BER BASED FRR ANALYSIS OF LOW PARAMETER GRADE 2D BARCODES

Thesis submitted in the partial fulfillment of the requirement for the award of the Degree of

MASTER of ENGINEERING (M.E.)

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ELECTRONICS AND COMMUNICATION ENGINEERING

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DECLARATION

I, Gaurav Yadav hereby declare that this report entitled, **"BER Based FRR Analysis of Low Parameter Grade 2D Barcodes"** is an authentic record of my own work carried out towards the partial fulfillment for the award of degree of M.E. (Electronics and Communication Engg.) at Thapar University, Patiala, under the guidance of Mr. Parminder Singh Reel, Lecturer, ECED during January to June 2009.

I have not submitted the matter presented in the thesis for award of any other degree of this or any other university.

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Gaurav Yadav

ABSTRACT

The recent popularity of camera equipped mobile phones has introduced a new field for use of 2D bar codes. A code can be printed on everyday items and be interacted with using a camera phone. 2D bar codes were designed to carry significantly more data with higher Information density and robustness than its 1D counterpart. A two dimensional bar code contains binary and alphanumeric information, which is decoded by camera equipped mobile phones. Data entry for mobile phones has always been limited by the phone's numeric keypad. One way to overcome this is through 2D barcodes read by the phone's camera. Bar code reading applications use phone's camera to capture an image of bar code and then use the phone's processor for decoding.

My thesis reviews the causes of low parameter grade in Data matrix 2D barcodes and suggests the image processing techniques to improve BER performance for low parameter grade 2D barcodes. Previous related work in this field is also presented in literature survey. 2D Barcode symbol grade is the most important parameter for communicating the print quality of a symbol. The scan grade is the lowest grade achieved for parameters Symbol contrast, Modulation, Fixed Pattern Damage, Axial non-uniformity, Grid non-uniformity, Angle of distortion. I have considered the fidelity of the camera phone's captured image as a metric for gauging reading reliability. Bit Error Rate (BER) is used as an indicator for having a good First Read Rate (FRR). First Read Rate is an advanced and better gauge for bar code reading reliability. The aim of thesis is to improve this BER by applying known image processing based algorithms on individual parameter prone low-grade bar codes to help increasing the FRR. In this thesis, I set up test experiments for same low-grade barcodes, which will be enhanced using image processing techniques using Matlab.

CONTENTS

DECLARATION i
ACKNOWLEDGEMENT ii
ABSTRACT iii
CONTENTS iv
LIST OF FIGURES vi
LIST OF TABLES x

1. INTRODUCTION………………………………………………….... 1-6

1.1 NEED OF 2D BARCODES………………………………………………..... 1
1.2 POSSIBLE CAUSES OF LOW PARAMETER GRADES
IN 2D BARCODES………………………………………………………….. 3
1.3 OBJECTIVE OF THESIS…………………………………………………. 5

2. LITERATURE SURVEY……………………………………….. 7-13

3. BACKGROUND OF BARCODES…………………………… 14-34

3.1 BARCODES……………………………………………………………... 14
3.1.1 1D Barcodes……………………………………………………...... 15
3.1.2 2D Barcodes……………………………………………………...... 17
3.1.2.1 Stacked barcodes………………………………………..... 18
3.1.2.2 Matrix barcodes…………………………………………... 19
3.2 TWO DIMENSIONAL BARCODE FOR CAMERA PHONE…………... 20
3.2.1 Quick Response Code……………………………………………... 21
3.2.2 Data Matrix Code……………………………………………… 24
3.2.3 Visual Code……………………………………………………….. 26

3.3 POSSIBLE CAUSES OF LOW PARAMETER GRADES IN 2D
2D BARCODES…………………………………………………………..... 27
3.3.1 Symbol Contrast……………………………………………………... 27
3.3.2 Modulation…………………………………………………………... 29
3.3.3 Angle of Distortion………………………………………………….. 30
3.3.4 Fixed Pattern Damage……………………………………………….. 30
3.3.5 Axial Non-Uniformity……………………………………………….. 31
3.3.6 Grid Non-Uniformity………………………………………………... 31
3.3.7 Print Growth/Loss…………………………………………………..... 32

3.4 FIRST READ RATE ANALYSIS……………………………………… 33

4. PROPOSED APPROACHES TO IMPROVE FRR USING VARIOUS IMAGE PROCESSING ALGORITHMS AND RESULTS………………………………………………………… 35-70

4.1 PROPOSED APPROCHES TO IMPROVE FRR USING VARIOUS IMAGE PROCESSING ALGORITHMS……………………………... 35
4.1.1 Pixel Brightness Transformations……………………………………. 35
4.1.2 Geometric Transformations………………………………………….. 36
4.1.3 Local Pre-Processing……………………………………………….... 37
4.1.4 Image Restoration……………………………………………………... 37

4.2 IMPLEMENTATION RESULTS………………………………………….. 38

5. CONCLUSION AND FUTURE WORKS…………………… 73-75

5.1 CONCLUSION………………………………………………………… 73
5.2 FUTURE WORKS……………………………………………………… 74

6. REFERENCES………………………………………………… 76-78

LIST OF FIGURES

Figure 1.1	1D Bar Code Symbol...……………………………….……….…..…….....	2
Figure 1.2	2D Bar Code Symbol……...…………………………….……….…...…..	2
Figure 1.3	The Difference between Traditional 1D barcodes and 2D barcodes….	2
Figure 3.1	Code 39 Symbol………………..……………………..……………..	16
Figure 3.2	EAN-8/EAN-13Code Symbol.………………………………………	16
Figure 3.3	UPC Code Symbol…………………………………..…….............	16
Figure 3.4	Code 16K Symbol……………………………….……..…………...	18
Figure 3.5	PDF 417 Symbol……..……………………………………………	18
Figure 3.6	Most Common 2D Bar codes…….…………………………………..	19
Figure 3.7	Most Commonly Used 2D Bar Codes For Mobile Phones.………….	21
Figure 3.8	QR Codes…………………………………...	22
Figure 3.9	Data Matrix Code Symbol…………………………..……………	25
Figure 3.10	Visual Code Symbol……………………………...........................	26
Figure 3.11	Symbol Contrast…………………………………………………..	27
Figure 3.12	Modulation……………………...………………………………...	29
Figure 3.13	Angle of Distortion……………………….………………………	30
Figure 3.14	Fixed Pattern Damage………………………………….……………	30
Figure 3.15	Axial Non-Uniformity……………………..................................	31

Figure 3.16	Grid Non-Uniformity …………………………..........................	32
Figure 3.17	Print Growth/Loss……………………….……………………...	33
Figure 4.1	Flow Chart for Rotation of tilted image……………………………...	38
Figure 4.2	Rotation of 5 degree tilted image (180x180) (Clock wise)…………..	39
Figure 4.3	Rotation of 10 degree tilted image (180x180) (Clock wise)………....	39
Figure 4.4	Rotation of 15 degree tilted image (180x180) (Clock wise)…………	40
Figure 4.5	Rotation of 20 degree tilted image (180x180) (Clock wise)...............	40
Figure 4.6	Rotation of 25 degree tilted image (180x180) (Clock wise)…………	41
Figure 4.7	Rotation of 30 degree tilted image (180x180) (Clock wise)...............	41
Figure 4.8	Rotation of 35 degree tilted image (180x180) (Clock wise)…………	42
Figure 4.9	Rotation of 40 degree tilted image (180x180) (Clock wise)…………	42
Figure 4.10	Rotation of 45 degree tilted image (180x180) (Clock wise)…………	43
Figure 4.11	Rotation of 5 degree tilted image (180x180) (Anticlock wise)……...	44
Figure 4.12	Rotation of 10 degree tilted image (180x180) (Anticlock wise)…….	44
Figure 4.13	Rotation of 15 degree tilted image (180x180) (Anticlock wise)…….	45
Figure 4.14	Rotation of 20 degree tilted image (180x180) (Anticlock wise)…….	45
Figure 4.15	Rotation of 25 degree tilted image (180x180) (Anticlock wise)…….	46
Figure 4.16	Rotation of 30 degree tilted image (180x180) (Anticlock wise)…….	46
Figure 4.17	Rotation of 35 degree tilted image (180x180) (Anticlock wise)…….	47
Figure 4.18	Rotation of 40 degree tilted image (180x180) (Anticlock wise)…….	47

Figure 4.19 BER Plot For Tilted Image (180x180) By Using Bilinear Transformation…………………………………………….. 48

Figure 4.20 BER Plot For Tilted Image (180x180) By Using Nearest Transformation…………………………………………….. 49

