# FEATURE MATCHING BASED ROBUST IMAGE MOSAICING USING OPTIMIZATION ALGORITHM AND POSTPROCESSING

## DISSERTATION-II

*Submitted in partial fulfillment of the*

*requirement for the award of the*

*Degree of*

**MASTER OF TECHNOLOGY**

**IN**

**Electronics & Communication Engineering**

*By*

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# CERTIFICATE

This is to certify that the Dissertation titled "**Feature matching based robust Image Mosaicing using Optimization algorithm and Postprocessing"** that is being submitted by **Jyoti Patel** is in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY, is a record of bona-fide work done under my guidance. The contents of this dissertation, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

**Dr. Sarabpreet Kaur**

**Supervisor**

**Lovely Professional University**

**Examiner I** **Examiner II**

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# DECLARATION

I, Jyoti Patel student of M.Tech (ECE) under Department of Electronics and Communication Engineering of Lovely Professional University, Punjab, hereby declare that all the information furnished in this dissertation report is based on my own intensive research and is genuine.

Date**:** **Jyoti Patel**

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Certified that the above declaration made by the students is correct and best to our knowledge and belief.

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# ABSTRACT

This research works presents an efficient robust image mosaicing technique based on SURF (Speeded-Up Robust feature). The leading contribution of the proposed work lies in the primary detection of features using SURF feature detector and descriptor. This step plays an important role as it detects the robust features and then describes the detected features further for matching purpose. For image registration frequency based approach has been used. The proposed approach is global, has robustness to noise and computationally efficient and this is only possible from the shift property of the FT (Fourier Transform) and use of FFT (Fast Fourier Transform) routines for the speedy computation of correlations. The Fourier method differs from other registration strategies because they search for the optimal match according to information in the frequency domain. The registration process is followed by Homography computation which is achieved using RANSAC (Random Sample Consensus algorithm) algorithm. In this the unwanted matching pairs are completely discarded in order to reduce the complexity. Lastly alpha blending technique is applied which marks a smooth transition between the images. It produces the mosaiced image with larger field of view which is perfectly seamless. All the experimental results obtained conclude that the proposed technique produces better mosaiced image in less computational time with better performance evaluation parameters.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| **FFT** | Fast Fourier Transform |
| **SIFT** | Scale Invariant feature transform |
| **SURF** | Speeded-Up Robust Features |
| **2D** | Two Dimensional |
| **FOV** | Field Of View |
| **RANSAC** | Random sample Consensus |
| **BBF** | Best Bin First |
| **IMM-UKF** | Interacting Multiple Model- Unscented Kalman Filter |
| **MVSC** | Mean Value Seamless Cloning |
| **MRI** | Multi-Resolution Imaging |
| **CT** | Computerised Tomography |
| **LPU** | Lovely Professional University |
| **MATLAB** | Matrix Laboratory |
| **SSD** | Sum of square differences |
| **DoG** | Difference of Gaussian |
| **3D** | Three Dimensional |
| **FT** | Fourier Transform |
| **FFT** | Fast Fourier Transform |
| **IFFT** | Inverse Fast Fourier Transform |
| **PSNR** | Peak Signal to Noise ratio |
| **RMSE** | Root Mean Square error |
| **SSIM** | Structural Similarity Index Measurement |
| **MI** | Mutual Information |
| **NAE** | Normalized Absolute error |

# CHAPTER 1

# INTRODUCTION

Image mosaicing has wide applications in real time. It is the process of joining small images of the same scene which may be clicked at different times, or with different cameras, or illumination variation and produces the image with bigger view. All the information from small images which are stitched together produces image which depicts better understanding by summing up all the information contained in those images [1]. Key point is that the images which are to be stitched should have certain percentage of overlapping regions and they should too have similar exposures, if not it will not give appropriate output.

## 1.1 Overview

"**Mosaic**" originates from an old Italian word "**mosaico**" which means a picture or pattern produced by arranging together small pieces of stone, tile, glass etc. The input images which are to be stitched can minimum be two or more than that and it is better understood from the geometric relationship between them. Panorama contains the combination of many small images. Image mosaicing is a growing field in the research area due to its potential and scientific abilities. Image mosaicing process enables to increase the field of view clicked from camera without variating the original resolution. The resultant image is the mosaiced image with a field of view greater than that of a single image. Major steps involved in image mosaicing procedure are feature extraction, image registration, image stitching, image warping and blending. For image stitching, methods should have nearly exact overlapping regions and identical exposures to produce seamless results [2].

In feature extraction desired features from the input images are extracted. The process of feature extraction from the input images decreases the quantity of available resources required to represent the huge set of data.

Image registration is required at the time of matching process after feature extraction. Registration is the most important task of image mosaicing procedure. Basically it is the geometrical alignment among the given set of input images. This set can be two or more than two images of the same scene, clicked at different time instants, from different viewpoints or from different sensors or cameras [3]. In the process of image registration one image is designated as the reference image and geometric transformation is applied on the other image which is to be mosaiced with so that in a common reference frame all the three transformation, comparison and analyzation can be done together [4].

Registration methods can be categorized into following classes:

- Region based matching: The algorithms which are based on region uses the values of the pixel from the images directly. Good example is correlation methods.
- Frequency based matching: The algorithms which are based on frequency matching completely works in the frequency domain. Example for this can be any Fast Fourier Transform (FFT) based methods.
- Features based matching: The algorithms which are based on features matching extract the low level features from images which can be either corners or edges. Example is feature based methods [5].
- Another algorithm which is based on extracting all high level features from images like image objects present in the image. Example can be the graphical methods.

The third step of image mosaicing is homography. Two different spaces present can be mapped with the homography. In simple terms when homography is computed in each and every pixel of the existing image, the new image is generated which will be called as the warped form of the existing one [6]. Homography is possible under certain valuable conditions like: the input images taken should be clicked at two different angles but from the same camera and the input images taken from two different angles should focus the same plane. It is the process or removing unwanted corners not falling in the overlapping region of the input images.

Image warping is the process of correcting all kind of distortions. Distortion can be like any shapes noticed in an image [7]. So this process overcomes all kinds of distortion and along with this it is also used for various innovative tasks. Warping is broadly divided into two: forward warping and inverse mapping. Inverse mapping is preferred over forward mapping.

Image blending is the final step of image mosaicing. The use of blending removes the seam line that is visible after mosaicing. All the color pixels which completely fall in the overlapping region between input images are mixed properly to generate a blended image. The result will be an image having no such seam line in it [8]. Blend modes are used for blending which mixes the two layers perfectly within each other. In general the procedure is shown below in Figure 1.1

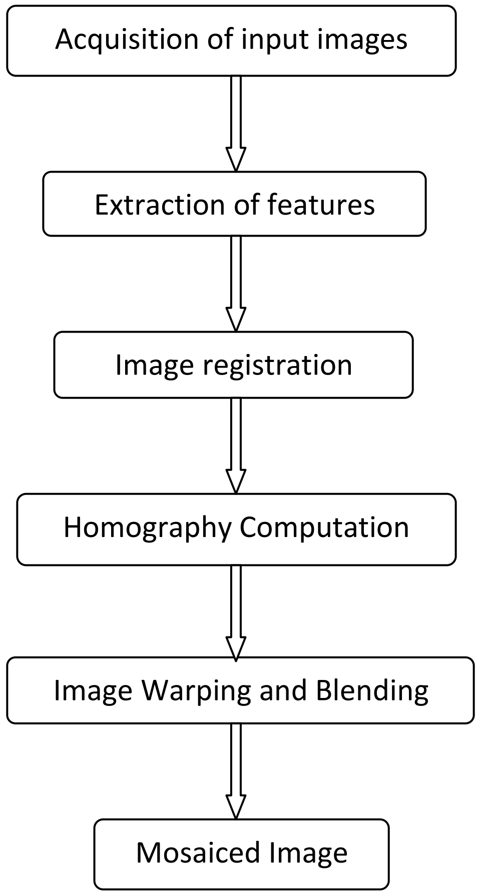



Figure 1.1 General flow chart of image mosaicing

It is always not possible to cover the entire large scene or very big documents all together in a single click, great example for this can be scanners, Xerox machine which cannot capture all the information at once in a single stretch. Output of all these are the splitted documents with small information in it. So mosaicing procedure joins all the different documents containing small information all together into a single image which reflects the entire information [9]. It gives the bigger field of view when mosaiced. Panorama images which are stitched version give better view and also give pleasant and soothing aesthetics of the entire scene [10].

Some applications of image mosaicing are as follows:

1. Reconstruction of 3 Dimensional images.

2. Creating panoramic images.

3. Video compression.

4. Military automatic target recognition.

5. The mosaic of satellite remote sensing image.

6. Medical imaging.

7. Meteorological and environmental monitoring.

8. Geological survey, sea bottom surveying.

9. The digitized saving of file.

10. Image mosaicing for Tele-Reality applications.

## 1.2 Types of image features

In general features are the distinct objects which are present in the input images. In almost many algorithms of computer vision the first step is to extract features and start with it. The algorithm is good only and only if it has got good feature detector. Feature detector repeatability is one of the desired properties [11]. The different types of image features are as follows:

### 1.2.1 Edges:

Edge points are the pixels at or around which the image value goes a sharp variation. It can be step edge, roof edge or ridges edge. Towards one specific direction the gradient is high and the direction which is orthogonal to it will have low gradient [12]. Whenever there is sharp change or variation in the brightness of image it depicts edges. Edges are one dimensional.

### 1.2.2 Corner points:

Corners or it can also be called as interest points are also treated as one of the good features of an image. Unlike edges corner points are two dimensional. Initially the algorithms were particularly designed for the detection of the edges but later noticed that at certain corners, edges have got sharp variation. In this case the algorithms based on edge detection do not work and there was a need for algorithm for corner detection. As already mentioned corners are also called as interest points but traditionally or locally known as corners.

### 1.2.3 Blobs/Regions of Interest points.

Corners are more point like features, but blobs provide complementary description of image features called as regions. Blob detectors detect areas in an image which are too smooth that can be detected by a corner detector. There exist various algorithms for blob detection [13].

## 1.3 Image mosaicing algorithms

Different image mosaicing algorithms are either based on edges, corners or blobs and are used very frequently in image mosaicing. Most approaches in image mosaicing should have certain good percentage of overlapping regions between the input images and also should have similar exposures [14]. These two are the necessary requirements for producing perfect seamless output image.

### 1.3.1 Harris Corner Detector

Harris corner detector is a technique given by Chris Harris & Mike Stephens in the year 1988. Harris and Stephens improved the earlier existing moravec’s operator. Moravec corner detection algorithm came before Harris corner detection algorithm and the main problem with the moravec’s operator was that if the edge detected was not in the same direction as their neighbors, then by default still that edge would be considered as the interest point.

Harris is a point feature extracting algorithm which is based on the detection of random corner points. The matching points in successive frames of image are needed to be matched as per moravec said, but here actual need was to detect the corners and edges in those successive frames [15]. So Chris Harris & Mike Stephens proposed corner detector which overcomes all the drawbacks occurred in the moravec operator. This Harris detector is desirable in terms of repeatability and detection but takes more computational time. This algorithm is widely used in spite of high computational demand.

### 1.3.2 SIFT (Scale Invariant Feature Transform)

This SIFT (Scale Invariant Feature Transform) is an algorithm proposed by David Lowe, University of British Columbia in the year 1999. It is a feature detection algorithm. The features which are needed to be detected should be identical in other images.This algorithm is both rotation invariant as well as scale invariant. SIFT help us to find key points and descriptors. Key points are the image features. Application includes 3 dimensional modelling, image mosaicing, recognition of objects or gestures, tracking videos, mapping and navigation in robotics field etc [16].

### 1.3.3 SURF (Speeded-Up Robust Features)

SURF (Speeded-Up Robust Features) is a modified version of existing SIFT algorithm but with a different procedure. It is a robust feature detector algorithm first presented by Herbert Bay et al. in 2006. The feature detection process in SURF requires three steps known as: first detection of features, followed by description of the detected feature and at last matching. The features extracted by this way present fixed size and fixed rotation, also show partly in variation in lighting transformation, affinities and projective transformation. It is scale and rotation invariant interest point detector and descriptor. SURF is the modified version of SIFT, infact it is the speed up version of SIFT. The focus of algorithm is more on speeding up the matching step. Unlike in SIFT here the use of Hessian matrix speed up the matching process [17]. It is based on the concept of 2D Haar wavelet responses and the use of integral images efficiently. The standard version of SURF is much faster than SIFT and more robust against different image transformations than SIFT. The various applications are automatic object tracking, motion based segmentation, stereo calibration, robot navigation etc.

## 1.4 Problems Encountered in Image Mosaicing

There are various problems which may occur during the process of image stitching. This problem results in unrealistic mosaiced images. Some of the problems which commonly occur have been discussed below.

1. Global alignment: It comprises the calculation of transform and with the help of this the input images are aligned. If the images are not aligned in a proper way or series it may generated the deformed image.

2. Local adjustment: Although after getting perfect alignment globally, there still exists some pixels, which do not get align and due to this particular reason there is effect of ghosting or blurring in the blended image.

3. Image blending: Using the image homography one image out of the two input images has been transformed. Overlapping region which occurs between the input images has to assigned appropriate color and the decision of color is very important in blending.

4. Auto exposer compensation: Now a day's most of the cameras have a benefit of automatic exposer control. So there may be a chance that when there will be a brightness variation in the overlapping region, it will reflect the unreal mosaiced image which is not soothing and unrealistic.

# CHAPTER 2

# SCOPE AND OBJECTIVE

## 2.1 Scope of study

Image mosaicing is one of the interesting fields. Various interesting future research work is based on the same. The mosaiced image which is to be produced should be perfectly seamless. It can be based on any existing technique or some proposed innovative method. Different techniques like Harris corner detection, SIFT, SURF, fast method, Graph cut method etc are there and are used in different ways to overcome the possible problems occurring in image mosaicing. The computational complexity can be decreased during extraction of features. Major part of work in image mosaicing involves two images so it can be extended for multiple images. It would be more challenging if the proposed work is based on fusion which will help in stitching the satellite image or aerial images or it can be videos which will be mosaiced quickly. When large number of images are to be stitched there generates cumulative errors especially this problem is seen in the biomedical images e.g. spinal cord, tumors etc. so cumulative errors can be reduced to focus on the desired images more accurately. So image mosaicing has got various scopes on which work can be paid.

## 2.2 Objective of study

Strong vision in human beings allows observing different situations occurring in the world. Human eye has got the FOV (Field of view) which is reachable up to 200x135°. The need is to increase this field of view from 200x135° to 360 x180°, and for this purpose panorama is used. In panorama different images which are stitched got common FOV among them. So in all when finally stitched increases the overall field of view.

