resolution image. The first high resolution image is created from the input low resolution image, significantly reducing the pixels.

The first image is downsampled, thus creating the observed low resolution image. The simulated low resolution image is subtracted from the analyzed low resolution image. The high resolution image is computed by back reflecting the error of the observed low resolution images and with a high pass filter for edge projection and simulated. By repeating this situation, the error is minimized. Figure 2.1 shows the block diagram of the IBP algorithm. Mathematically, the SS steps are as follows according to the IBP algorithm:

$$X^{(n+1)} = X^{(n)} + X_e + HPF(X^{(0)})$$

In this formula, $x^{(n+1)}$is the calculated high resolution image of n+1 iterations. $X^{(n)}$ is the calculated high resolution image of n iterations. Xe is bug fix. HPF($X^{(0)}$) is the high frequency data of $X^{(0)}$ obtained from interpolation of the initial low resolution image.

High resolution images are downsampled to calculate Low Resolution images in the Iterative Back Projection Technique. Images may be distorted when downsampling. Gaussian filter is used to remove these distortions. As a result, this Low resolution image error operation can be summarized with the formula.

$$X_e = (y-y^{(n)}) \uparrow s$$

$\uparrow$ error occurred during calculation is denoted by X_e, subsampling is denoted by s, low resolution image of iteration shown is n, basic input notation y, $y^{(n)}$, input is low resolution image, The simulated downloaded version would look like this:

$$y^{(n)} = (X^{(n)}*W) \downarrow s$$

$\downarrow$ s is subsampling; The simulation of $y^{(n)}$ n repetitions worked in the run; W is the reduction function; $x^{(n)}$ is the calculated high definition run of n iterations; The last step is as in the high definition equation $X^{(n+1)} = X^{(n)} + X_e + HPF(X^{(0)})$ as in the X_e state Project.

The Robust super resolution method is a more powerful version of the Iterative Back Projection method. The only difference with the lterative Back projection algorithm is in the calculation of the gradient. In this method, the gradient with the median of all errors is calculated.

3.6. Image Recording Methods

3.6.1. Vandewalle Method

The Vandewalle Method converts a change in space to a linear change during the Fourier transform of the image. This method was developed at the École Polytechnique Federale de Lausanne University. Similarly, a spin in the space domain can be seen in the amplitude of the Fourier transform. In short, the Vandewalle algorithm calculates the Fourier transform of the images and determines the 1-dimensional changes in their amplitude and phase. By removing high-frequency components, it prevents distortions that may occur in the image. Thus, the strongest aspect of this method is that it prevents image disturbances.

3.6.2. Marcel Method

Most frequency domain recording methods are based on the fact that two shifted images differ in the frequency domain by only one phase shift. This fact can be found from the correlation of the two images. Using the log-polar transformation of the magnitude of the frequency spectrum, the rotation and scale of the image can be converted into horizontal and vertical shifts. This can be calculated using the phase correlation method. This planar motion calculation algorithm was developed by Reddy and Chatterji and Marcel.

3.6.3. Keren Method

This algorithm is calculated using one and more downsampled versions of images. First, it calculates the rotation and shift of the 4-times downsampled versions of the images using the Taylor series. This process is also done on the 2 times subsampled version of the images. With this process, the rotation and shift values of the images become more. And finally, the same process is applied to the original images. Thus, Calculations are optimized. The same operations are performed using the twice downsampled version of the images, thereby slightly improving the shift and rotation parameters. At the end, the same operations are applied to the original images and in this way the calculations are optimized.