Figure 4.21 BER Plot For Tilted Image (180x180) By Using Bicubic Transformation…………………………………………….. 50

Figure 4.22 Rotation of 5 degree tilted image (140x140) (Clock wise)…………. 51

Figure 4.23 Rotation of 10 degree tilted image (140x140) (Clock wise)……….. 51

Figure 4.24 Rotation of 15 degree tilted image (140x140) (Clock wise)……….. 52

Figure 4.25 Rotation of 20 degree tilted image (140x140) (Clock wise)……….. 52

Figure 4.26 Rotation of 25 degree tilted image (140x140) (Clock wise)……….. 53

Figure 4.27 Rotation of 30 degree tilted image (140x140) (Clock wise)……….. 53

Figure 4.28 Rotation of 35 degree tilted image (140x140) (Clock wise)……….. 54

Figure 4.29 Rotation of 40 degree tilted image (140x140) (Clock wise)……….. 54

Figure 4.30 Rotation of 45 degree tilted image (140x140) (Clock wise)……….. 55

Figure 4.31 Rotation of 5 degree tilted image (140x140) (Anticlock wise)…….. 56

Figure 4.32 Rotation of 10 degree tilted image (140x140) (Anticlock wise)……. 56

Figure 4.33 Rotation of 15 degree tilted image (140x140) (Anticlock wise)……. 57

Figure 4.34 Rotation of 20 degree tilted image (140x140) (Anticlock wise)……. 57

Figure 4.35 Rotation of 25 degree tilted image (140x140) (Anticlock wise)……. 58

Figure 4.36 Rotation of 30 degree tilted image (140x140) (Anticlock wise)……. 58

Figure 4.37 Rotation of 35 degree tilted image (140x140) (Anticlock wise)……. 59

Figure 4.38 Rotation of 40 degree tilted image (140x140) (Anticlock wise)……. 59

Figure 4.39	BER Plot For Tilted Image (140x140) By Using Bilinear Transformation…………………………………………..	60
Figure 4.40	BER Plot For Tilted Image (140x140) By Using Nearest Transformation…………………………………………..	61
Figure 4.41	BER Plot For Tilted Image (140x140) By Using Bicubic Transformation…………………………………………..	62
Figure 4.42	Flow Chart for improve Axial non-uniformity………………………	63
Figure 4.43	Processing for Axial non-uniformity …………………………….	64-66
Figure 4.44	BER Plot For Deformed Image due to Axial Non-Uniformity……..	67
Figure 4.45	Flow Chart for improve Grid non-uniformity……………………….	68
Figure 4.46	Processing for grid non-uniformity……………………………….	69-71
Figure 4.47	BER Plot For Deformed Image due to Grid Non-Uniformity………	72

LIST OF TABLES

Table 5.1 BER For Tilted Image (180x180) By Using Bilinear Transformation…… 48

Table 5.2 BER For Tilted Image (180x180) By Using Nearest Transformation……. 49

Table 5.3 BER For Tilted Image (180x180) By Using Bicubic Transformation……. 50

Table 5.4 BER For Tilted Image (140x140) By Using Bilinear Transformation……. 60

Table 5.5 BER For Tilted Image (180x180) By Using Nearest Transformation…….. 61

Table 5.6 BER For Tilted Image (180x180) By Using Bicubic Transformation…….. 62

Table 5.7 BER For Tilted Image (180x180) By Using Bicubic Transformation…….. 67

Table 5.8 BER For Tilted Image (180x180) By Using Bicubic Transformation…….. 72

CHAPTER 1

INTRODUCTION

1.1 NEED OF 2D BARCODES

The idea to use barcodes for the reliable and fast entering of data was developed soon after the invention of the computer. Due to the lack of suitable opto-electronic readers for scanners the development of barcodes could not be seriously pursued until after World War II. An initial patent for a round code was registered in the USA in 1949. The big breakthrough for barcode systems finally came in the 1960's and 70's thanks to various efforts to introduce unified systems and standards (1972, introduction of the Coda bar; 1973, introduction of the Universal Product Code (= U.P.C.); 1974, introduction of Code 39, the first industrial barcode; 1976, establishment of the European Article Number Code (= EAN-Code) in Europe).

Bar codes have been widely used for dozens of years, which performs the role of an index key for accessing a database. A bar code is simply a series of stripes (usually black) on a light background (usually white) that can be scanned and read directly into a computer. They are interpreted virtually and without errors by a barcode reading system. However, the traditional 1D barcodes have an apparent shortness in terms of information density. The vertical dimension does not carry any information but only provides a redundancy that is especially convenient for decoding by handset laser scanner when the user is not careful about the orientation and registration bounds. Nowadays more and more applications require a much longer barcode to encoding larger amount of information tips such as the price, product name, manufacturer, functionality, and expiration date of a product. Therefore the 2D barcodes were designed to carry significantly more data than its 1D counterpart.

These two types of barcodes, which work as index key for accessing a database, are given in following figures.

Figure 1.1: 1D Barcode Symbol

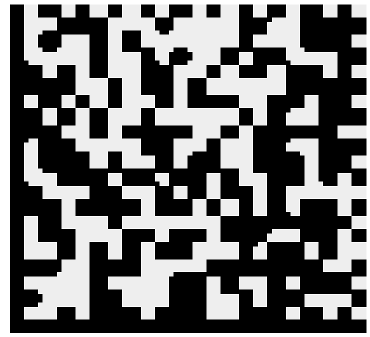


Figure 1.2: 2D Barcode Symbol

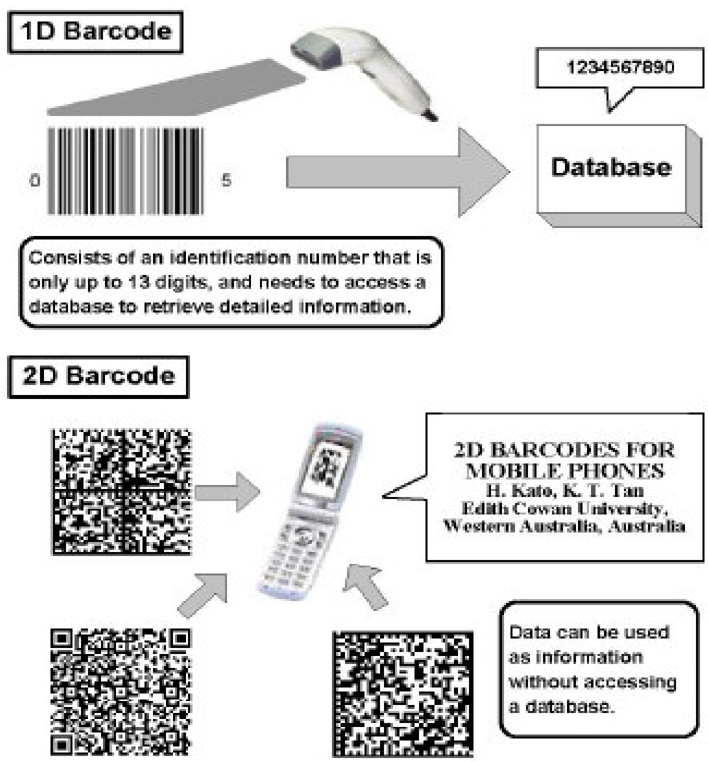


Figure 1.3: The Difference between Traditional 1D Barcodes and 2D Barcodes [1]

An area scanner, such as a charge coupled device (CCD) scanner, is generally used in industries to scan a 2D barcode. The emergence of camera phones may change the current status. It will bring mobility to the traditional barcode readers so as to build a ubiquitous information and computing platform based on which many compelling applications will be driven.

Modern mobile phones are equipped with high-resolution color displays, they support different standards of wireless networking, and they have reasonable processing power and memory. Although still primarily used for voice communication, with the inclusion of digital cameras these devices have become a potential platform for machine vision applications such as barcode recognition. An interesting approach is capturing barcodes with their cameras and decoding them with software running on the phone. Depending on the nature of the application, alternative actions can follow the decoding stage: A number can be dialed, a text message can be sent, a web page can be displayed, or a back-end application can be accessed. The relationship between resolution, decoding ability, and decoding time is used to find the optimum combination for acceptable overall application usability [2].

1.2 POSSIBLE CAUSES OF LOW PARAMETER GRADES IN 2D BAR CODES

In this thesis, I preferred 2D barcodes, which are used frequently for camera equipped mobile phones. When we capture an image of 2D barcodes by camera equipped mobile phones, it is deformed by different causes given below:

1) Symbol Contrast

The causes of low symbol contrast are either a low background or space reflectance under the illumination conditions used for verification, or a high reflectance of the bars, or a combination of both.