Image mosaicing has been an emerging field. Steps involved in image mosaicing are feature extraction, matching of features, image registration, homography computation, lastly followed by warping and then blending. Information which the image contains is like shape, some structure or colour information but these are not only the limited information. Apart from these all there can be a camera movement, images which are clicked can have moving objects or moving person in the particular scene or picture. Different lot image mosaicing algorithms are already in existence. Output for all the algorithms are not always same ,there is always a slight variation in the generated mosaiced output, may be its not visually observable but based on performance metrics one can differentiate it clearly.

The main objective of this research work is to propose such a methodology which produces the perfectly seamless mosaiced image. This is obtained by performing following steps:

- Features are extracted using Speeded- Up Robust features algorithm.
- For image registration Fast Fourier Transform technique has been used which increases the computational time.
- Unwanted matching pairs are removed using RANSAC (Random Sample Consensus) algorithm to reduce the complexity.
- Alpha blending technique is used in blending step to produce the seamless mosaiced image.

# CHAPTER 3

# ORGANISATION OF WORK

The entire thesis work is divided into different parts which was planned and moved accordingly. Below there are two tables which represents the amount of work done in which time. On the basis of content the entire work has been mainly divided into two chapters 6 and 7 describing. Chapter 6 includes all the image mosaicing techniques, ways or different algorithms. In this research work mainly three algorithms Harris corner detector, SIFT and SURF have been considered. Chapter 7 includes the proposed methodology and its implementation.

Table 3.1 shows the plan of first half work and next table 3.2 shows plan of the rest of the work for the completion of report.

| S. NO | MONTHS / WORK | Aug 2016 | Sept 2016 | Oct 2016 | Nov 2016 | Dec 2016 |
|---|---|---|---|---|---|---|
| 1. | Study of Harris corner detector and SIFT algorithm | ☆ | ☆ | | | |
| 2. | Study of SURF (Speeded-Up Robust Feature) algorithm and FFT approach. | | | ☆ | ☆ | |
| 3. | Generating results of SURF algorithm | | | | ☆ | ☆ |

Table 3.1 First Half work plan

| S. NO | MONTHS / WORK | Jan 2017 | Feb 2017 | March 2017 | April 2017 |
|---|---|---|---|---|---|
| 1. | Implementation of FFT based approach for image registration | ☆ | | | |
| 2. | Implementation of RANSAC after FFT based registration | | ☆ | | |
| 3. | Comparison of SURF and Proposed Method | | | ☆ | |
| 4. | Report writing | | | | ☆ |

Table 3.2 Rest Half work plan

# CHAPTER 4

# LITERATURE REVIEW

This chapter collectively includes all the research papers which helped us throughout for the presented thesis work. It helped to understand all the different techniques, algorithms and the way of implementing different algorithms according to the situations. The analysis of all the papers has been shown below with description.

Dr N.M Patel et al., in their paper [18] proposed a method of image registration which is based on features extracted using SURF. This paper used primarily SURF for the process of feature extraction, matching process based on sum of square differences and it generates all the matching lines between the input images, for the removal of all false match pairs, they have used RANSAC algorithm, which produces only the required matching lines. In blending step multi band blending has been used in their paper for the proper generation of mosaiced image. Their work is basically to generate the panorama image without the seam line.

Akshay Jain et al., in their paper [19] proposed an image mosaicing technique which used frequency based (FFT) approach. In their paper scheme which is based on correlation has been used and the scheme works in the frequency domain. The main work of the paper is to depict the translational and rotational parameters which are used further in the process of image stitching. This proposed work is applicable for all kinds of light microscopy imaging.

Nan Geng et al., in their paper [20] used optimized SURF algorithm for camera based image mosaicing. This work denotes contribution for real time. In this paper there is the overlapping region which occurs between the reference and the other image which has to be aligned with. Features are extracted from that overlapping area by using rapid matching algorithm called as Best Bin First (BBF), Further RANSAC to eliminate the unwanted matches, which results in the registered image. Then fusion of the registered images occurs with the use fusion algorithm called as evolutional fusion algorithm to generate the mosaiced image. The proposed work of this paper can stitch images which are captured with the web cameras including noise or with variation in lighting.

Stafford michahial et al., in their paper [21] proposed automatic image mosaicing. This automatic image mosaicing uses SIFT algorithm, RANSAC and then computed homography. This paper mainly focussed on major five steps of image mosaicing which includes:

acquiring the input images, registration procedure, homography computation and lastly warping and blending. Features are extracted using SIFT algorithm which is the core of this paper work.

Devi Renuka [22] in this paper phase correlation based image mosaicing is compared with the feature based image mosaicing approach. Both the approaches are entirely different. This phase correlation approach is a featureless registration whereas the feature based is of course based on extracted features. For extracting features used SIFT algorithm is used extracting the key points as descriptors. Both the procedure is different but results to the same as mosaiced image.

Xinbei Bai et al., in their paper [23] worked for Rovers vision navigation. Mainly the comparison of different feature detection and matching algorithms which are used in the Rovers vision navigation is done in this paper. The main focus of the work is on the precision and speed both. Particularly the computation time, number of features extracted, all the matching points and results show that SURF gives the best result out of Harris, SIFT and SURF.

Wibool Piyawattanametha et al., in their paper [24] presented efficient image mosaicing algorithm. Two main challenges in link with image mosaicing which are faced in medical applications on which paper has particularly worked are first scene deformation and other is cumulative errors occurred during image registration. Images are acquired in vivo taken from the hand held dual axes confocal microscope. For scene deformation algorithm based on local alignment is used, or called as local alignment algorithm directly. To work on those cumulative errors generated during registration global alignment algorithm is used. There main work is on scene deformation and cumulative errors.

Shengping Zhang et al., in their paper [25] presented a dynamic image mosaic method based on the combination of SIFT feature detection algorithm and dynamic programming. In this paper a combination of both is used efficiently. The main work is done to remove the effect of ghosting and parallax effect which occur between the adjacent images and with the combination of SIFT and dynamic programming it overcomes both problems. The proposed method of this paper is feasible.

Cindy Cappelle et al., in their paper [26] presented a comparison of Harris, SIFT and SURF features for vehicle geo-localization and it is based on the 3 dimensional model and the camera. For the fusion of data from all the different sensors used algorithm which is used is IMM-UKF (Interacting Multiple Model- Unscented Kalman Filter). The matching is done between the 3D model virtual image and the real image clicked by the camera. The process is broadly divided in two main parts. In first part the extraction of features and matching of those extracted features between both the virtual image and the real image takes place. Pose computation process is the second part which is obtained from POSIT algorithm. This proposed work is experimented on the real sequence and proves its robustness and feasibility.

R.B. Inampudi et al., in their paper [27] presented the design of new software. This software is high performance software whose task is to implement geometrical corrections and also radiometrical corrections. This both corrections are done over only two or more than two images. This work does not involve any hardware entirely. This work is done on the images of retina and the Qutub minar image.

S. Peleg et al., in their paper [28] proposed the manifold projection on images. It creates the mosaic image from the videos, taken under normal conditions. Stitched image is generated using planar and cylindrical manifold together. This proposed method is computationally efficient. The movement of camera does not affect the proposed output.

B. Rouso et al., in their paper [29] proposed the method of producing the mosaiced image in most general cases. The work is on pipe projection, this is used in the very challenging situations, especially in the case of zooming and other the forward motion. The forward motion and zooming is the problematic in the other mosaicing approaches. This method helps in removing the parallax during complex motion.

J. Wang et al., in their paper [30] proposed the image mosaicing algorithm which is the fusion of visual attention model and MVSC (Mean Value Seamless Cloning) algorithm. This proposed method uses the visual attention model to extract the features, followed by standard registration method. The features extracted are matched with the help of image registration which matches the clone of the source with the target one. Hence these both clones are fused together with the help of MVSC algorithm. This results in the good quality mosaiced imge.

Kee Baek Kim et al., in their paper [31] proposed the algorithm image registration which is fourier based. It is build using pyramid edge detection and line fitting together. Image registration is the central task of every image mosaicing procedure. With the help of this algorithm information regarding registration of each sub pixel is obtained, in order to get accurate registration. This is used in various appliactions like Multi-Resolution Imaging (MRI), Computerised Tomography (CT), in weather forecasting etc.

I. Zoghlami et al., in their paper [32] proposed the efficient method to solve the case when the homography is majorly a translation, means around the optical axis the rotation factor and zooming factor both are small. The proposed methodology does not need any kind of human interaction for optical axis rotation as well as large zooming factor.

# CHAPTER 5

# MATERIAL AND EXPERIMENTAL SET-UP

## 5.1 Source of Input images

The camera used for acquisition of the images in the present research work is from Canon camera. The model of camera is Canon EOS 600D. Considered several set of images and each data set contain a pair of images which have certain common region between them. These images are all clicked within the LPU (Lovely Professional University), Phagwara Campus. Images are clicked from the same camera, do not have any illumination variation or scale variation. Images are clicked at various different locations within the campus to give better impact.

## 5.2 MATLAB (Matrix Laboratory)

The proposed work and all the existing algorithms give the mosaiced image as an output. These results are obtained from the implementation of work in Matlab Software. In obtaining these results, particularly we have used Matlab version R2013a. This Matlab is executed over laptop with following configuration as AMD Dual-Core Processor E-350 (1.6 GHz), with windows 7 Home Basic (64-bit), memory of 2 GB.

Matlab stands for matrix laboratory. Cleve Moler started developing Matlab in the late 1970s. He served as the chairperson of the computer science department at the University of New Mexico. His main task behind developing this Matlab was to provide ease to all his students and gradually it became famous software to be used at other universities too. Matlab provides a friendly environment, it is fourth generation high level language computed on Matlab software available in different versions. The latest version of Matlab is Matlab2016. It provides a wonderful platform for all programmers. Math works developed the Matlab software. Matlab enables all programmers to develop their own code work, or enhance the existing one, helps in analysing the given data, to explore new models, various applications and much more. It contains huge in built functions which helps to do coding in the easier way. When comparison comes coding is much easier because of in built functions than earlier existing traditional programming languages like C, C++, Java, FORTAN etc. In Matlab for doing any mathematic calculations there are about more than hundreds of commands in built available. One can plot functions, any kind of equations can be solved and much more innovative work can be done. This software can also be used in the animation graphics field. It has got various tool boxes which can directly be used, toolbox in almost every field is available. It is a very innovative and versatile tool.

# CHAPTER 6

# IMAGE MOSAICING TECHNIQUES

Panoramic imaging and virtual environment has been an interesting and upcoming field for research. It is a growing field with the combination of computer interfacing and brain together to deal with the real time applications. The goal of this research work is to create a script that stitches two images together to create image with larger field of view. This stitched image increases the visual aesthetics of a scene.

Firstly Harris corner detector has been discussed. It is a corner detection algorithm which is very popular and widely used algorithm. Secondly for extracting feature points SIFT (Scale invariant feature transform) has been discussed in detail with all the steps involved within it. Then comes SURF (Speeded-Up Robust features algorithm) which extracts all the desired interest points from the input images. All this algorithms Harris corner detector, SIFT and SURF which have been discussed completely works in spatial domain.

## 6.1 Harris corner detection algorithm

It is a point feature extracting algorithm which is based on the detection of random corner points. Image mosaicing is a method of stitching multiple images together to create one larger image. In this process three steps are involved. In the first step the corners points are detected from the given input images, followed by removing the false matching corner points from input images and third step is to compute homography, matched corner points are detected and finally stitched image is generated.

### 6.1.1 Flow Chart

The flow chart of image mosaicing using Harris corner detector is shown in Figure 6.1

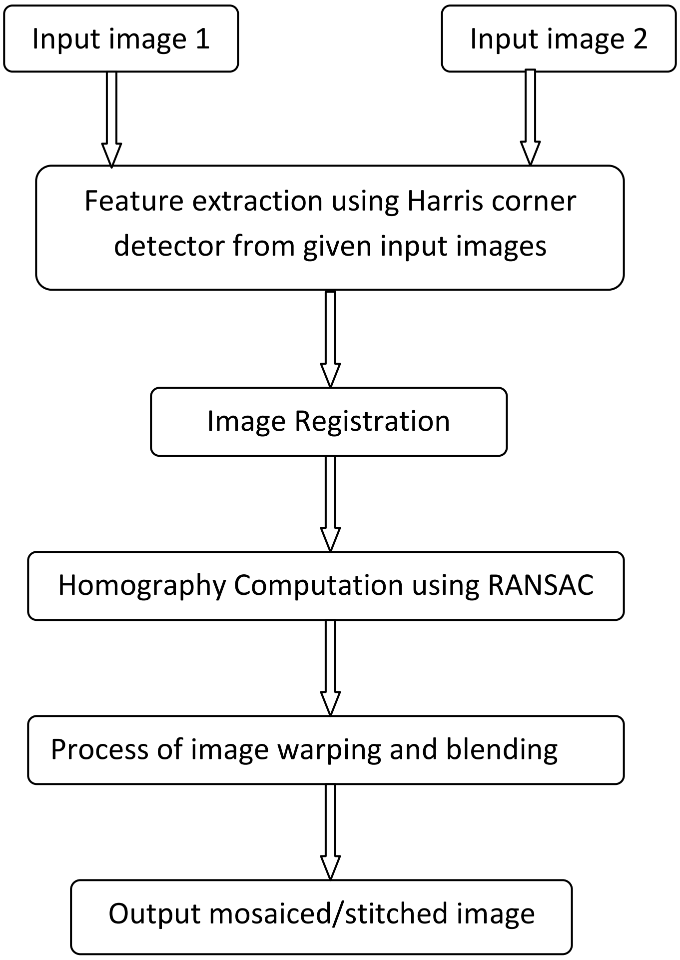



Figure 6.1 Flow chart of image stitching using Harris corner detector

### 6.1.2 Feature Extraction

In simple words features are the salient structures which are observed or extracted from the given images or feature extraction is detection of certain interesting features of an image. Feature can vary or they can be same in the input images. In images the intersection of lines, points, blobs, regions, corners all are understood as features. These features should be there in the input images so that they can be detected during the feature matching stage [33]. One important point to keep in mind is that while conducting an experiment these features should maintain their stability with respect to time, they should remain stable at all time to get the accurate output or results.