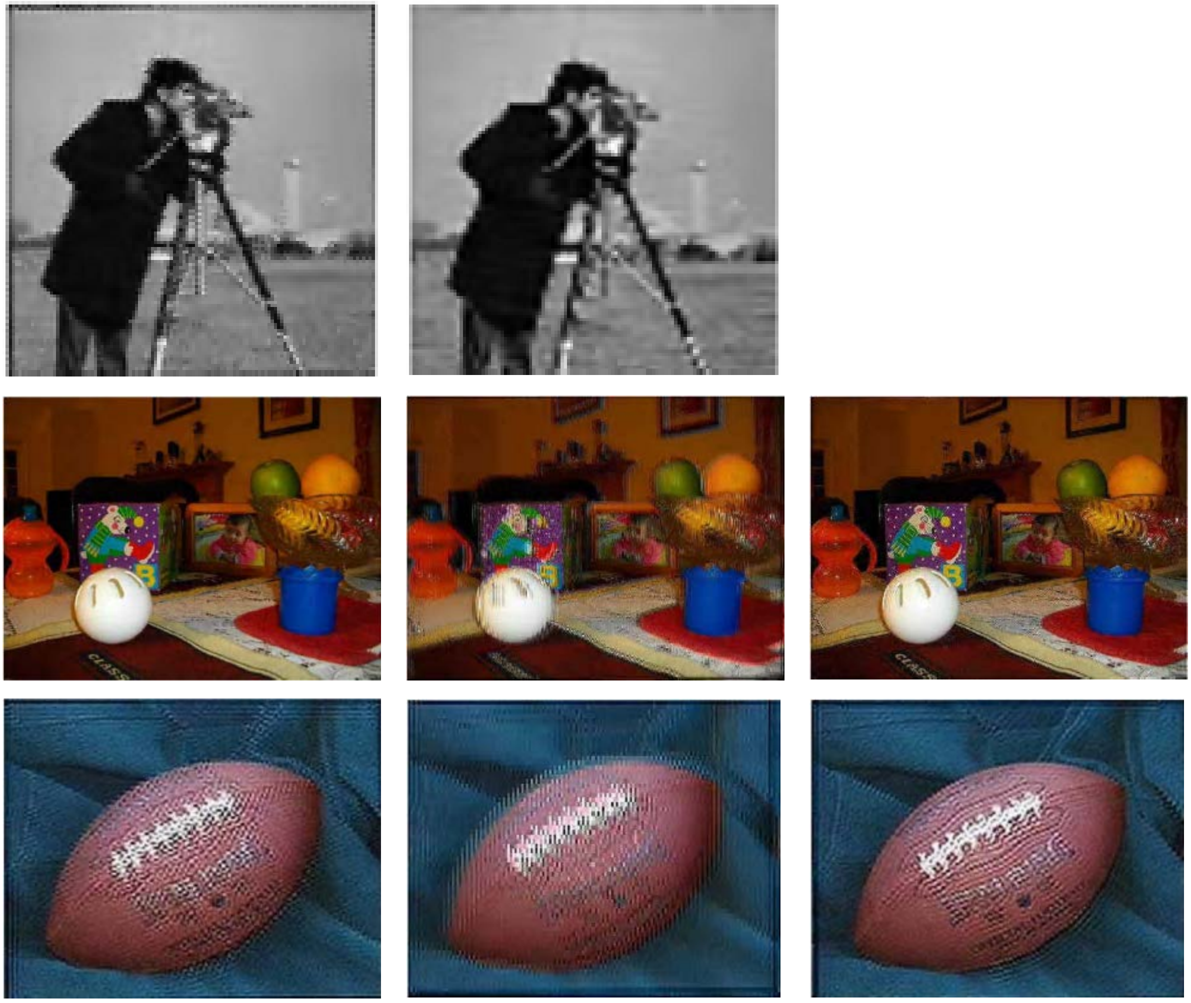
4. RESULTS

Projection onto Convex Sets

Vandewalle Marcel Keren

Figure 4.1. Image results with POCS algorithm, Vandewalle, Marcel and Keren recording methods.

Iterative Back Projection



Vandewalle Marcel Karen

Figure 4.2. Super Resolution image results with Iterative Back Projection Super Resolution algorithm, Vandewalle and Marcel recording methods, respectively.

Results for comparing numeric SSIM values for Cameraman image

	Vandewalle	Marcel	Keren
IBP	0.4658	0.4481	/
POCS	0.6604	0.6308	0.6289

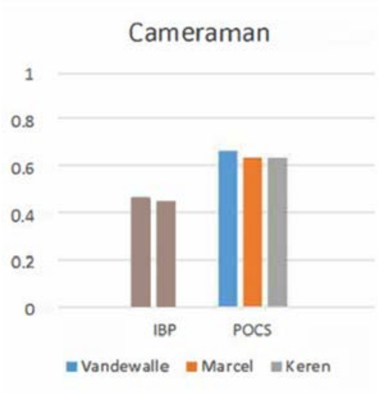
Results for comparing numeric SSIM values for Toys Flash image

	Vandewalle	Marcel	Keren
IBP	0.8462	0.7606	0.871
POCS	0.9155	0.9155	0.9155

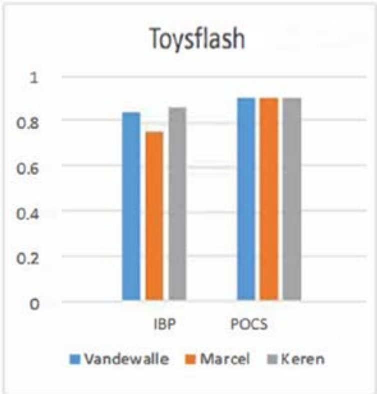
Results for comparing numeric SSIM values for Football image

	Vandewalle	Marcel	Keren
IBP	0.7621	0.7427	0.7849
POCS	0.8928	0.8886	0.8886

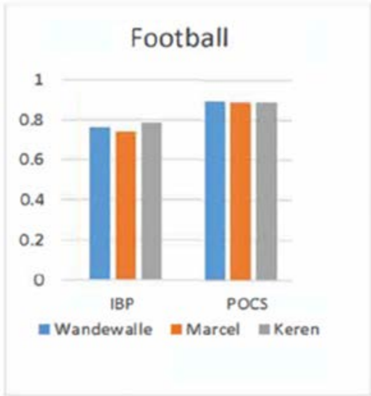
Graphical comparison of Super Resolution methods for camera



Graphical comparison of Super Resolution methods for Toysflash



Graphical comparison of Super Resolution methods for Football



5. Conclusion

High resolution pictures are obtained by using low resolution images taken from different angles and different devices. This is called Super resolution. In order to achieve super resolution, it was observed that the motion and rotation calculations between the images before merging the images are the key elements to achieve good performances at super resolutionThere are different algorithms and methods for super resolution. Among these image recording methods and super resolution methods, those that are more used in the literature were selected and tested with three different images to compare their performance on them.

The methods used for the examples were Vandewalle, Marcel and Keren methods, respectively. The methods used for super resolution are Iterated Back Projection and POCS, respectively. As a result, 3 different pictures were used and the results were shown in a Picture and Numerical table. When a comparison was made between the methods based on the visual and numerical results in the results obtained, Keren from the image recording methods and Projection onto Convex Sets from the super resolution methods were found to be the most successful.