2) Modulation

Most frequently print growth or loss is the underlying reason for low modulation values. Voids within dark modules or spots within light modules introduced modulation. Variation in ink pigmentation or background reflectance is another cause for modulation.

3) Angle of Distortion

Angle is a parameter defining the angle of incidence (relative to the plane of the symbol) of the illumination. The images are captured at different position of camera's phone, which causes the tilting of images. These tilted images cause the distortion at particular angle.

4) Axial Non-Uniformity

Axial Non-Uniformity is the amount of deviation along the symbol's major axes. The most likely cause of non-uniform scaling of the symbol in different axes is a mismatch between the speed of transport of a print head and the height of the symbol.

5) Grid Non-Uniformity

Grid Non-Uniformity refers to a symbol's cell deviation from the ideal grid of a theoretical "perfect symbol".

6) Print Growth/Loss

Print growth can be either positive or negative (print loss). The detailed causes of this are dependent on the print technology used and on the substrate. Print Growth refers to the deviation (larger or smaller) of actual element size from intended element size due to printing problems.

1.3 OBJECTIVE OF THESIS

In my thesis, I proposed to decrease BER by applying known image processing based algorithms in Matlab on individual parameter prone low parameter grade 2D barcodes which helps in increasing the FRR.

To achieve these objectives, I have taken low parameter grade 2D barcodes as input images, which are captured by camera of mobile phone. Camera equipped mobile phones works as barcode reader. In this thesis, I processed low parameter grade image by different image processing techniques to decrease BER. The BER is decreased by using different transforms available in image processing as mentioned below.

1) Brightness Transformations

There are two classes of pixel brightness transformation [3]: Brightness corrections, Gray scale transformations. Brightness correction modifies pixel brightness taking into account its original brightness and its position in the image. While gray-scale transformations do not depend on the position of the pixel in the image.

2) Geometric Transformations

Geometric transform [3] permit the elimination of the geometric distortion that occur when an image is captured. A geometric transform typically consists of two basic steps: Pixel coordinate transform, Brightness Interpolation. First is the pixel co-ordinate transformation, which maps the co-ordinates of the input image pixel to the point in the output image. The second step is to find the point in the digital raster which matches the transformed point and determine its brightness value. The brightness is usually computed as an interpolation of the brightnesses of several points in the neighborhood. The three most common interpolation methods are nearest neighbor, bilinear, and bi-cubic.

3) Local Neighborhood Pre-Processing

Local Pre-processing [3] methods use a small neighbourhood of a pixel in an input image to produce a new brightness value in the output image. For the pre processing two groups are common: smoothing and detection. Smoothing aims to suppress high frequencies in the Fourier transform domain. While edge detectors are a collection of very important local image pre-processing methods used to locate changes in the intensity function; edges are pixels where this function (brightness) changes abruptly.

4) Image Restoration

Image restoration [3] methods aim to suppress degradation using knowledge about its nature. Most image restoration methods are based on de-convolution applied globally to the entire image. Image restoration techniques can be classified into two groups: deterministic and stochastic. Deterministic methods are applicable to images with little noise and a known degradation function. The original image is obtained from the degraded one by a transformation inverse to the degradation. Stochastic techniques try to find the best restoration according to a particular stochastic criterion, e.g., a least-squares method.

5) Inverse Perspective Transform

The input image has a deformed shape because of being captured from the camera device. The inverse perspective transformation [4] is used to normalize the code shape. This transform maps deformed vertexes (x_i, y_i) of original image to normalize vertexes (u_i, v_i).

$$u_i = \frac{c_{00} \times x_i + c_{01} \times y_i + c_{02}}{c_{20} \times x_i + c_{21} \times y_i + c_{22}}$$

$$v_i = \frac{c_{10} \times x_i + c_{11} \times y_i + c_{12}}{c_{20} \times x_i + c_{21} \times y_i + c_{22}}$$

CHAPTER 2

LITERATURE SURVEY

1) A TWO-DIMENSIONAL BARCODE READER

N. Normand and C. Viard-Gaudin present this paper in 1994 at IEEE International Conference.

This paper provided a complete scheme allowing locating and reading bar codes with a 2D vision system. It is composed of two main functions: bar code localization on the overall image, and the reading stage. The localization of the symbol, which can be oriented in any direction, is carried out with an original method, which relies upon the extraction of high-density area of mono-oriented gradients. The reading method is based on the detection of the transitions between the stripes by extracting the zero-crossings of the second derivative of the ID signal reconstructed from the 2D bar code block.

2) A COMMON IMAGE PROCESSING FRAMEWORK FOR 2D BARCODE READING

E.Ottaviani, A.Pavan, M.Bottaz, E.Brunclli, F.Casclli, and M.Guerre jointly presented this paper in 1999 at Image Processing and its Applications, Conference.

This paper describes an image processing system able to locate segment and decode the most common 2D symbol used in applications. The different symbol are treated exploiting their similarities, in order to achieve an unified computational structure The paper presents a general image processing architecture in order to locate and decode 2D symbols like Maxi code, QR-code and Data matrix. The approach ensures high reading performances even under bad lighting conditions and strong perspective deformations.

3) BARCODE READERS USING THE CAMERA DEVICE IN MOBILE PHONES

This paper is presented by Eisaku Ohbuchi, Hiroshi Hanaizumi and Lim Ah Hock in 2004 at International Conference on Cyberworlds.

This paper shows new algorithm and the implementations of image reorganization for QR barcode in mobile phones. The mobile phone system used here consists of a camera, mobile application processor, digital signal processor (DSP) and display device, and the source image is captured by the embedded camera device. The introduced algorithm is based on the code area found by four corners detection for 2D barcodes. The input image has a deformed shape because of being captured from the embedded camera device thus in this paper an algorithm known as inverse perspective transformation is used to normalize the code shape.

4) 2D BARCODES FOR MOBILE PHONES

H. Kato and K. T. Tan. presented this paper at IEEE 2nd International Conference on Mobile Technology, Applications and Systems (MTAS 05) in 2005.

This paper provides that 2D barcodes are often used in industrial information tagging application where high data capacity, mobility and data robustness are required. Mobile phones have evolved from just a mobile voice communication device to what is now a mobile multimedia computing platform. Recent integration of these two mobile technologies has sparked some interesting applications of 2D bar codes in mobile phones with camera. However, mobile technology is still in progress and it is important that the standardized 2D bar code not only satisfies the criteria set, but also have features that can meet the demand of applications in the future.

5) A SKEW DETECTION METHOD FOR 2D BAR CODE IMAGES BASED ON THE LEAST SQUARE METHOD

Ying-Hong Liang, Zhi-Yan Wang in 2006 presented this paper at IEEE International Conference.

In this paper robust and fast algorithm for skew detection in 2D bar code images is proposed. It is based on the least square method. Unlike the methods based on Hough transforms that are computationally expensive, it quickly obtains skew angles making it applicable to real-time applications. This method includes two processes, the segmenting process searches for the bar code region, and then the line fitting process fits the borderline and obtains the skew angle. Experimental results show this method reduces the running time. Using the line information of the bar code's borders, this method can search for the borders' skew angle, even when the detected image has high noise.

6) REAL-TIME RECOGNITION OF TWO-DIMENSIONAL BARCODE ON ARM AND DMA

This paper is presented by Kun Zhu, BaifengWu and Qiang Yu in 2006 at IEEE International conference.

This paper presents that two dimensional barcode symbology is an emerging technology used for storing and retrieving the information. Accompanied with the development of technology of 2D barcode and speech coding, the dream of storing the speech on the paper has come true. Since the data capacity of speech 2D-barcode is large and must be decoded with the least delay, a high-performance, low-cost device is extremely needed in the decoding system. ARM (Advanced RISC Machines) microcontroller is widely used in many fields due to its characteristics of high-performance, small volume, low power dissipation and low-cost exactly.

7) BAR-CODE RECOGNITION SYSTEM USING IMAGE PROCESSING

This paper is presented by Mikio Kuroki, Takayuki Yoneoka, Tetsuo Satou, Yoichi Takagi Tadaaki Kitamura, and Noriaki Kayaniori at IEEE International Conference in 2006.

This paper present that information processing is fast developing in various sectors along with the spread of computer technology. The same goes for the commodity production and distribution Industries where the barcode system is increasingly utilized as one of the most useful tools for recognizing unique information related to each commodity. While handy type bar-code readers are normally used by retail shops where small amounts of diverse products are handled, a system to quickly and automatically read out bar-code data pasted on a continuous flow of products is required for use in production sites or distribution centers where large volumes of products are handled.