#### 6.1.2.1 Harris Corner Detector

Harris corner detector is a detector proposed by Chris Harris & Mike Stephens in the year 1988. This Harris detector is desirable in terms of repeatability and detection but takes more computational time. This algorithm is widely used in spite of high computational demand. The *I (x, y)* be the gray intensity of pixel *(u, v)* and there is shift of *(u, v)* in the gray intensity *I (x, y),* the weighted SSD (Sum of square differences) between the original and the shifted one is expressed as below:

$$E(u,v) = \sum_{x,y} w(x,y)[I(x+u, y+v) - I(x,y)]^2 \tag{6.1}$$

Here *w (x, y)* represents the window function which can be a Gaussian or rectangular window. The center point of the window is extracted as a corner point. Using Taylor series expansion in equation 6.1 it can be approximated as below:

$$E(u,v) = \sum_{x,y} w(x,y)[I_u(x,y)u + I_v(x,y)v]^2 \tag{6.2}$$

In other way, we can write equation 6.2 in the matrix form, considering for small shift *(u, v)* which is as:

$$E(u,v) \cong [u \quad v] M \begin{bmatrix} u \\ v \end{bmatrix} \tag{6.3}$$

Where matrix *M* is calculated from the derivatives $I_x$ and $I_y$ of given image. The matrix size is 2x2 and it is given as:

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x I_x & I_x I_y \\ I_x I_y & I_y I_y \end{bmatrix} \tag{6.4}$$

The image derivative $I_x$ is in *x* direction and image derivative $I_y$ is in *y* direction respectively. Matrix *M* has two large eigen values *λ1* and *λ2* for an interest point. The corner, edge or flat area of an image is determined based on the magnitude of these eigen values which is shown below. The Figure 6.2 shows all the area.

1. If *λ1* and *λ2* both are almost equal to zero, then its flat area.

2. If out of both *λ1* and *λ2* one is smaller and the other larger, then edge is found.

3. If both *λ1* and *λ2* has large positive values, then corner is found.

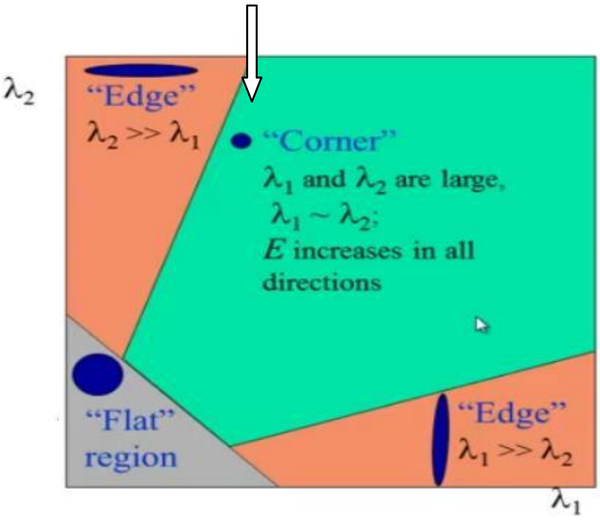



Figure 6.2 Harris Operator

After this there is a need to create a score, which is nothing but a mathematical equation. Based on this equation a decision is taken whether the selected window contains a corner or does not contain.

$$R = \det(M) - k(trace(M))^2 \tag{6.5}$$

For the above equation 6.5, *det* and *trace* are defined based on the two $\lambda 1$ and $\lambda 2$ eigen values as below:

$det\,(M) = \lambda 1\ \lambda 2$

$trace\,(M) = \lambda 1 + \lambda 2$

### 6.1.3 Image Registration

It is the central job of image mosaicing procedure. It is not only the central task but is the foundation of image mosaicing. Image registration involves the procedure of matching between the input images, which can be two or more than two. For different kinds of problem in image mosaicing like in monitoring satellite images, for diagnosis of biomedical images image registration is the problem occurring part. Image registration is applied in vast applications so it is almost impossible to develop a general method which is optimized for all the uses [34]. Reference image is represented as *P1*(*x, y*) and the image to be matched as *P2*(*x, y*), both are 2D arrays. So in image registration *P1*(*x, y*) and *P2*(*x, y*) are related as:

$$P1(x,y) = g(P2(f(x,y))) \tag{6.6}$$

Where $f$ is transform function for coordinates ($x$, $y$). It can be described by three common global transformation models: rotation, affine transformation and perspective transformation model. Affine transformation particularly tells the mapping of a line from the reference image to the image of the same scene to be matched and it keeps balance through this affine transformation model.

### 6.1.4 Homography Computation

In homography the corners which are not of our interest or in particular falling out of overlapping area are removed. For computing homography there exist many powerful robust techniques. One of the most attractive techniques is RANSAC. RANSAC stands for "RANdom Sample Consensus. It is a technique which is very well suited for estimation problems with small no. of parameters and having large percentage of outliers. So how homography is computed using RANSAC has been discussed.

#### 6.1.4.1 Random Sample Consensus algorithm

It is a method to estimate the parameters of a particular model, from a set of data containing large amount of outliers. It is an iterative, non-deterministic algorithm which uses least-squares method to estimate model parameters. The input data of the algorithm is a set of observed data values and a mathematical model that will be matched to the data set and few parameters. RANSAC is an iterative process which iteratively selects a subset from the given data. The steps of the RANSAC algorithm are as follows:

1. Randomly $N$ data items have been selected which detect the parameters of model.
2. Next parameter $x$ is solved.
3. Now from $N$ data items, the data items which fits the model with the above solved parameter $x$ are separated and see whether they fit with the user defined tolerance. Let tolerance be $K$.
4. If the value of $K$ is large, success is achieved and the process stops.
5. Otherwise the steps from 1 to 4 are repeated.

The entire process is repeated for few times. Every time it produces different model, a model sometimes gets rejected because of detection of very less inliers as compared to outliers or a model which contains error measure. The advantage of this particular method is that the percentage of outliers which can be handled by RANSAC can be larger than 50% of the whole data set. One disadvantage of this algorithm is that for computing the parameters there is no bound on time, in case when there is limited iterations, it may not give the optimal results.

### 6.1.5 Image Warping and Blending

In image warping the input images which are to be mosaiced are warped together with the use of geometric transformation. It is the process of mapping of positions from the plane of first image to the plane of second image. Warping is used for creative purposes as well as any kind of image distortion can be corrected with the use of warping. Warping is used in many cases like when there is illumination variation between images, or when images are distorted due to some or other reason. The mapping can be forward mapping or reverse mapping.

- Forward mapping: This mapping is directly applied from the available sources to their associated images.
- Reverse mapping: This mapping is just inverse of forward mapping, in this we map from the image to the associated source.

Out of both reverse mapping is preferred because in this each and every pixel from the second image is mapped to the source image whereas in forward mapping while mapping from the source to the destination image, there are some pixels left which are never mapped and are treated as holes.

Image blending is the method which is applied at the very last step to make the mosaiced image more attractive. With the help of image blending, the seam line is removed making image seamless. In this the gray levels of the image which falls around the boundary of seam line or stitching line is modified, so that a smooth transition is obtained between the joined images and the blended image is originated.

## 6.2 Scale Invariant Feature Transform

SIFT is preferable over Harris because Harris is rotational invariant, rotational invariant means even when image is rotated we can find the same corners. In the rotated image corners remain corners. But corner do not remain corner when the image is scaled. So SIFT algorithm came up in year 2004 which is both rotation as well as scale invariant. It is used for extracting distinctive invariant features so that we can match features from one image to the other image [35]. It is robustness to affine distortion, change in 3D view point, and change in illumination. There are four computational phases involved in SIFT algorithm which is shown below:

### 6.2.1 Flow Chart

The flow chart of SIFT procedure is shown in Figure 6.3

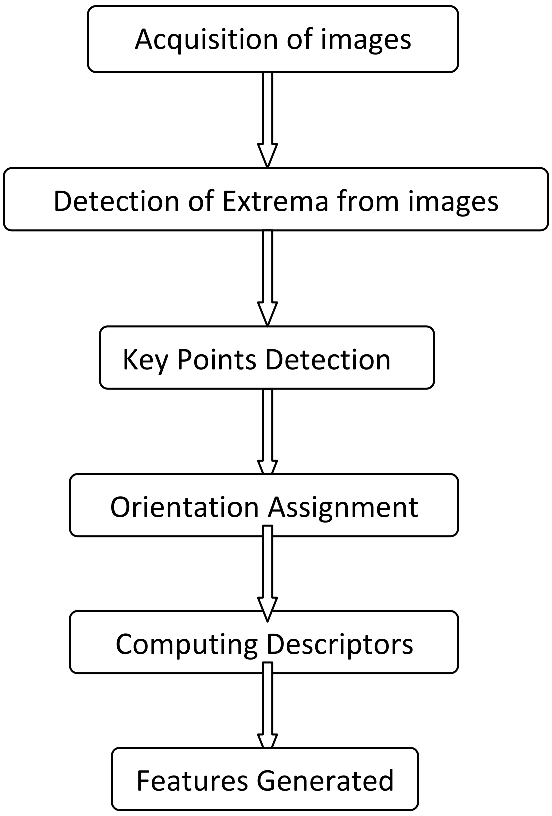



Figure 6.3 Major Phases of the SIFT algorithm

### 6.2.2 Approximate Key point Location

This is the first phase of SIFT. In this DoG (Difference of Gaussian) is used to depict the intensity variation between two nearby scales. DoG is calculated between two different scales as shown below in equation 6.9. The Gaussian relation is given in equation 6.7 below.

$$G(x, y, \sigma) = \frac{1}{2\prod\sigma^2} e^{-(x^2+y^2)} / ^{2\sigma^2} \quad (6.7)$$

In equation 6.8 the convolution operator is the convolution between the Gaussian filter and an image *I*. Scale refers to the $\sigma$ in the Gaussian.

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y) \quad (6.8)$$

So DoG is:

$$D(x, y, \sigma) = (G(x, y, k\sigma) - G(x, y, \sigma)) * I(x, y)$$
$$= L(x, y, k\sigma) - L(x, y, \sigma) \quad (6.9)$$

In the Figure 6.4 it is seen that within an octave, the scales that are adjacently present differ by certain factor *k*, here *k* is referred as a constant factor. In the single octave if it contains $s$+1

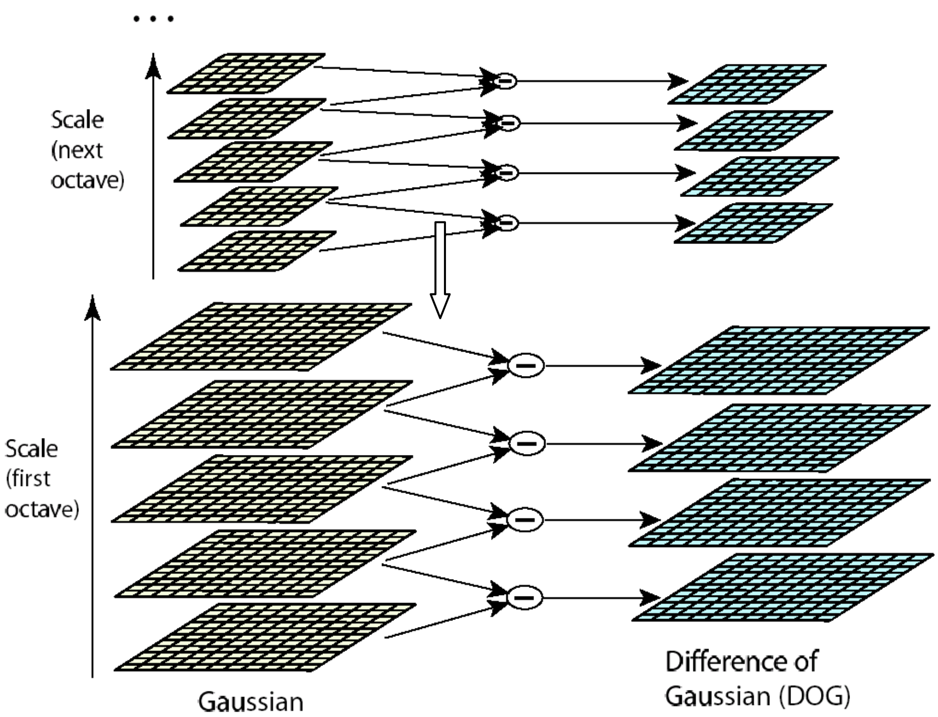
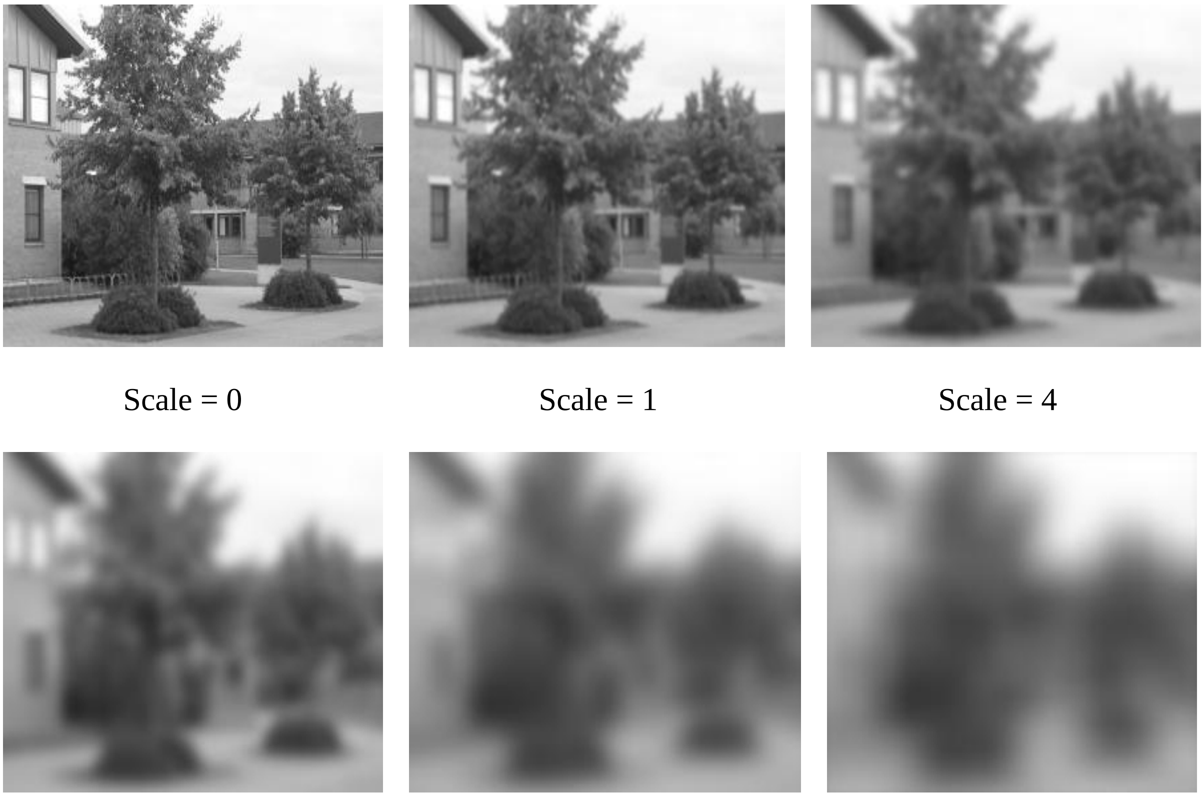



Figure 6.4 Sequence of images forming scale space

image, from this the *k* will be equal to $2_{(1/s)}$ i.e. $k = 2_{(1/s)}$. So $\sigma_0$ is the scale of the first image, similarly it will go further and $k_1\sigma_0$ is scale of the second image, for the third image the scale is $k_2\sigma_0$ and it goes in the same way and lastly the scale for the last image is $k_s\sigma_0$. All this successive images form a sequence of images which is convolved with Gaussians of $\sigma$ increasing constantly and this all together form a space called the scale space. Figure 6.5 shows the same image at different scales.