8) TWO DIMENSIONAL BAR CODE DECODING WITH CAMERA-EQUIPPED MOBILE PHONES

Tasos Falas (Cyprus College) and Hossein Kashani (New York Institute of Technology) presented this paper in 2007 at Fifth Annual IEEE International Conference. This paper presents two dimensional bar-code reading using camera phones. Bar code reading applications use the phone's camera to capture an image of a bar code, and then use the phone's processor for decoding.

This paper has presented 2D barcode decoders using mobile phones. The software is implemented in Java, for platform independence on phones supporting J2ME and the approach is promising, with a broad range of applications, from plain data entry on the phone, to product identification and tracking, to linking the physical world to the virtual digital world. There is also discussion about the relationship between resolution, decoding ability, and decoding time, needs to be studied, to find the optimum combination for acceptable overall application usability.

9) THE QR-CODE REORGANIZATION IN ILLEGIBLE SNAPSHOTS TAKEN BY MOBILE PHONES

Aidong Sun (College of Informatics South China Agriculture University), Yan Sun (School of Computer Sci. and Tech., Beijing Univ. of Posts and Telecommunications) and Caixing

Liu (College of Informatics South China Agriculture University) presented this paper in 2007 at Fifth International Conference on Computational Science and Applications.

This paper gave an algorithm for the analysis and correction of the distorted QR barcode (QR-code) image. The introduced algorithm is based on the code area finding by four corners detection for 2D barcode.

Here canny edge detection combines with contours finding algorithms to erase noises and reduce computation and utilize two tangents to approximate the right-bottom point. Then, it gives a detail description on how to use inverse perspective transformation in rebuilding a QR-code image from a distorted one. This algorithm assumes that input image is the skewed code symbol but not curved for all edges. However, this algorithm possibly would be applied to the curved code symbol.

10) PERVASIVE 2D BARCODES FOR CAMERA PHONE APPLICATIONS

Hiroko Kato and Keng T. Tan wrote this invited paper in 2007 for IEEE Computer Society.

This paper provides the overview of six barcodes that can be used in camera equipped mobile phones. It considered that the fidelity of the camera phone's captured image as a metric for gauging reading reliability. They have also discussed that first-read rate is used to quantitatively verify our earlier results and better gauge reading reliability.

11) THE QR-CODE REORGANIZATION IN ILLEGIBLE SNAPSHOTS TAKEN BY MOBILE PHONES

Aidong Sun, Yan Sun and Caixing Liu jointly presented this paper in 2007 at Fifth International Conference on Computational Science and Application.

This paper gives an algorithm for the analysis and correction of distorted QR bar code image. The introduced algorithm is based on the code area finding by four corners detection for 2D barcode. This paper also gives a detail description on how to use inverse perspective transformation in rebuilding a QR–code image from a distorted one. This algorithm assumes that input image is the skewed code symbol but not curved for all edges. However, this algorithm possibly would be applied to the curved code symbol.

12) FIRST READ RATE ANALYSIS OF 2D-BARCODES FOR CAMERA PHONE APPLICATIONS AS A UBIQUITOUS COMPUTING TOOL

This paper presented by H. Kato and K. T. Tan in 2007 at IEEE International Conference.

This paper presents a detailed study on the first read rate (FRR) of seven 2D- barcodes currently used for camera phone applications. Through whole analysis, it is identified that three factors to improve the robustness of 2D-barcodes reading, the range of the reading distance and the stability of the readers, which are consistent and independent from particular implementation. This will contribute to the widespread use of 2D-bar code mobile technology as a ubiquitous computing tool.

13) UNDERSTANDING 2D-BARCODE TECHNOLOGY AND APPLICATION IN M-COMERCE –DESIGN AND IMPLEMENTATION OF A 2D BARCODE PROCESSING SOLUTION

Jerry Zeyu Gao, Lekshmi Prakash, and Rajini Jagatesan presented this paper at 1st Annual International Computer Software and Application Conference 2007.

This paper provided that with the swift increase of the number of mobile device users, more wireless information services and mobile commerce application are needed. Since various barcodes have been used for decades as a very effective means of traditional commerce systems, today people are looking for innovative solutions to use barcodes in the wireless world. Recently, the mobile industry began to pay more attention to barcode applications in m-commerce because 2D-barcodes not only provide a simple and inexpensive method to present diverse commerce data, but also improve mobile user experience by reducing their inputs.

This paper discusses the importance of 2D barcodes and their usage and impacts in mobile commerce and wireless applications. It reviews the current innovative initiatives in 2D barcode enabled mobile application systems.

14) USEOF 2D BARCODE TO ACCESS MULTIMEDIA CONTENT AND THE WEB FROM A MOBILE HANDSET

S. Lisa, G. Piersantelli presented this paper in 2008 at IEEE International Conference.

This paper describes the features, the applications, the functionalities and the benefits of the 2D barcodes, pictorial machine-readable representations of information and data. Mobile phones with digital camera can act as bar code reader: a software client installed on the mobile phone controls the digital camera in order to acquire, scan and decode a 2D bar code and retrieve the information from the Internet.

15) CONTEXTUAL QR CODES

Jose Rouillard presented this paper in 2008 at IEEE International Conference.

This paper presented the technology, usage and way of programming two dimensional bar codes, called QR codes. They offer an interesting way to capture and distribute a tremendous amount of information in a simple, quick and efficient manner. Using camera phones to read two dimensional bar codes for various purposes is currently a popular topic in both research and in practical applications.

CHAPTER 3
BACKGROUND OF BARCODES

3.1 BARCODES

Barcode is a fast, easy and accurate automatic data collection method. Barcode enables products to be tracked efficiently and accurately at speed not possible using manual data entry system. Barcode is basically a way of cheaply printing machine readable information on objects. Barcode, as machine-readable representation of information in a visual format can be easily stored, transferred, processed and validated [5]. Using barcodes provide a simple and inexpensive method of encoding text information that is easily read using electronic readers. There are many different kinds of barcodes, ranging from only being able to store a small number to several thousand bytes. The barcode reader only used to recognize the bar code.

Barcode is one of the most prevalent automatic identification, keyless data entry technologies. Traditional one dimensional (1D) barcode, which encodes limited number of globally unique digits, works as an index to a backend database. It enables efficient sales and inventory management, providing real-time information on products. However, the demand for a barcode that carries more data in less space rose in certain industries such as pharmaceutical industries, which resulted in the invention of two dimensional (2D) bar codes. Carrying data within itself, 2D barcode works as a portable data file [6].

Originally arising from the logistics department of large supermarket chains, today barcode systems have won a place in many areas of everyday life. Barcodes allow a reliable identification of samples or goods, are simple and universally applicable, and thus facilitate a smooth transfer of information. It is also used in the field of high throughput screenings in the identification and sorting of active ingredients and test results.

A barcode contains information, which is encoded according to specific conventions (symbology) and graphically presents this information within the barcode field in the form of colored stripes or bars and colorless spaces. Normally a barcode contains no descriptive data, instead consisting of a different number of numbers or characters, depending on the type of barcode, which make up a reference number. With the aid of the reference number, information deposited in the form of a data set can be classified and retrieved. In order to handle numbers or characters in an electronic data processing, these must be brought into a form which is understandable for the machine, in other words in machine readable form. For a barcode, the specific information is encoded in the width of the bar, i.e. in the time needed to read it. The aim of the encodement is always to achieve the maximal reliability and distinguishability of the characters.

The barcode is read by an optical reader. For 1D barcodes this is usually a scanner, for 2D barcodes generally a camera system. Thereby the light source of the scanner is absorbed by the dark bars, while the light spaces are reflected. The scanner produces a weak electrical signal for the spaces and a strong signal for the bars. The duration of the signal is determined by how broad or narrow the individual elements are. This signal is converted by an integrated or an external decoder in a temporal sequence and transmitted to a computer.

3.1.1 1D Barcodes

1D or linear barcodes is the code type most people are familiar with. These symbologies are based on multiple side by side vertical bars of different widths and could only encode numbers. One dimensional barcodes consist of a line with colored bars and colorless spaces and can be sub classified into two width and multiple width codes.

- **Two width barcodes:** Two width codes include among others the codes of the family **2/**5 **o**r Code 39.

- **Multiple width barcodes:** Multiple width codes include among others Code EAN-13 and its American counterpart, the UPC-A**,** as well as Code 128.