Scale = 0 Scale = 1 Scale = 4

Scale = 16 Scale = 64 Scale = 256

Figure 6.5 The image at Scale 0,1,4,16,64 and 256

For scale space peak detection, interest points or key points are supposed to be detected. The stack of DoG images forms the scale-space-pyramid. So the interest points are maxima or minima in the entire scale-space-pyramid formed. In Figure 6.6 the pixel is indicated with $X$ which is to be compared. There are 3x3 neighbourhoods on the same scale, above and below, in all we have 26 neighbours. The pixel $X$ is compared with 26 pixels in current and adjacent scales (indicated with round circles). The pixel is selected if it is larger or smaller than all its 26 neighbour pixels.

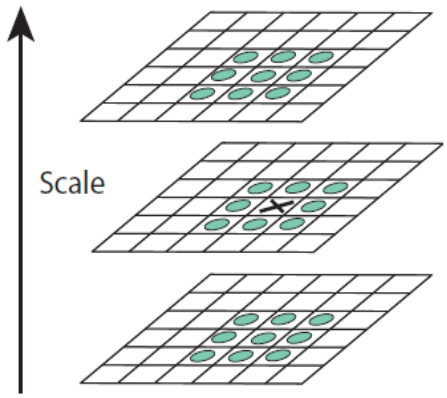



Figure 6.6 Pixel *X* is compared with 26 neighbours in 3x3 regions at the current and adjacent scales

### 6.2.3 Key Point Localization

For localization of key points, the DoG function around the detected interest point ($x_i$, $y_i$, $\sigma_i$) is expressed in the 3D neighbourhood by using second order Taylor Series expansion.

$$D(x,y,\sigma) = D(x_i, y_i, \sigma_i) + \left(\frac{\partial D(x,y,\sigma)}{\partial(x,y,\sigma)}\right)^T_{\substack{x=x_i\\ y=y_i\\ \sigma=\sigma_i}} \Delta + \frac{1}{2}\Delta^T \left(\frac{\partial^2 D(x,y,\sigma)}{\partial(x,y,\sigma)^2}\right)_{\substack{x=x_i\\ y=y_i\\ \sigma=\sigma_i}} \Delta \tag{6.10}$$

Where, $\Delta = \begin{pmatrix} x - x_i \\ y - y_i \\ \sigma - \sigma_i \end{pmatrix}$

The equation 6.11 gives the location of maxima or minima given below:

$$\begin{pmatrix} \hat{x} \\ \hat{y} \\ \hat{\sigma} \end{pmatrix} = -\left(\frac{\partial^2 D(x,y,\sigma)}{\partial(x,y,\sigma)^2}\right)^{-1}_{\substack{x=x_i\\ y=y_i\\ \sigma=\sigma_i}} \left(\frac{\partial D(x,y,\sigma)}{\partial(x,y,\sigma)}\right)_{\substack{x=x_i\\ y=y_i\\ \sigma=\sigma_i}} \tag{6.11}$$

If the value of $D(x, y, \sigma)$ is greater than the threshold (0.03), that key point is removed and it helps to reject it as outlier. For further outlier rejection the key points which lie along the edges are removed. For this purpose the hessian matrix is computed as shown in equation 6.12. It is a second order derivative.

$$H = \begin{bmatrix} D_{xx} & D_{xy} \\ D_{xy} & D_{yy} \end{bmatrix} \tag{6.12}$$

It is assumed that the scale space or DoG as a surface. The eigen values originated from $H$ helps to locate the principal curvatures of the surface. In fact it gives the idea about the structure around particular interest point. Along the edge one of the Principal curvatures will be low but across the edge will be high. So by doing the evaluation as shown in below equations 6.13 and 6.14, the outliers are removed.

$$Tr(H) = D_{xx} + D_{yy} = \alpha + \beta \tag{6.13}$$

$$Det(H) = D_{xx}D_{yy} - (D_{xy})^2 = \alpha\beta \tag{6.14}$$

Sum of eigen values is called trace whereas product of eigen values is called determinant. Now,

$$\frac{Tr(H)^2}{Det(H)} = \frac{(\alpha+\beta)^2}{\alpha\beta} = \frac{(r\beta+\beta)^2}{r\beta^2} = \frac{(r+1)^2}{r} \quad ; \ \alpha = r\beta \tag{6.15}$$

This trace to determinant ratio shown in equation 6.15 should be less than the threshold (10). Eliminate the key points if it is greater than the threshold because those are the unwanted edges. Hence it removes the further outlier.

### 6.2.4 Orientation Assignment

To achieve the orientation assignment the gradient magnitude and the direction of $L$ is computed at the scale of key point $(x, y)$ from the equations 6.16 and 6.17 given below.

$$m(x,y) = \sqrt{(L(x+1,y) - L(x-1,y))^2 + (L(x,y+1) - L(x,y-1))^2} \tag{6.16}$$

$$\theta(x,y) = \tan^{-1}((L(x,y+1) - L(x,y-1))/(L(x+1,y) - L(x-1,y))) \tag{6.17}$$

Orientation for each of the interest point is calculated. Generally for orientation 36 bins are chosen. In Figure 6.7 it is shown that the most dominant orientation becomes the orientation of the key point which is indicated with yellow bar. But when we have multiple same orientations i.e. displayed with two red bars, then for each orientation separate descriptor is created but all will be having same scale and location.

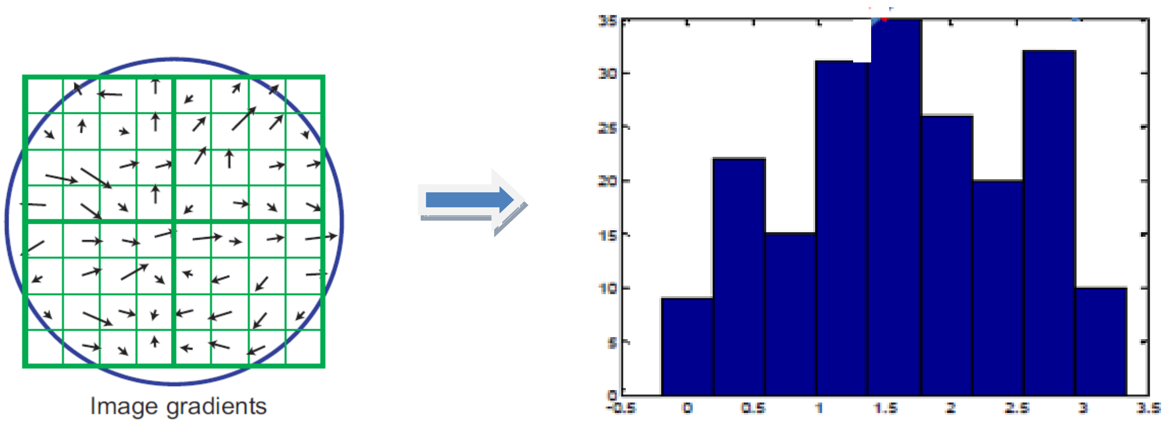



Figure 6.7 Plotted Histogram of 36 bins based on their orientation

### 6.2.5 Key Point Descriptor

The next step is to provide description to the detected interest points. Around particular interest point small region is considered and divide that region into *n* x n cells, generally n is taken 2. Figure 6.8 shows that each cell is of 4x4 sizes. For each cell gradient orientation histogram is build. Each histogram is weighted for 4x4 regions by the gradient magnitude and Gaussian weighing function with $\sigma = 0.5$. The window size should be adjustable according to the scale of the interest points hence it becomes scale invariant.

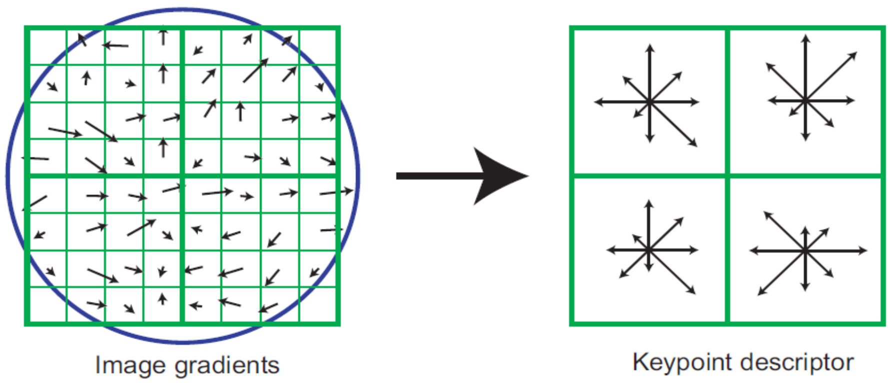



Figure 6.8 Feature vector generation

Normalize the descriptor to unit vector. Bound unit vector items to maximum (0.2) to remove the larger gradients and again renormalize to unit vector.

## 6.3 Speeded-Up Robust Feature Algorithm

SURF stands for Speeded Up Robust Feature, from the name itself its known that it is robust feature detector algorithm. In the year 2006 it was first proposed by Herbert Bay and later came into vision. This algorithm can be used in various field of computer vision, like in recognition of objects, 3D reconstruction etc. SURF came up after SIFT (Scale Invariant feature transform), hence it is a modified version of SIFT. In other way it is a speeded up version of SIFT and it is approximately three times faster than SIFT. SURF is both scale as well as rotation invariant. The feature detection process in SURF requires three steps known as: first detection of features, followed by description of the detected feature and at last matching. SURF focus is more on increasing the matching step [36]. The various applications are like automatic object tracking, motion based segmentation, stereo calibration, robot navigation etc.

It is based on the concept of 2D Haar wavelet responses and the use of integral images efficiently. Integer approximation is used in a way it is applied to the hessian blob detector's determinant. For detection of features, the sum of Haar wavelet response is calculated around the interest point.

### 6.3.1 Flowchart

The flow chart of image mosaicing using SURF algorithm is shown in Figure 6.9

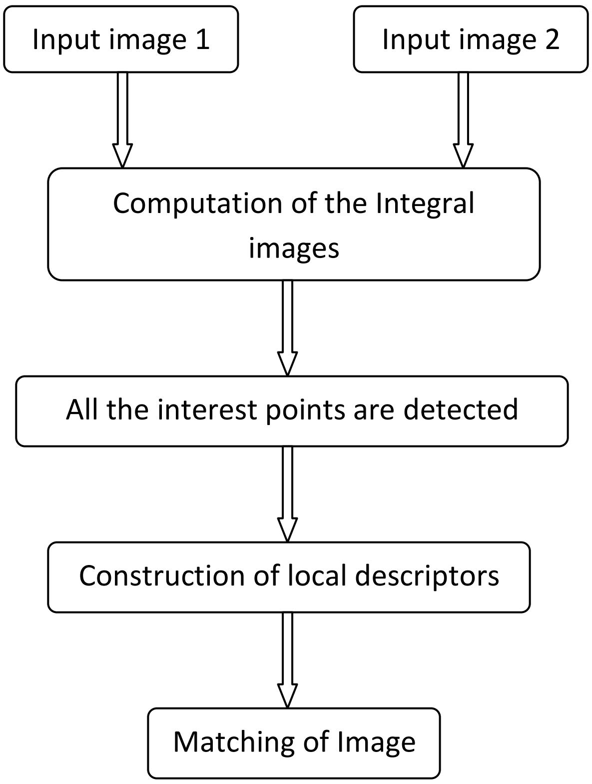



Figure 6.9 Flow chart of SURF algorithm

### 6.3.2 Interest Point Detection

Harris corner detector is a very popular detector and the biggest disadvantage of Harris detector is that it is variant to scale, leading to other interest point detectors overcoming this particular disadvantage. For the detection of interest points different detectors which are invariant to scale have been proposed which uses the SURF approximation of the Hessian matrix. Set of feature point candidates is formed by applying the local maxima of Hessian determinant matrix to the scale space. Based on the selected feature point candidates decision is taken, by defining a threshold value and observing the response. If the response is above our defined threshold value then that particular interest point is compared to its twenty-six pixels lying in the neighborhood. Based on the comparison we choose the feature point, if the extreme point detected is greater than all neighboring values, then it's a feature point. The steps are explained below:

#### 6.3.2.1 Establishing Integral Images

For establishing integral image, a digital image is taken into consideration. For this digital image only gray values are considered. The range of gray values lies between 0 to 255. Consider image *I* and for any point *X* in the image the coordinate is (*x*, *y*). So the integral image for the image *I* will be stated as:

$$I(X) = \sum_{i=0}^{i \le x} \sum_{j=0}^{j \le y} I(i, j) \tag{6.18}$$

The integral image is utilized to increase the computation speed of box type convolution filter. An example is considered to understand the integral image concept in a better way is shown in Figure 6.10. In this figure an image *I* is convoluted with two-dimensional rectangular function, all the pixels get summed up within the rectangular area.

Mathematically,

$$\sum = A - B - C + D \tag{6.19}$$

*A, B, C, D* are the four vertices of the rectangle and the integral image is calculated by just using the addition and subtraction operation but nowhere the size of the rectangular area is involved. So computation speed is not dependent upon the box size, because the only operation involved in the procedure is addition. So it is more convenient if one uses the filter with big sizes.

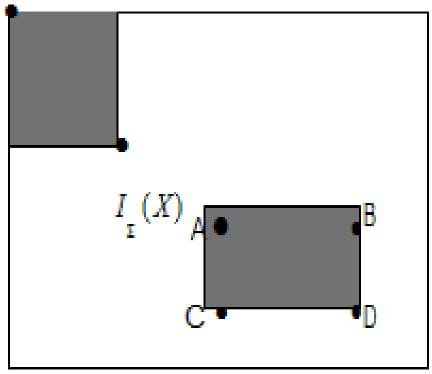


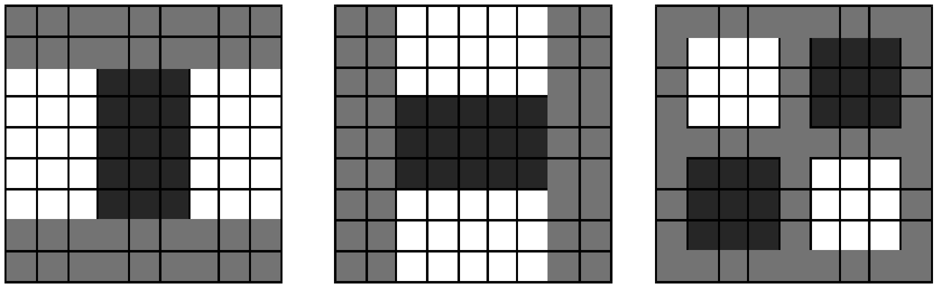

Figure 6.10 Sum of rectangle are with an Integral Image

#### 6.3.2.2 Hessian Matrix

Hessian matrix is used in SURF because it has got certain advantages. First the computation time taken by Hessian matrix is very less and second it gives better accuracy. The two parameters of the interest point i.e. scale and location both are determined with the help of this Hessian matrix. Local maxima are detected from Hessian matrix, for the calculation of Hessian matrix an image *I* is considered and for any point *x* in the image *I* the coordinate is (*x*, *y*). So the Hessian matrix at scale $\sigma$ and in scale *x* is as below:

$$H(x,\sigma) = \begin{bmatrix} L_{xx}(x,\sigma) & L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma) & L_{yy}(x,\sigma) \end{bmatrix} \tag{6.20}$$

$L_{xx}(x,\sigma)$ denotes the convolution between Gaussian second derivative as $\frac{\partial^2 g(\sigma)}{\partial x^2}$ and of the image $I$ in the *x* point and similarly all other $L_{xy}(x,\sigma)$, $L_{yy}(x,\sigma)$ are denoted in the same way. Here the Gaussian needs to be cropped and even after cropping, when the further resulted images are sub-sampled, they results in aliasing, so overall here the use of Gaussian does not give efficient result. Gaussian is replaced with approximations of box filters, this approximation replaces the second order derivative, and use of integral images speed up the evaluation process not considering the size of box filters into an account. Below in Figure 6.11 is shown the box filters with 9x9 pixels.



(a) x direction (b) y direction (c) xy direction

Figure 6.11 Box Filters with 9x9 pixels

An approximate Hessian matrix determinant represented as det ($H_{approx}$) is given in equation 6.21 below:

$$\det(H_{approx}) = D_{xx} D_{yy} - (w * D_{xy})^2 \qquad (6.21)$$

$D_{xx}$ represents the approximate value of the convolution between Gaussian second derivative as $\frac{\partial^2 g(\sigma)}{\partial x^2}$ and the image $I$ in the $x$ point and others in a similar way as per directions given. The $w$ is weight which is taken 0.9 and it is decided a per Forbenius norm. 0.9 is standard value which is kept same for any box sizes. It will not differ with the size of boxes. The box type filters are used to build the image pyramid. The use of integral images and box filters prevents from iteratively applying the same filter to the previous filter layer output instead any filter size can be directly applied to the original image but at the same speed. The first layer will be the output of box filters with 9x9 pixels with the scale of 1.2. Other filter sixes of 9x9, 15x15, 21x21, the scale size will also increase accordingly. Thus for the new octaves, the filter size increases and gets double.

Next for the localization of interest points local maximum suppression is applied. And it is applied to 3x3x3 of its neighborhood shown in Figure 6.13. In the first level the extrema points compared among all the other eight neighbors becomes the interest points, similarly compared to its all neighbors above and neighbors below. So all the relation between the octaves, levels, neighborhood is shown in the single Figure 6.12. Scale space interpolation is achieved by taking the maxima of the determinant of the Hessian matrix, which is discussed above from an equation provided [37].

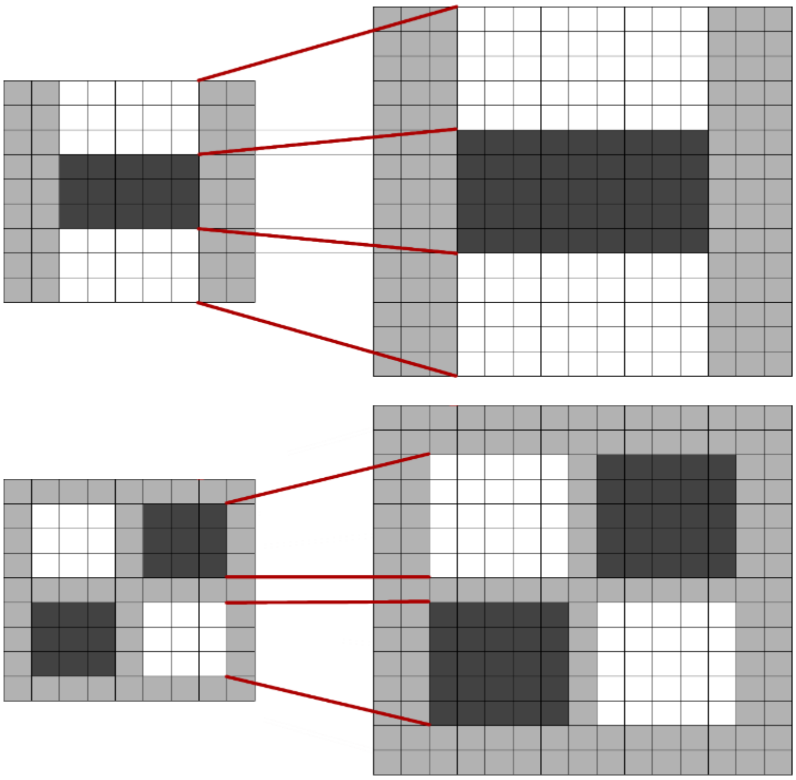


Figure 6.12 Kernel size increases from 9x9 pixels to 15x15 and goes successively

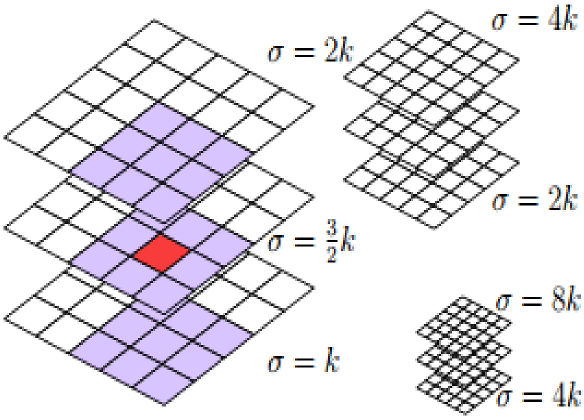



Figure 6.13 Non maximum suppression of 3x3x3 neighborhood of 3 octaves having 3 levels

### 6.3.2.3 Scale Space Representation

Continuous sampling of scale $\sigma$ is required in SURF, which is similar in SIFT. So in both, the sampling of scale is done. The scale is divided into number of octaves. Further octaves are divided into different intervals or in the other way say levels. Filter size can be calculated as:

$$FilterSize = 3 \times (2^{Octave} \times \text{interval} + 1)\frac{1.2}{9} \tag{6.22}$$

Where octaves represents layers and interval means within that particular layer what is the image sequence number. So for sampling of scale in SURF, the formula is:

$$\sigma = CurrentFilterSize.\frac{1.2}{9} \tag{6.23}$$

Or

$$\sigma = 3 \times (2^{Octave} \times \text{interval} + 1).\frac{1.2}{9} = \frac{1.2}{3}((2^{Octave} \times \text{interval} + 1) \tag{6.24}$$

**6.3.3 Interest Point Descriptor**

Interest point detected in the previous steps now needs to be properly descripted. The need of description is to provide a robust and unique detail for detected interest points. Around an interest point the circular region is drawn, and orientation is achieved from the information obtained from circular region. Entire description process is divided into two steps Orientation Assignment and Sum of Haar wavelet responses. The steps are explained below.

**6.3.3.1 Orientation Assignment**

For description SURF uses Haar wavelet responses, whereas SIFT uses the Hough Transform. The point which is same in both algorithms is orientation which is determined. For each interest point there is a unique orientation which makes it rotation invariant. The descriptors of SURF are rotation invariant. The SIFT is down version but SURF is upright version. Around the interest point the area of 6*s* is considered and within this region the orientation is calculated. Here the s represents the same scale which was used at the time of detecting the interest point. For orientation the Haar wavelet responses are calculated respectively in the *x* direction and *y* direction. In all total only six operation are involved in any *x* or *y* direction. After all the responses of wavelets are calculated they are represented in space as vectors. In space along the abscissa the horizontal response is represented and along the ordinate vertical response is represented. The sum of all responses falling in the window covering area of 60 degree decides the dominant orientation direction shown in Figure 6.14 the new vector is generated when horizontal and vertical both responses are added up. So the vector which is longest becomes orientation which will be unique for the interest point.

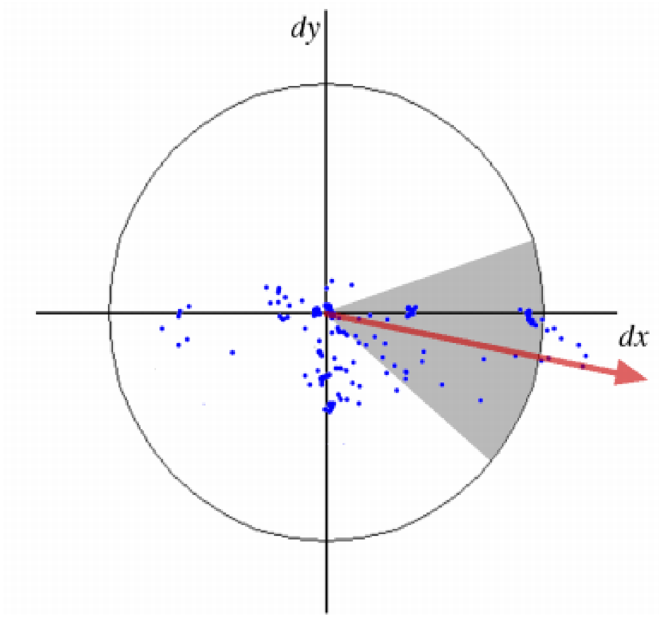



Figure 6.14 Haar wavelet response within are of 60 degree

### 6.3.3.2 Sum of Haar wavelet responses

For extracting the descriptor, window size is chosen as 20*s*, where *s* is scale. The entire area is divided into small square sub regions of size 4x4, for every sub region the feature are computed for 5x5 uniformly spaced sample points like shown in Figure 6.15. *dx* represents Haar wavelet response horizontally and *dy* Haar wavelet response vertically. For the feature vector set of entries is created by summing up *dx* and *dy* in every 4x4 sub region. |*dx*| and |*dy*| are also calculated which represents the sum of absolute values of *dx* and *dy* respectively for change in polarity of intensity. The vector *v* is calculated for every sub region of 4x4 given by equation 6.25 below. For 4x4 sub regions in all total length of the vector will be 64.

$$v = \left\{ \sum dx \quad \sum dy \quad \sum |dx| \quad \sum |dy| \right\} \tag{6.25}$$

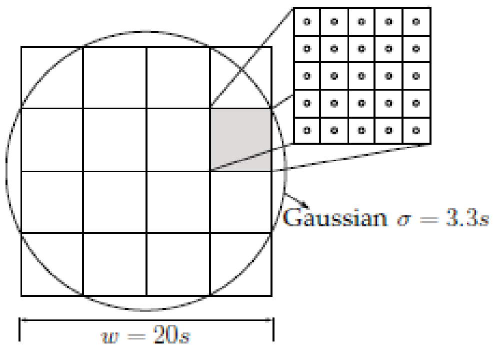



Figure 6.15 20s divided into 4x4 sub regions, each sub region sampled further at 5x5 sample points

For different different pattern of intensities the responses of Haar wavelet are also different. This is explained in a better way from Fig 6.16. These responses of wavelet are robust towards illumination changes and for being invariant towards contrast descriptors are normalised to unit vector.

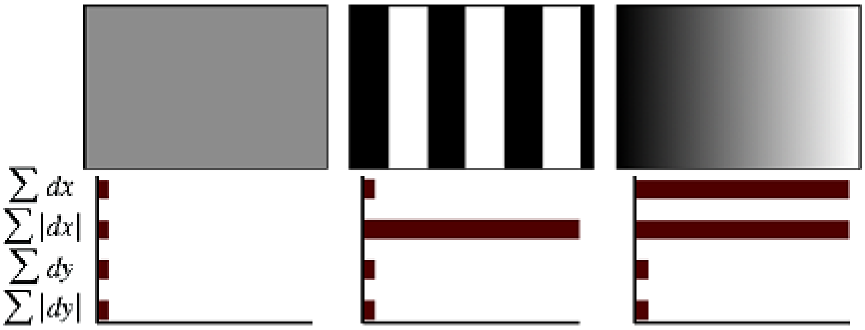



Figure 6.16 Sum of Haar wavelet response respective to the given intensity pattern

# CHAPTER 7

# PROPOSED METHODOLOGY

## 7.1 Introduction

All algorithms Harris, SIFT (Scale invariant feature transform), SURF (Speeded- Up robust feature transform) which have been discussed completely works in spatial domain. The corresponding information or details in each individual image scenes in spatial and temporal domain is combined to generate scene using images of smaller field of view. The proposed method, presents an efficient robust image mosaicing technique based on SURF (Speeded-Up Robust feature). The leading contribution of the proposed work lies in the primary detection of features using SURF feature detector and descriptor. This step plays an important role as it detects the robust features and then describes the detected features further for matching purpose. Secondly for image registration frequency based approach has been used which operates in the frequency domain. It possesses various interesting properties. Firstly, the use of correlation enables thorough search for the unknown motion parameters and so, the large motions can be recovered with no prior information. Secondly this particular approach is global and has robustness to noise. Lastly the approach is computationally efficient and this is only possible from the shift property of the FT (Fourier Transform) and use of FFT (Fast Fourier Transform) routines for the speedy computation of correlations. In this method instead of standard correlation, phase correlation is used for converting from Cartesian into log-polar space. The Fourier method differs from other registration strategies because they search for the optimal match according to information in the frequency domain.

Then the removal of false matched pairs is performed for finding the homography computation using RANSAC (Random Sample Consensus algorithm) algorithm. The final mosaic image is obtained by warping the images perfectly into a single plane, and then applies alpha blending which marks a smooth transition between the images. This methodology generates mosaiced image which is perfectly seamless when compared with the results obtained from SURF algorithm, in which the seam line is lightly visible.