Different types of 1D barcodes are given in following figures:

Figure 3.1: Code 39 Symbol

Figure 3.2: EAN-8/EAN-13 Symbol

Figure 3.3: UPC Code Symbol

3.1.2 2D Barcodes

After one dimensional barcodes became successfully established in the 1970's and 80's in numerous application areas, the demand arose for barcodes, which were able to encode larger amounts of data error-free. This demand was met with the development of two dimensional barcodes. Until today the most important optical machine readable symbols have been the 1D barcodes. This is a well known and established technology but it shows some limitations in terms of quantity of information stored in a symbol and error correction capability. Also the intrinsic robustness of the barcode symbols is not very high, because many codes do not have any check capability and just some of them make use of a check digit that reduces but does not eliminate the risk of misreading [7].

To overcome these limitations many 2D symbols have recently appeared, in which the optical readable information is stored using the whole area occupied by the symbol. They offer many advantages:

- It is possible to encode up to several thousand characters of machine readable data so they can he viewed as a fully portable data file containing all information required for automatic identification.

- If only short information is required it can be stored in a very small area in which a 1D barcode is not suitable (e.g. silicon wafer electronic components. small pharmaceutical items ...).

- They have an error detection and correction structure increasing the reliability and robustness of the identification.

The research for storing more data in barcodes led to the development of 2D barcodes that can store large amount of data in a small area to support information distribution and detection without accessing a database. But 2D barcodes require sophisticated devices for decoding, which was a challenge until recently. Today, with the advance of the image processing and multimedia capabilities of mobile devices, they can be used as portable bar code encoding and decoding devices.

With the integration of the built-in cameras, mobile phones can work as scanners, barcode readers and portable data storages, maintaining network connectivity. So an interesting approach is capturing barcode with their cameras and decoding them with software running on the phone. When used together with such camera phones, 2D barcodes work as a tag to connect the digital and real world. The most popular application is to link camera phones to Web pages via 2D barcodes. Saved in mobile phones, 2D barcodes can also be used as portable data files such as e tickets/e-coupons. They can be purchased and exchanged via Internet.

Two dimensional barcodes fall into two different classes: the class of stacked barcodes and the class of matrix codes.

3.1.2.1 Stacked barcodes

The basic idea of a stacked code is the linking of individual 1D barcode, in that several bar codes are arranged one over the other. Hereby the actual information is encoded along the x-axis, and the row information in the y-axis. The advantages of stacked codes include the minimal additional effort in going from 1D to 2D**,** since the same printing and evaluation systems can be used. Leading stacked symbologies include **PDF417, Code 49**, and **Code 16K**. Laser scanners, linear imagers and area imagers are used as bar code reader.

Figure 3.4: Code 16 K Symbol

Figure 3.5: PDF 417 Symbol

3.1.2.2 Matrix barcodes

Matrix barcodes encode data in dark and light geometric elements arranged in a grid. The position of each element relative to the center of the symbol is a key variable for encoding. Matrix codes are as a rule read with cameras and other image processing systems**.** Processing (= recognition) of the barcode is possible in any arbitrary position of the code. Matrix codes must however be equipped with fixed code elements for the recognition of position for the scanner. The advantage of all matrix codes is the high information density and low space requirement. Matrix symbologies are most commonly used for small item marking, and also for unattended and high speed reading applications. Common examples include **Data Matrix**, **MaxiCode**, and **QR Code** etc.

Matrix symbologies are decoded by processing the complete image to determine each element's relative position. Laser scanners cannot read matrix codes because they can't view the entire image at once – area imaging is the only barcode scanning technology capable of doing so. A major advantage to using area imagers is that matrix and other bar code symbols can be read in any orientation.

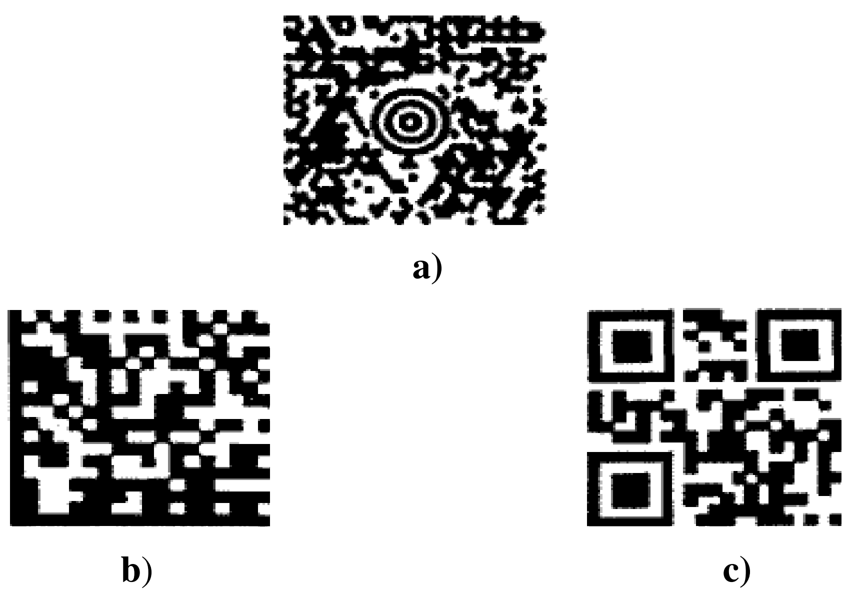


Figure 3.6 Most common 2D barcodes - a) Maxicode, b) Data Matrix-code, c) QR-code [7].

Though each 2D symbol has its own morphological Structure, different symbols may be grouped in three main classes:

- Multi-row (or stacked) codes, in which a set of linear barcodes are stacked together in a single, multi-row symbols. A typical example is the PDF417.
- 2D codes with a locating target, in which a special pattern is used to locate the symbols against a complex or unknown background. Two typical examples are the Maxicode and the QR-code.
- 2D codes without a locating target, in which the locating must exploit the internal structure of the code itself. A typical example is the Data Matrix.

3.2 TWO DIMENSIONAL BARCODE FOR CAMERA EQUIPPED MOBILE PHONES

Although there are more than thirty 2D barcodes are in use. At present, seven 2D barcodes are used for camera phone applications among them. These are: QR Code, VeriCode, Data Matrix, mCode, Visual Code, ShotCode and ColorCode. We can divide them into two categories:

- Database 2D Barcodes
- Index-based 2D Barcodes

The database 2D barcodes QR Code, Veri Code, mCode and Data Matrix were initially invented to improve data capacity for industrial applications However, when integrated into mobile phones with built-in cameras that can scan and decode data; these 2D barcodes can operate as portable databases, letting users access information anytime, anywhere, regardless of network connectivity.

The index-based 2D barcodes Visual Code, Shot Code, and Color Code were developed for camera phones, so they take into account the reading limitations of these built-in cameras.

They have a much lower data capacity than database 2D barcodes, but they offer more robust and reliable barcode reading. Each barcode basically works as an index that links the digital world to the real world, so these barcodes require network connectivity. Figure 3.7 presents these 2D-barcode symbols.

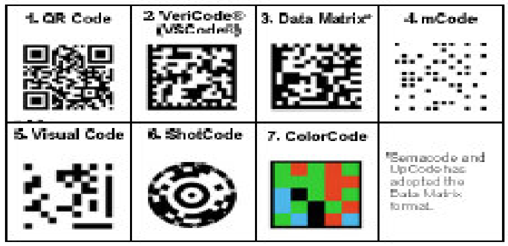


Figure 3.7: Most Commonly used 2D Bar codes for mobile phones

Here we discuss three barcodes, which are frequently used in camera equipped mobile phones.

3.2.1 Quick Response Code: (QR Code)

The QR Code was developed in 1994 by the Nippon Denso Company in Japan to improve the reading speed of complex structured 2D barcodes. The main feature of QR Code is its large capacity and capability to encode Japanese kanji and kana characters. This kind of bar code was initially used for tracking inventory in vehicle parts manufacturing and is now used for variety of industries. QR stands for "Quick Response" as the creator intended the code to allow its contents to be decoded at high speed [8]. It contains information in both vertical and horizontal directions, whereas a classical barcode has only one direction of data (usually the vertical direction).

QR Code's distinctive feature is its position detection patterns, located at three of symbol's corners (see Figure 3.8a) [9]. The squares in the bottom left, top left, and top right corners are locator patterns. When a reader scans a symbol, it first detects these patterns. The ratio of the black and white on a line that passes through the center of the pattern (that is, B: W: B: W:

B) is 1:1:3:1:1 from any angle. This lets the reader quickly find the detection patterns, which in turn promotes ultra-high speed barcode reading.

In the QR Code standard, corners are marked and estimated so that the inside-code can be scanned. QR Code can encode all types of data including symbols, binary data, control codes, and multimedia data. The maximum data capacities are 7,089 characters for numeric data, 4,296 characters for alphanumeric data, and 2,953 bytes for binary data. The symbol versions of QR Code range from version 1 (21 X 21 modules) to version 40 (177 X 177 modules). However, mobile applications use only versions 1–10 to take into account camera phone limitations.

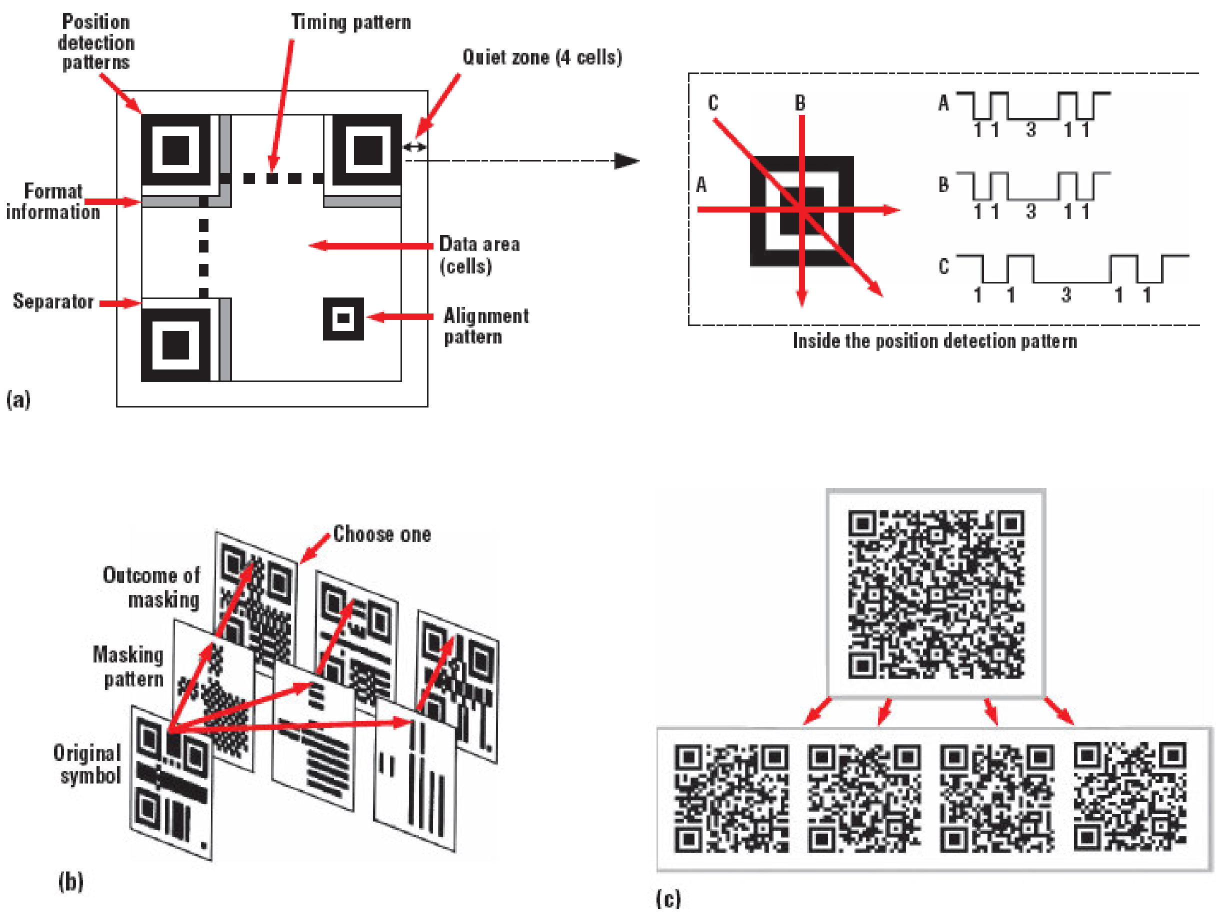


Figure 3.8: QR Codes. (a) Symbol Structure [9], (b) Masking Operation [10], (c) Structure-append feature, which enhances the codes scalability by dividing it multiple data areas [11].

The features of QR barcode symbol are large capacity, small printout size and high speed scanning etc. QR code comprised of the following pattern: finder pattern, timing pattern, format information, alignment pattern, and data cell. The finder patterns located at three corners of the symbol intended to assist in easy location of its position, size and inclination. In 2000 years, QR Code is being issued as National standard in China. QR Code is being used in a wide variety of applications, such as manufacturing, logistics, and sales applications.

Several QR Code features can enhance the code's reading robustness, including error correction, a masking technique [10], and a structured-append function [11]. By applying Reed-Solomon error correction coding, QR Code can restore upto 30% of available codewords (8 bits/codeword) even if the symbol is damaged. Four different error-correction levels are available according to the user's requirement: Level L (approximately 7 percent, M (approximately 15 percent), Q (approximately 25 percent), and H (approximately 30 percent). (The percentages are the data restoration rates for total code words—a unit that constructs the data area. One codeword of QR Code is equal to eight bits.)

The masking technique allocates the black and white dots evenly and helps prevent pattern duplication. This helps readers avoid code misreading so they can quickly process the code. Eight masking patterns exist, and encoders evaluate each pattern to select the best one (see Figure 3.8b). So, after masking, if lines and blocks still exist those are the same colors, the points for the masks are reduced. The encoder selects the mask with the highest mark. The structured-append function enhances a QR Code's scalability by dividing the code into up to 16 data areas. This means we can break a large QR Code symbol into smaller ones (see Figure 3.8c), so we can manipulate the code's cell size and data capacity and satisfy the limitations of camera phone applications. A decoder can then reconstruct the information stored in the multiple QR Code symbols. The error correction level and code division depend on the application, the quality of scanner, or user preference.

3.2.2 Data Matrix Code:

Data Matrix Code was invented by RVSI Acuity CiMatrix (USA). Data Matrix is one of the most well known 2D barcode standards. Each Data Matrix symbol consists of data region which contain nominally square modules set out in a regular way. These modules distributes in matrix elements location and express data information. Data code bit stream is presented by different combination of unit models distributed at matrix element places [12].

The only advantage of QR code is its ability to efficiently encode Japanese Kanji characters. Considering all other comparison criteria, Data Matrix is preferred. It has a higher data capacity for the same code size, being the most space efficient of all 2D symbologies. Data Matrix Code uses between 30% and 60% less space than a QR Code containing the same data. The minimum size for QR Code is 21x21 modules, while Data Matrix has a much more space-efficient minimum size of 10x10 modules

Data Matrix is very compact code. It is very reliable, as it has a powerful error correction algorithm (Reed-Solomon) built in. It employs the Reed-Solomon error correction to enable accurate read when substantial parts of the code are distorted. There is reconstruction of the data content even after damage to the total code symbol of up to 25%. It provides omnidirectional readability also at high transport speeds. It is widely used in the automotive, aerospace and computer manufacturing industries, for large data capacity labelling, such as direct part marking and package marking. The symbology is in the public domain, free of any licensing or royalties.

Data Matrix has a finder pattern comprising two solid lines and two alternating dark and light lines on the symbol's perimeter, which is surrounded by a quiet-zone border (see Figure 3.9) The L shaped solid border defines the physical size, orientation, and symbol distortion, and the broken border on the opposite corner defines the symbol's cell structure.

Data Matrix [13] uses two types of error correction algorithms, depending on the error checking and correcting level employed. ECC levels 000 to 140 offer five different error-correction levels and use convolutional code-error correction. However, ECC-200, which is in common use, uses Reed-Solomon error correction. The symbol size determines ECC-200's correction level.

Data Matrix ECC-200 symbols have an even number of modules on each side. Although the maximum size is 144 rows× 144 columns, each block size is limited to 24 rows ×24 columns to prevent symbol distortions. When the data exceeds the block size, the symbol is divided into four blocks. The maximum data capacity is 3,116 digits, 2,335 alphanumeric characters, or 1,556 bytes. The Data Matrix symbol can be square or rectangle. Several features enhance Data Matrix's reading robustness. First is its size. In a comparison with QR Code and Veri Code in which eight digits were encoded in a .25 mm cell, it created the smallest symbol (3.3× 3.3 mm) and maintained the same level (10–15 percent) of error correction.