## 7.2 Flow chart of proposed method

Flow chart of the proposed method is shown below in Figure 7.1

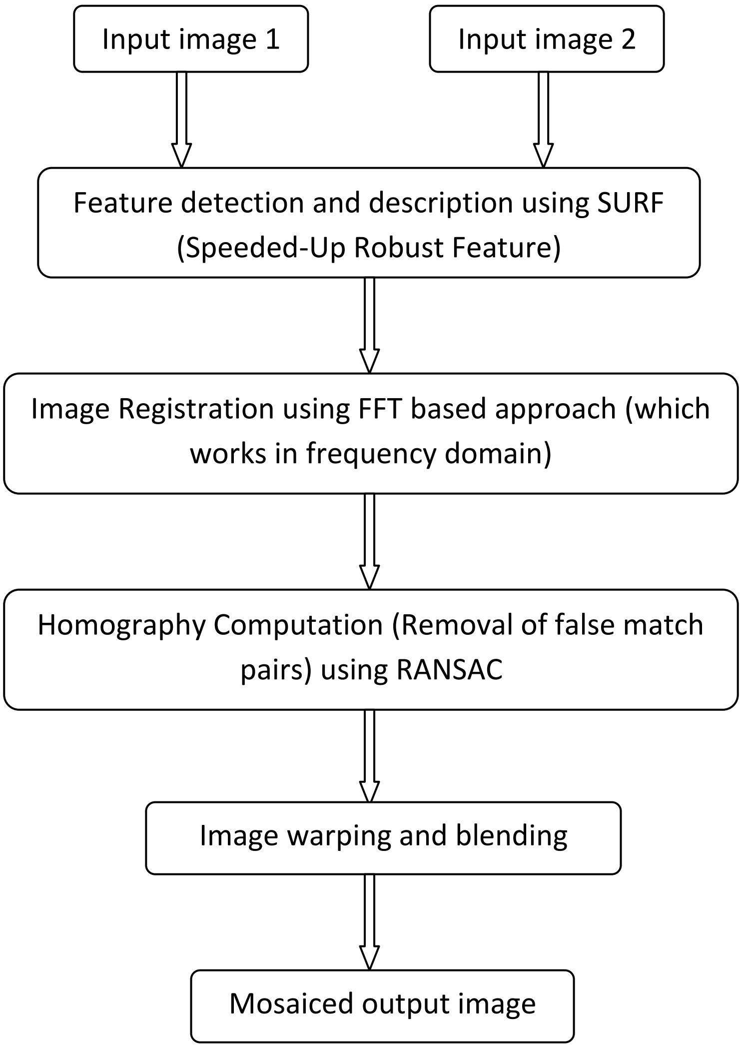



Figure 7.1 Flow chart of proposed method

### 7.2.1 Feature detection and description using SURF

SURF algorithm was first proposed by Herbert Bay in the year 2006 and later it came into vision. SURF has been already discussed in very detail in the previous section. So in the proposed methodology for the detection of features from the input images, SURF has been used. It is a robust algorithm. It is based on the concept of 2D Haar wavelet responses and the use of integral images efficiently [37]. Integer approximation is used in a way it is applied to the hessian blob detector's determinant. For detection of features, the sum of Haar wavelet response is calculated around the interest point. It is broadly divided into two steps interest point detector and interest point descriptor.

#### 7.2.1.1 Interest Point Detector

For the detection of interest points different detectors which are invariant to scale have been proposed which uses the SURF approximation of the Hessian matrix. Set of feature point candidates is formed by applying the local maxima of Hessian determinant matrix to the scale space. Based on the selected feature point candidates decision is taken, by defining a threshold value and observing the response [38]. The steps are explained below:

1. Establishing Integral Images

For establishing integral image, a digital image is taken into consideration. Consider image $I$ and for any point $X$ in the image the coordinate is $(x, y)$. So the integral image for the image $I$ will be stated as given in equation 7.1. The integral image is utilized to increase the computation speed of box type convolution filter.

$$I(X) = \sum_{i=0}^{i \le x} \sum_{j=0}^{j \le y} I(i, j) \tag{7.1}$$

2. Hessian Matrix

The Hessian matrix provides less computational time and better accuracy. Scale and location of the interest point both are determined with the help of this Hessian matrix. Local maxima are detected from Hessian matrix, for the calculation of Hessian matrix an image $I$ is considered and for any point $x$ in the image $I$ the coordinate is $(x, y)$. So the Hessian matrix at scale $\sigma$ and in scale $x$ is as below:

$$H(x,\sigma) = \begin{bmatrix} L_{xx}(x,\sigma) & L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma) & L_{yy}(x,\sigma) \end{bmatrix} \tag{7.2}$$

The use of Gaussian does not give efficient result. So Gaussian is replaced with approximations of box filters, this approximation replaces the second order derivative, and use of integral images speed up the evaluation process not considering the size of box filters into an account. An approximate Hessian matrix determinant is given in equation 7.3 below.

$$\det(H_{approx}) = D_{xx} D_{yy} - (w * D_{xy})^2 \tag{7.3}$$

The $w$ is weight which is taken 0.9. It is standard value which is kept same for any box sizes. The box type filters are used to build the image pyramid. The use of integral images and box filters prevents from iteratively applying the same filter to the previous filter layer output instead any filter size can be directly applied to the original image but at the same speed.

For the localization of interest points local maximum suppression is applied on 3x3x3 of its neighborhood shown on Figure 7.2. In the first level the extrema points compared among all the other eight neighbors becomes the interest points, similarly compared to its all neighbors above and neighbors below.

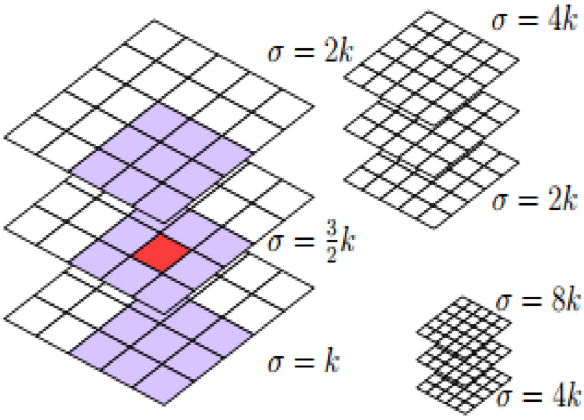



Figure 7.2 Non maximum suppression of 3x3x3 neighborhood of 3 octaves having 3 levels

3. Scale Space Representation

Continuous sampling of scale $\sigma$ is done. The scale is divided into number of octaves. Further octaves are divided into different intervals or levels. For sampling of scale in SURF, the formula is given in equation 7.4

$$\sigma = CurrentFilterSize \frac{1.2}{9} \tag{7.4}$$

**7.2.1.2 Interest Point Descriptor**

The need of description is to provide a robust and unique detail for detected interest points. Around an interest point the circular region is drawn, and orientation is achieved from the information obtained from circular region. The steps are explained below.

1. Orientation Assignment

Around the interest point the area of 6*s* is considered and within this region the orientation is calculated. Here the s represents the same scale which was used at the time of detecting the interest point. For orientation the Haar wavelet responses are calculated respectively in the *x* direction and *y* direction. In all total only six operation are involved in any *x* or *y* direction. After all the responses of wavelets are calculated they are represented in space as vectors. So the vector which is longest becomes orientation which will be unique for the interest point.

2. Sum of Haar wavelet responses

For extracting the descriptor, window size is chosen as 20*s*, where *s* is scale. The entire area is divided into small square sub regions of size 4x4, for every sub region the feature are computed for 5x5 uniformly spaced sample points like shown in Figure 7.3. *dx* represents Haar wavelet response horizontally and *dy* represents Haar wavelet response vertically. The vector *v* is calculated for every sub region of 4x4 given by equation 7.5 below. For 4x4 sub regions in all total length of the vector will be 64.

$$v = \left\{ \sum dx \quad \sum dy \quad \sum |dx| \quad \sum |dy| \right\} \tag{7.5}$$

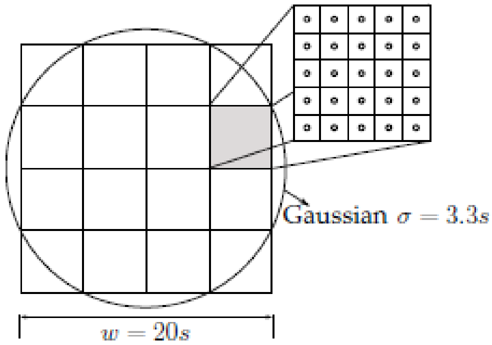



Figure 7.3 20s divided into 4x4 sub regions, each sub region sampled further at 5x5 sample points

### 7.2.2 FFT (Fast Fourier Transform) based Image Registration

This approach has been used for the registration of images. It finds the transformation parameters for the registration of images. The Fourier method differs from other registration strategies because they search for the optimal match according to information in the frequency domain [39]. In this method instead of standard correlation, phase correlation is used for converting from Cartesian into log-polar space. Applying phase correlation to a pair of images produces the third image [40]. The third image which is generated contains a single peak which is the highest peak. The location of this peak decides the translation offset between both the input images.

In phase correlation method Fast Fourier transform is used. FFT used computes the cross correlation between two images. The procedure followed is as:

1. Applying window function (like Hamming window) to improve the edge effects, but this is optional.

2. Then 2D Fast Fourier Transform is implemented over one image and similarly the complex conjugate of 2dimensional Fast Fourier Transform over the other image.

3. The output generated from both images are multiplied with each other and divided with the absolute values. It is done in order to calculate the cross power spectrum.

4. Lastly do the IFFT (Inverse Fast Fourier Transform) of the result obtained from step 3 and then location of the peak is determined.

5. The location of the peak corresponds to the relative offset between the images.

The highest peak obtained at last performing all the steps occurs only at that point where there is indication of pure translation offset between the images shown in Figure 7.2

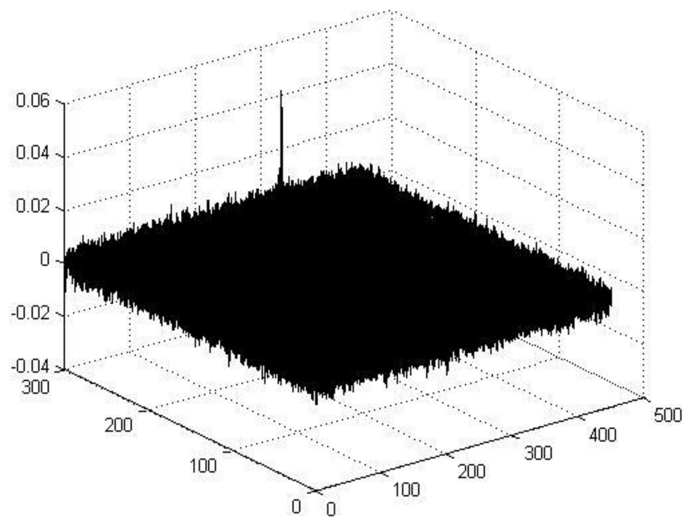



Figure 7.4 IFFT of Cross power Spectrum

### 7.2.3 RANSAC for Homography Computation

It is a method to estimate the parameters of a particular model, from a set of data containing large amount of outliers. It is an iterative, non-deterministic algorithm which uses least-squares method to estimate model parameters. The input data of the algorithm is a set of observed data values and a mathematical model that will be matched to the data set and few parameters [41]. RANSAC is an iterative process which iteratively selects a subset from the given data. The steps of the RANSAC algorithm are as follows:

1. Randomly $N$ data items have been selected which detect the parameters of model.

2. Next parameter $x$ is solved.

3. Now from $N$ data items, the data items which fits the model with the above solved parameter $x$ are separated and see whether they fit with the user defined tolerance. Let tolerance be $K$.

4. If the value of $K$ is large, success is achieved and the process stops.

5. Otherwise the steps from 1 to 4 are repeated.

The entire process is repeated until the optimum result is obtained. Every time it produces different model, a model sometimes gets rejected because of detection of very less inliers as compared to outliers or a model which contains error measure. The advantage of this particular method is that the percentage of outliers which can be handled by RANSAC can be larger than 50% of the whole data set. One disadvantage of this algorithm is that for computing the parameters there is no bound on time, in case when there is limited iterations, it may not give the optimal results.

### 7.2.4 Warping and Blending

In image warping the input images which are to be mosaiced are warped together with the use of geometric transformation. In this points to points are matched without the change of colors. It is the process of mapping of positions from the plane of first image to the plane of second image. Warping is used for creative purposes as well as any kind of image distortion can be corrected with the use of warping. Warping is used in many cases like when there is illumination variation between images, or when images are distorted due to some or other reason.

Image blending is the method which is applied at the very last step to make the mosaiced image more attractive. In this thesis work alpha blending technique is used. With the help of image blending, the seam line is removed making image seamless. In this the gray levels of the image which falls around the boundary of seam line or stitching line is modified, so that a smooth transition is obtained between the joined images and the blended image is originated.

# CHAPTER 8

# RESULTS AND DISCUSSION

## 8.1 Results and Discussion

This chapter covers all the results which have been obtained from the implementation of the SURF algorithm and from the proposed method. In all considered five set of images as Set A, B, C, D and E. Every set has input image 1 and input image 2, so first result comes from SURF. In the proposed section there are three results, first is the matching lines obtained from both the images, second is the output obtained after the implementation of RANSAC algorithm and third is the mosaiced image obtained from proposed methodology. All the results are shown below.

**Set A:**

Fig.8.1 Input Image 1 (Upper is Right Portion) and Input image 2 (Lower is left Portion)

Fig.8.2 Result using SURF algorithm

The Figure 8.2 is the mosaiced image which is obtained after the implementation of SURF algorithm. In this figure there is a seam line which is very lightly visible to our eyes, which is highlighted and circled with red color. This is repeated for set B, C, D, E and F. In every set the seam line which is visible in the result of the SURF algorithm is marked with the same color. Next are the results of proposed method. There are three results which have been obtained under proposed method which is shown in Figure 8.3, 8.4 and 8.5. Figure 8.3 shows all the matching points obtained after FFT based image registration. Figure 8.4 shows the result which is obtained after applying RANSAC algorithm. It discards the unwanted matching points to reduce the complexity. Figure 8.5 shows the mosaiced image from proposed method in which there is no seam line visible which is obtained lastly by applying alpha blending technique. It purely blends the two images into each other. This is repeated for Set B, C, D, E and F.