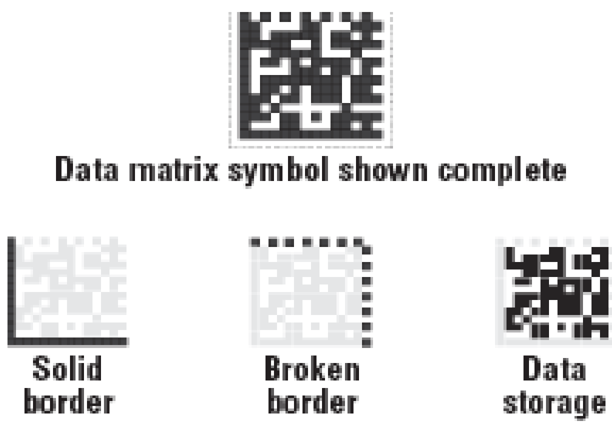


Figure 3.9: Data Matrix Code (Symbol Structure) [14].

Second, a structured-append function can divide a Data Matrix symbol into 16 multiple symbols. The original data can be restored from these, regardless of scanning order, by adding three bytes to each of the smaller symbols. The first additional byte identifies the position for the particular symbol and the total number of symbols in the sequence. The remaining two bytes serve as a file (a "file" is the linked Data Matrices) identifier with a possible value (or ID number) between 1 and 254 (thus allowing up to 254 x 254 = 64,516 identifiers). Third, data compaction can compress data before encoding it in a Data Matrix symbol. This increases the barcode's data capacity. Sema code has adopted the Data Matrix format to encode plain-text URLs and implement them as physical hyperlinks. For example, in Figure 3.9, a phone scans a business card to display the company's URL [14].

3.2.3 Visual Code:

Visual Code [15] was developed to enable Human Computer Interface (HCI) using camera phones. Each code introduces a code coordinate system with its origin at upper left edge of the code and one unit corresponding to a single code bit pattern. The code coordinate system is independent of the orientation of the code in the image. The code recognition algorithm is able to map arbitrary points in an image plane to corresponding points in the code plane.

Also, camera phones, because they are mobile, sometimes randomly rotate or tilt symbols when scanning them. Visual Code can use the amount of rotation and tilt in a captured image as additional input parameters. So, users can obtain different information by rotating the phone, and the users can continuously update the information by moving the phone. This enables applications that support real-time interactions between the camera phone and nearby active displays (see Figure 3.10).

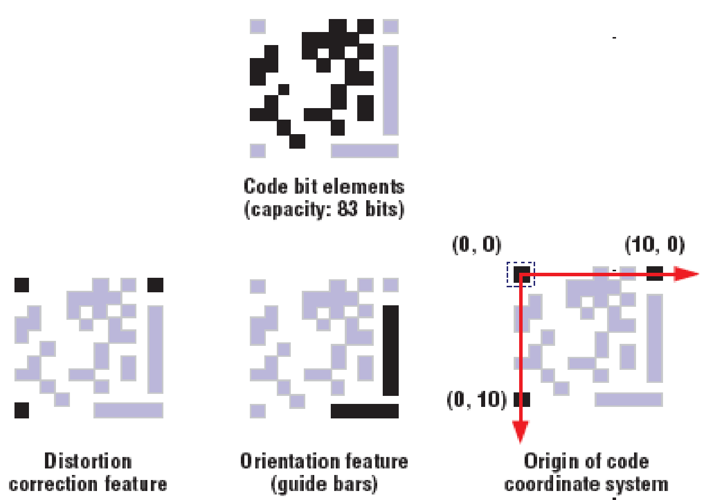


Fig 3.10: Visual Code (Symbol Structure)

Visual code markers provide a convenient means of storing decodable information about products. By reading the bit patterns in a marker, a computer vision system, such as a cell phone equipped with a digital camera, can extract the information and use it to make decisions about the associated product. In a visual code system developed by Rohs [15], an 83-bit sequence is divided into nine adjacent columns of black and white squares.

These columns form the central region of the marker. The pattern within the central region will vary between different encodings. What remain fixed, though, are five structures outside the central region: three corner squares and two rectangles. Altogether, the central region and surrounding guide elements form an 11-by-11 grid, which defines the entire visual code marker [16].

Although the data capacity is limited to 83 bits, Visual Code can function both as a portable database and as an index to a remote database.

3.3 POSSIBLE CAUSES OF LOW PARAMETER GRADES IN 2D BARCODES

3.3.1 Symbol Contrast:

The causes of low symbol contrast are either a low background or space reflectance under the illumination conditions used for verification, or a high reflectance of the bars, or a combination of both as shown in Figure 3.11 [17].

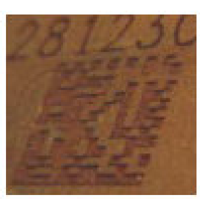


Figure 3.11: **Symbol Contrast**

The Symbol Contrast is the difference between the highest and the lowest reflectance values in the profile. The maximum reflectance (R_{max}) may occur anywhere, in a space or a Quiet Zone. The minimum value (R_{min}) will always be in a bar. The importance of this parameter is that the higher the Symbol Contrast, the more easily distinguishable from each other the bars and spaces will be. SC of 70% or higher is graded 4, while SC below 20% is grade 0.

1) Low background/space reflectance:

Many of these appear to the reading system to be of relatively low reflectance, e.g. visually dark materials under broadband light, blue papers when a red light source is used. Glossy window materials with a high degree of specular reflection can also prevent adequate diffuse reflection from the underlying symbol. Show through from a dark insert, where the opacity of the substrate is low, may also contribute. Extreme amounts of satelliting with ink-jet printers can contribute to a reduction in the reflectance of light modules.

2) High bar reflectance:

The most likely reason for this is the choice of an unsuitable ink formulation/color for the franking marks, one, which exhibits low absorption of the incident light under the specified illumination conditions. Failure to deposit sufficient ink on the substrate will also have the same result. A further reason can be the effect of window material which, if of insufficient clarity or excessively glossy, will reflect a proportion of the incident light before it can be absorbed by the dark areas of the symbol.

3) Minimum reflectance (R_{min}):

R_{min} must always be no higher than half of R_{max}. This is because, for a given level of Symbol Contrast, many scanners have greater difficulty distinguishing relatively light bars against a high-reflectance background than they do darker bars against a relatively low reflectance background.

3.3.2 Modulation:

Most frequently print growth or loss is the underlying reason for low modulation values. However, the use of a measuring aperture that is larger than that specified for the symbol X dimension will also reduce the measured edge contrast of narrow elements more than that of wide elements, and hence reduce the modulation value of the symbol. Irregular reflectance of the substrate (e.g. the effect of material fibers in a synthetic or recycled material, or of a printed background), uneven ink deposition (e.g. caused by a blocked ink jet nozzle) or show through of the contents of the mail-piece can also affect this parameter.

Although modulation shows itself in the form of apparent local variations in contrast it is also an effect of print growth or loss. Potential causes are therefore:

- Misplaced modules.
- Voids within dark modules (e.g. non-overlapping or missing printer dots) or spots within light modules.
- Variation in ink pigmentation or background reflectance (e.g. halftone printed background color, fibers in paper).
- Print growth or loss.
- Incorrect measuring aperture size.
- Show through of the contents of the mail-piece.

Modulation refers to the reflectance uniformity of a symbol’s light and dark elements. In the following example (Figure 3.12) [17], notice that light/dark values of some elements are inconsistent.

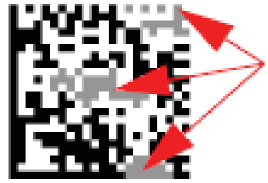


Figure 3.12: Modulation

3.3.3 Angle of Distortion:

Angle is a parameter defining the angle of incidence (relative to the plane of the symbol) of the illumination. It is required in the overall symbol grade if it is different from 45°. Angle of distortion is the symbol's deviation from a 90° relation between row and column. The standards allow a distortion up to 7°; it is shown in given Figure 3.13 [17].