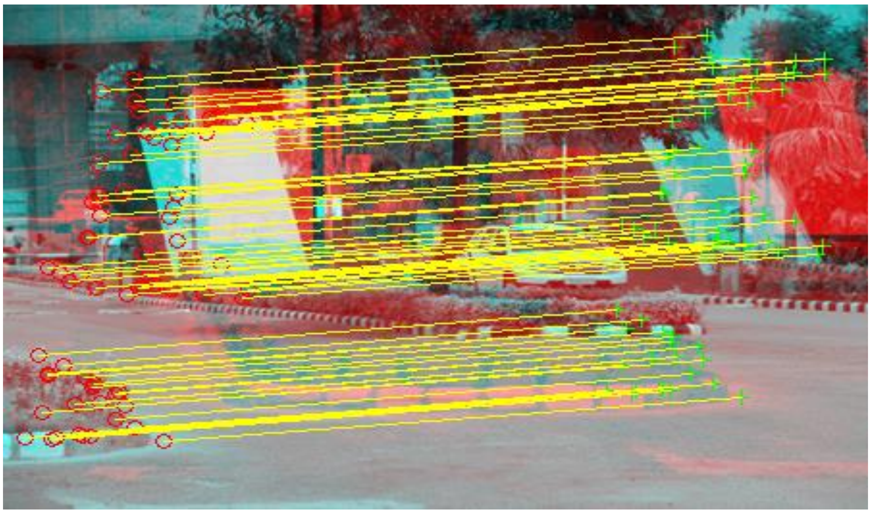


Fig.8.3 Matching points obtained between image 1 and 2

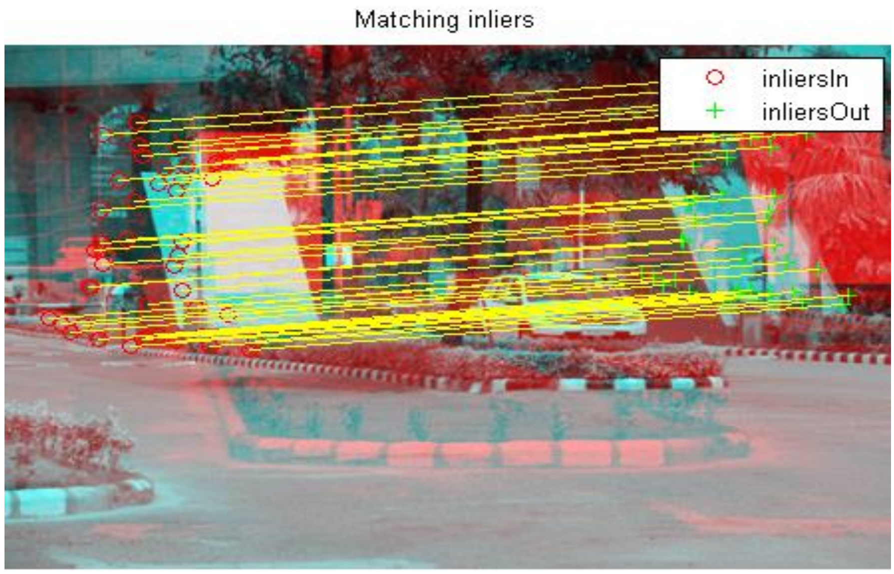



Fig.8.4 Output of RANSAC algorithm

Fig.8.5 Result of Proposed method

**Set B:**


Fig.8.6 Input Image 1 (Upper is Right Portion) and Input image 2 (Lower is left Portion)


Fig.8.7 Result using SURF algorithm

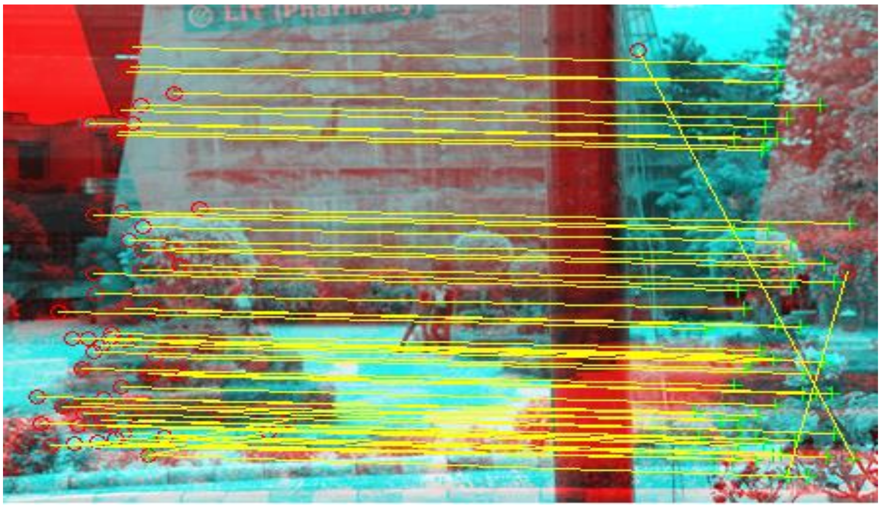


Fig.8.8 Matching points obtained between image 1 and 2

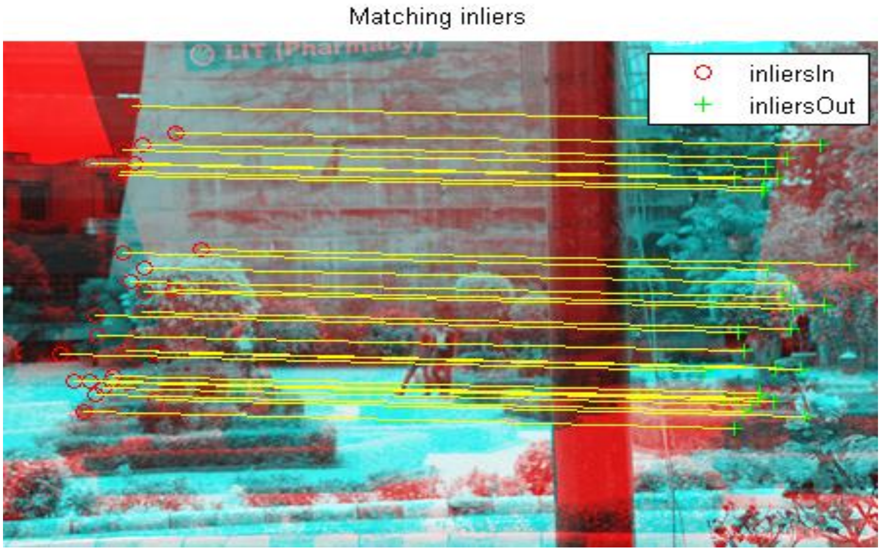



Fig.8.9 Output of RANSAC algorithm

Fig.8.10 Result of Proposed method

**Set C:**



Fig.8.11 Input Image 1 (Upper is Right Portion) and Input image 2 (Lower is left Portion)


Fig.8.12 Result using SURF algorithm

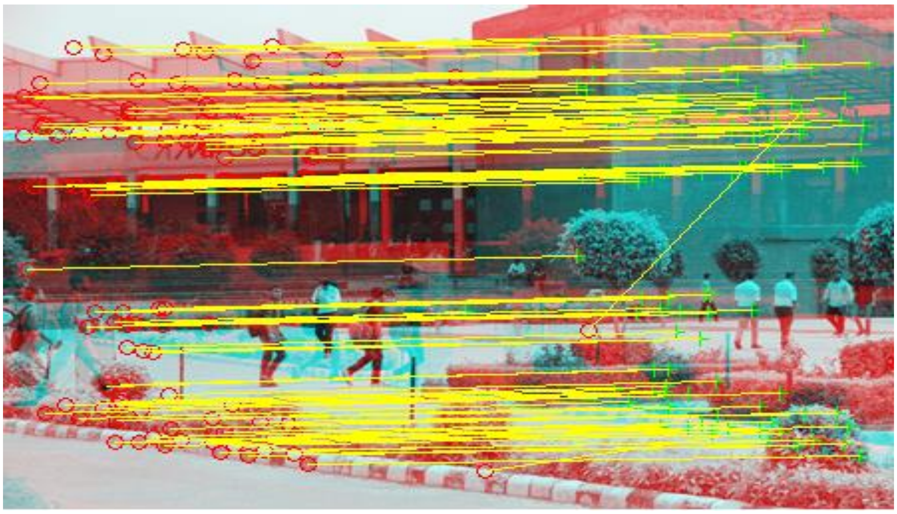


Fig.8.13 Matching points obtained between image 1 and 2


Fig.8.14 Output of RANSAC algorithm

Fig.8.15 Result of Proposed method

**Set D:**


Fig.8.16 Input Image 1 (Upper is Right Portion) and Input image 2 (Lower is left Portion)


Fig.8.17 Result using SURF algorithm

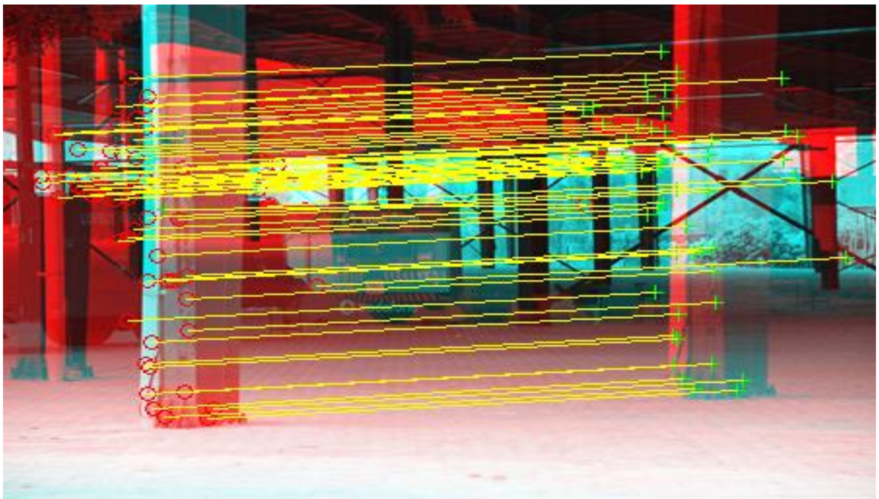


Fig.8.18 Matching points obtained between image 1 and 2

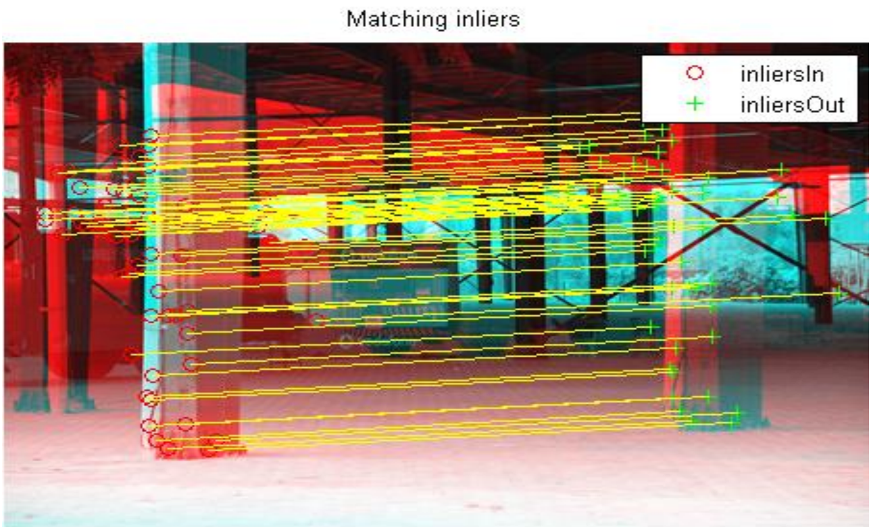



Fig.8.19 Output of RANSAC algorithm

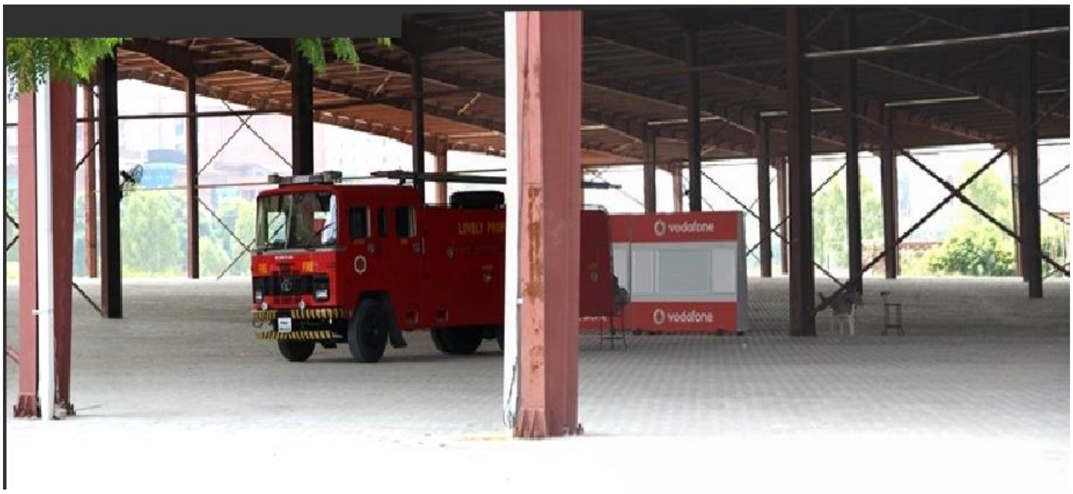



Fig.8.20 Result of Proposed method

**Set E:**

Fig.8.21 Input Image 1 (Upper is Right Portion) and Input image 2 (Lower is left Portion)

Fig.8.22 Result using SURF algorithm

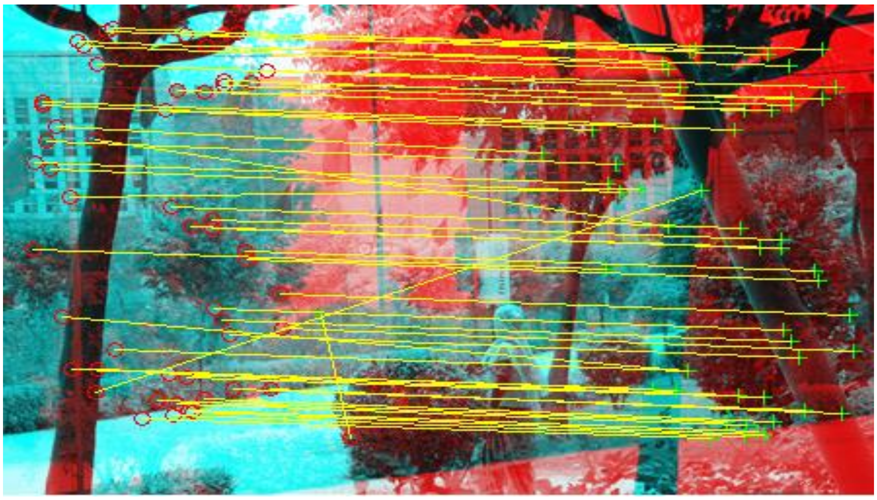


Fig.8.23 Matching points obtained between image 1 and 2

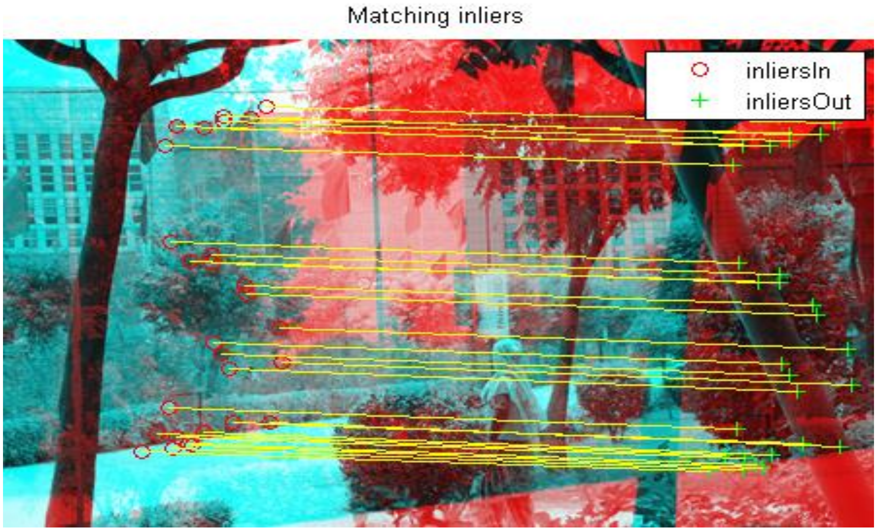



Fig.8.24 Output of RANSAC algorithm

Fig.8.30 Result of Proposed method

## 8.2 Performance Evaluation

There are certain image quality metrics or performance metrics based on which the quality of image is determined. In the image valuation in terms of both subjective and objective the performance evaluation plays a very important role in the entire process. The performance metrics based on which evaluation has been done are: PSNR (Peak Signal to Noise Ratio), RMSE (Root Mean Square error), SSIM (Structural Similarity Index Measurement), MI (Mutual Information), NAE (Normalize Absolute Error) and Run or computation time.

1. PSNR (Peak Signal to Noise Ratio)

It is Peak Signal to Noise Ratio. It is a measure to represent the quality of image in terms of signal to noise ratio. It is the calculation which is done between the one reference image and other the processed image. PSNR value should be high, higher the value higher is the quality of the reconstructed image. PSNR is calculated from the formula as given in the below equation:

$$PSNR = 10\log_{10}\frac{R^2}{MSE} \tag{8.1}$$

Where, *R* represents the maximum range in the input image data type.

2. SSIM (Structural Similarity Index Measurement)

It is the method to measure the similarity between the two images. It is a quality measure. It is based on basically three terms contrast, luminance and structural terms. It is combination of all these three terms.

$$SSIM(x,y) = [I(x,y)]^{\alpha}.[c(x,y)]^{\beta}.[s(x,y)]^{\gamma} \tag{8.2}$$

Where,

$$I(x,y) = \frac{2\mu_x\mu_y + C_1}{\mu_x{}^2 + \mu_y{}^2 + C_1} \tag{8.3}$$

$$c(x,y) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x{}^2 + \sigma_y{}^2 + C_2} \tag{8.4}$$

$$s(x,y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \tag{8.5}$$

Where $\mu_x$, $\mu_y$, $\sigma_x$, $\sigma_y$ and $\sigma_{xy}$ represents the means, standard deviation and cross covariance for any image say ($x$ ,$y$). So SSIM is given as:

$$SSIM(x,y)=\frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}+C_2)}{(\mu_x{}^2+\mu_y{}^2+C_1)(\sigma_x{}^2+\sigma_y{}^2+C_2)} \tag{8.6}$$

3. Mutual Information

It is a metric which measures the asymmetry between two images. *M* and *N* are two images, so mutual information between both can be calculated as:

$$MI=H(M)+H(N)-H(M,N) \tag{8.7}$$

*M (i, j)* is the mutual information of one image and *N (i, j)* is for the other image. *H(M)* denotes entropy for *M (i, j)* image. Similarly *H(N)* denotes entropy for *N (i, j)* image and *H (M, N)* is the joined entropy between both images *M (i, j)* and *N (i, j)*.

4. NAE (Normalized Absolute Error)

It is a quality measure, which can be calculated as:

$$NAE=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(|A_{ij}-B_{ij}|)}{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij})} \tag{8.8}$$

Where, *A* is the image based on ground truth and *B* is the mosaiced image. All this performance metrics are shown together in the Table 8.1. There is comparison between the SURF and the proposed method. The table 8.1 shows that the proposed method is superior then existing SURF as they have better performance metrics.

| **Parameters** | **SURF** | **Proposed Method** |
|---|---|---|
| Computational Time | 11.04 (sec) | 7.09 (sec) |
| PSNR | 39.30 | 42.50 |
| RMSE | 3.67 | 2.29 |
| SSIM | 1.014 | 0.993 |
| MI | 1.30 | 1.49 |
| NAE | 0.155 | 0.130 |

Table 8.1 Performance Analysis of SURF and Proposed Method

# CHAPTER 9

# CONCLUSION AND FUTURE SCOPE

## 9.1 Conclusion

The Speeded-Up Robust Feature algorithm is a modified version of existing SIFT algorithm. It is a robust feature detector algorithm. It is almost three times faster than the existing SIFT algorithm. It is so because it focuses more on the matching step. Unlike in SIFT, SURF uses the Hessian matrix which speed the matching procedure. But mosaiced image obtained from existing SURF contains lightly visible seam line which depicts unrealistic scene. Although it takes less computational time than SIFT but it is improved further with the use of proposed methodology. In proposed work the corresponding information in each individual image in spatial domain and time domain is combined to generate scene using smaller field of view. For image registration Frequency based approach has been used. This approach is global and robustness to noise. This has better computational time compared to the SURF. It is so because of the shift property of the Fourier Transform and also with the use of Fast Fourier Transform. This registration technique differs from other methods because they search for the optimal match thoroughly. In the blending step alpha blending is applied which completely merges two images into each other not allowing any seam line to occur. The mosaiced output obtained from this contains no seam line which perfectly reflects the realistic picture. The performance evaluation parameters like PSNR, RMSE, FSIM, MI, NAE and Computation time proves that the proposed method is superior to the existing SURF.

## 9.2 Future Work

The entire research work has been done on only two input images, which can be done even on multiple images, in which reducing the computation time will be challenging. It can also be done on videos or instead of taking simple 3D images cylindrical images or spherical images can be taken into consideration. In the proposed methodology where FFT based registration is done only on two images, same technique can be done for panorama generation considering videos.

# References


1. Ms.Parul M.Jain, Prof. Vijaya K.Shandliya, “A Review Paper on Various Approaches for Image Mosaicing,” International Journal of Computational Engineering Research, Vol. 03, Issue, 4.
2. G. Ward, "Hiding seams in high dynamic range panoramas,” Proc. of the 3rd ACM International symposium on applied perception in graphics and visualization, pp.153-155, 2006.
3. D. I. Barnea and H. F. Silverman, “A class of algorithms for fast digital registration,” IEEE Trans, Comput, vol. C-21, pp. 179-186, 1972.
4. L. G. Brown, “A survey of image registration techniques,” ACM Computing Surveys, vol.24, pp.325-376, 1992.
5. Gao Guandong and Jia Kebin, “A New Image Mosaics Algorithm Based on Feature Points Matching,” College of Electronic Information and Control Engineering, Beijing University of Technology.
6. Debabrata Ghosh, Naima Kaabouch, “ A Survey on Image Mosaicing Techniques,” Journal of Visual Communication and Image Representation October 2015.
7. G. Wolberg, “Digital Image Warping,” Proc. of IEEE Computer Society Press, California, pp.169-172, 1990.
8. Chris Solomon and Toby Breckon, “Fundamentals of Digital Image Processing, A Practical Approach with Examples in Matlab,” 2011 John Wiley & Sons, Ltd. Page No. [1-5].
9. Ting Lu, Shutao Li, Wei Fu, “ Fusion Based Seamless Mosaic for Remote Sensing Images,” Sens Imaging (2014) 15:101, DOI 10.1007/s11220-014-0101-0.
10. R. Karthik, A. Annis Fathima, V. Vaidehi, “Panoramic View Creation using Invariant Moments and SURF Features,” International Conference on Recent Trends in Information Technology (ICRTIT) ,IEEE , 2013.
11. D. Ghosh, S. Park, N. Kaabouch and W. Semke, “Quantum evaluation of image mosaicing in multiple scene categories,” Proc. of IEEE Conference on Electro/Information Technology, pp.1-6, 2012.
12. D. Marr and E. Hildreth, “Theory of Edge Detection,” Proc. of Royal Soc. London B, vol. 207, pp. 187-217, 1980.

13. D. G. Lowe, “Distinctive Image Features from Scale-Invariant Keypoints,” International Journal of Computer Vision, vol. 60, pp. 91- 110, 2004.
14. Hemlata Joshi, Mr. Khom Lal Sinha, “Image Mosaicing using Harris, SIFT Feature Detection Algorithm,” ISSN: 2278 – 7798 International Journal of Science, Engineering and Technology Research (IJSETR) Volume 2, Issue 11.
15. D.K. Jain, G. Saxena, V.K. Singh, “Image mosaicing using corner technique,” Proc. of International Conference on Communication System and Network Technologies, pp.79-84, 2012.
16. L. Juan et. al., “A comparison of SIFT, PCA-SIFT, and SURF,” International Journal of Image Processing, vol. 3, pp.143-152, 2009.
17. Mr. Venugopala Gowda D, Mrs. Padmajadevi G, “Image Stitching Using Speeded Up Robust Features,” International Journal on Recent and Innovation Trends in Computing and Communication Volume: 3 Issue: 6 ISSN: 2321-8169 3514 – 3519.
18. Ms. Mital S. Patel, Dr. N. M. Patel, Dr. Mehfuza S. Holia, “Feature Based Multi-View Registration using SURF,” 2015 International Symposium on Advanced Computing and Communication (lSACC), 978-1-4673-6708-0/15/$31.00 ©20 15 IEEE.
19. Ms. Durga Patidar, Mr. Akshay Jain, “Automatic Image Mosaicing: An Approach Based on FFT,” International Journal of Scientific Engineering and Technology (ISSN:Applied) Volume No.1, Issue No.1 pg:01-04.
20. Nan Geng, Dongjian He1, Yanshuang Song, “Camera Image Mosaicing Based on an Optimized SURF Algorithm,” TELKOMNIKA, Vol. 10, No.8, December 2012, pp. 2183~2193 e-ISSN: 2087-278X.
21. Stafford michahial, Latha M, Akshatha S, Juslin F, Ms Manasa B, Shivani U, “Automatic Image Mosaicing Using Sift Ransac and Homography,” ISSN: 2277-3754 ISO 9001:2008 Certified International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 10, April 2014.
22. Devi Renuka, “Image mosaicing using Phase Correlation and Feature based approach,” International Journal of Engineering Research, 2016, 4 (1).
23. Xinbei Bai, Xiaolin Ning, Longhua Wang, “Analysis and Comparison of Feature Detection and Matching Algorithms for Rovers Vision Navigation.”
24. Kevin E. Loewke*, David B. Camarillo, Wibool Piyawattanametha, Michael J. Mandella, Christopher H. Contag, Sebastian Thrun and J. Kenneth Salisbury, “In

Vivo Micro - Image Mosaicing," IEEE Transactions on Biomedical Engineering, VOL. 58, NO. 1, JANUARY 2011.

25. Lin Zeng, Shengping Zhang, Jun Zhang, Yunlu Zhang, " Dynamic image mosaic via SIFT and dynamic programming," Machine Vision and Applications" (2014) 25:1271– 1282 DOI 10.1007/s00138-013-0551-8.
26. Maya Dawood, Cindy Cappelle, Maan E. El Najjar, Mohamad Khalil and Denis Pomorski, " Harris, SIFT and SURF features comparison for vehicle localization based on virtual 3D model and camera," 978-1-4673-2584-4/12/$31.00©2012 IEEE.
27. R. B. Inampudi, "Image mosaicing," Proc. of International Conference on Geoscience and Remote Sensing Symposium, Seattle, pp.2363-2365, 1998.
28. S. Peleg and J. Herman, "Panoramic mosaics by manifold projection," Proc. of IEEE Computer Society conference on Computer Vision and Pattern Recognition, San Juan, pp.338-343, 1997.
29. B. Rousso, S. Peleg, I. Finci and R. Acha, "Universal mosaicing using pipe projection," Proc. of Sixth International Conference on Computer Vision, pp.945-950,1998.
30. J. Wang and Y. Li, "Image mosaicing algorithm based on salient region and MVSC," Proc. of International Conference on Multimedia and Signal Processing, pp. 207-211, 2011.
31. Kee Baek Kim, Jong Soo Kim, Jong Soo Choi, "Fourier Based Image Registration for Sub-Pixel Using Pyramid Edge Detection and Line Fitting," First International Conference on Intelligent Networks and Intelligent Systems.
32. I. Zoghlami, O. Faugeras, and R. Deriche, "Using geometric corners to build a 2D mosaic from a set of images," Proc. of the International Conference on Computer Vision and Pattern Recognition, Puerto Rico, pp.340-349, 1997.
33. Xin Zhang, Guojin He, Jiying Yuan, " A Rotation invariance Image matching method Based on Harris corner Detection," Center for Earth Observation and Digital Earth, Chinese Academy of Sciences Graduate University of Chinese Academy of Sciences.
34. B. Zitova and J. Flusser, "Image registration methods: A survey," Image and Vision Computing, vol.21, pp.977-1000, 2003.
35. D. G Lowe, "Object recognition from local scale-invariant features," International Conference on Computer Vision, vol. 2, pp.1150– 1157, 1999.

36. Herbert Bay, Tinne Tuytelaars, and LucVan Gool, “SURF: Speeded Up Robust Features.”
37. H. Bay, et al., “Speeded up Robust Features,” Proc. of the 9th European Conf. on Computer Vision, Cambridge, U.K., pp. 404-417, 2006.
38. D. G. Lowe, “Local feature view clustering for 3D object recognition,” IEEE Conference on Computer Vision and Pattern Recognition, Hawaii, pp.682-688, 2001.
39. Udhav Bhosle, Subhasis Chaudhuri, Sumantra Dutta Roy , “A Fast Method for Image Mosaicing using Geometric Hashing,” Indian Institute of Technology Bombay, Powai, Mumbai.
40. C. D. Kuglin and D. C. Hines, “The phase correlation image alignment method,” Proc. of IEEE Int. Conf. on Cybernet Society, New York, pp. 163-165, 1975.
41. Birute Ruzgiene & Wolfgang Förstner, “Ransac for outlier detection,” ISSN 1392-1541 Geodezija ir kartografija, 2005, XXXI t., Nr. 3,Geodesy and Cartography, 2005, Vol XXXI, No 3.