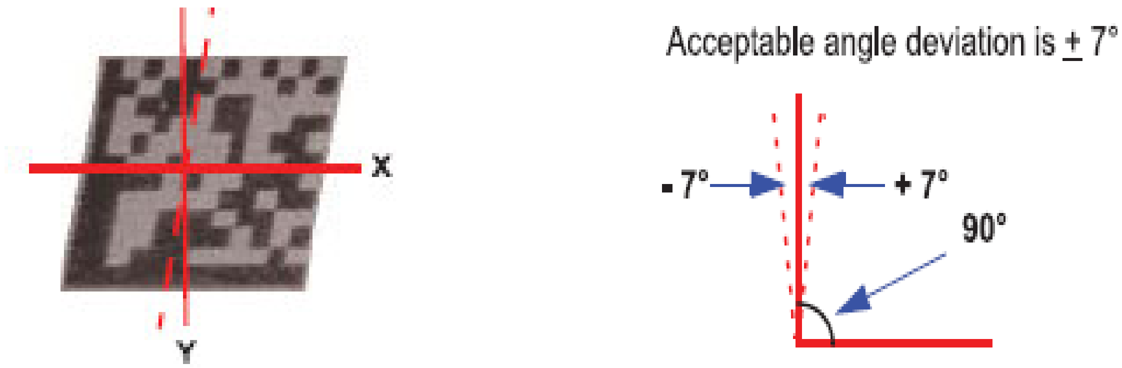


Figure 3.13: Angle of Distortion

3.3.4 Fixed Pattern Damage:

Fixed Pattern Damage refers to finder pattern and clock pattern damage or as physical damage to the symbol, e.g. scuffing, tearing in transit. Notice the missing elements in the clock pattern and the damaged L-pattern in the following example (Figure 3.14) [17], symbol.

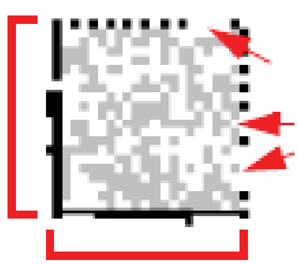


Figure 3.14: Fixed Pattern Damage

3.3.5 Axial Non-Uniformity:

The most likely cause of non-uniform scaling of the symbol in different axes is a mismatch between the speed of transport of a print head and the height of the symbol.

Axial Non-Uniformity is the amount of deviation along the symbol's major axes. In this example, the symbol's Y-axis dimension is clearly greater than its X-axis dimension. This indicates that the marking process is resulting in the Y-dimensions of individual modules being greater than their X-dimensions. This inconsistency of X- and Y-dimensions typically indicates movement of the object as it is being marked in the given Figure 3.15 [17].

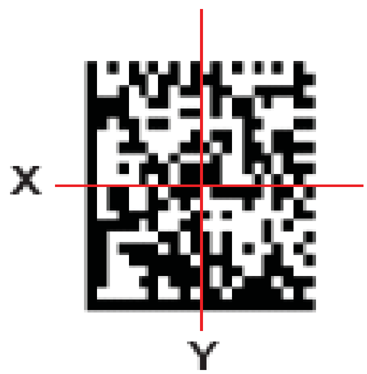


Figure 3.15: Axial Non Uniformity

3.3.6 Grid Non-Uniformity:

Grid Non-Uniformity refers to a symbol's cell deviation from the ideal grid of a theoretical "perfect symbol". The Data Matrix reference decode algorithm is applied to a binarized image of the symbol, comparing its actual grid intersections to ideal grid intersections. The greatest distance from an actual to a theoretical grid intersection determines the Grid Non-Uniformity grade given in following Figure 3.16 [17].

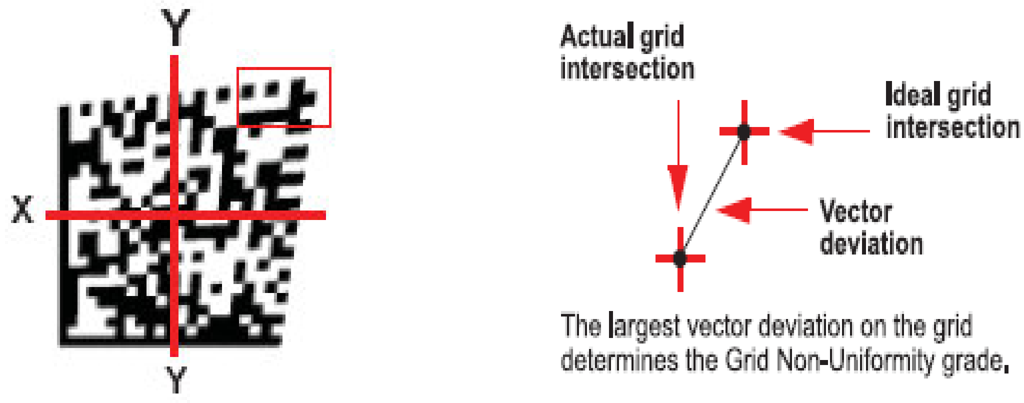


Figure 3.16: Grid Non Uniformity

Deformation of the symbol grid can arise from a number of causes, including:

- Transport errors during printing or reading (acceleration, deceleration, vibration, and slippage).
- Variations in print head to substrate distance due to mail-piece contents.
- Verifier or scanner axis not perpendicular to symbol surface.

3.3.7 Print Growth/Loss:

Print growth can be either positive or negative (print loss). The detailed causes of this are dependent on the print technology used and on the substrate. With ink-jet printing, the ink can be absorbed into the substrate and the image will spread; this can be progressive over some time (minutes or even hours after printing). The droplet size can be excessive or insufficient. The ink formulation can be unsuited to the type of substrate. If too many satellites are generated they can increase the apparent size of a feature. With thermal transfer printing, the most usual cause is incorrect print head temperature, resulting in the transfer of too much or too little pigment from the ribbon. Slippage of the mail-piece in transport past the print head can cause dragging and smearing of the image in one axis. Measurement of print growth is useful for process control purposes.

Print Growth refers to the deviation (larger or smaller) of actual element size from intended element size due to printing problems. When a symbol is printed, the ink may "bleed" when it comes in contact with the substrate, causing an Overprint. If there is not enough ink, or if there is some other problem with printing equipment, the result may be an under print shown in given Figure 3.17 [17].

Figure 3.17: Print Growth/Loss

3.4 FIRST READ RATE (FRR) ANALYSIS

First Read Rate is the probability of a successful (correct) reading by the scanner in its initial attempt. We have analyzed the first read rate (FRR) of each low grade 2D barcodes. We calculated the FRR by the numbers of successful first reads out of the number of attempts.

$$First\ Read\ Rate(FRR) = \frac{Number\ of\ successful\ first\ reads}{Number\ of\ attempted\ first\ reads}$$

The metric allows us to quantitatively verify the result and gauge the reading reliability of a given low grade 2D barcodes. On the basis of experiment results and observation, as far as FRRs are concerned, overall, index 2D-bar codes achieved better results (99.8%) than that of database 2D barcodes (91.5%). The FRRs of the index 2D barcodes were 100% regardless of lighting condition, symbol size, camera resolution, or data capacity.

Unlike the index 2D barcodes, factors such as symbol size and data density had a great impact on the FRRs of database 2D barcodes. Under the same conditions, the FRRs of larger symbols were always higher than that of smaller ones. Likewise, generally, the FRR of denser symbols was lower than that of sparser symbols. This is because data density, together with symbol size, determines the cell size of each symbol. Bigger symbol size with less data in a given print area means an increase in the cell size of a 2D-bar code symbol. Higher camera resolution was not very important to read both black/white and color barcodes.

CHAPTER 4

IMPLEMENTATION OF IMAGE PROOCESSING ALGORITHM AND RESULTS

4.1 PROPOSED APPROCHES TO IMPROVE FRR USING VARIOUS IMAGE PROCESSING ALGORITHMS

Using various image processing [18], [19] based algorithms; the BER of the Low Grade 2D Barcodes can be increased. This facilitates the FRR of these barcodes. I implemented these techniques to improve the FRR. These methods can be classified as follows:

- Brightness transformations
- Geometric transformation
- Local neighborhood pre-processing
- Image restoration

4.1.1 Pixel Brightness Transformations

There are two classes of pixel brightness transformation:

- **Brightness corrections**

Brightness correction modifies pixel brightness taking into account its original brightness and its position in the image [20]. This method can be used only if the image degradation process is stable. If we wish to suppress this kind of error in the image capturing process, we should perhaps re-calibrate the device (find error coefficients e (i, j)) from time to time.

- **Gray scale transformations**

Gray-scale transformations [21] do not depend on the position of the pixel in the image. A transformation T of the original brightness p from scale $[p_0, p_k]$ into brightness q from a new scale $[q_o, q_k]$ is given by

$$q = T(p)$$

Frequently used brightness transformation includes:

- Brightness thresholding
- Histogram equalization
- Logarithmic gray scale transform
- Look up table transform
- Pseudo color transform

4.1.2 Geometric Transformations

Geometric transform permit the elimination of the geometric distortion that occur when an image is captured. A geometric transform consists of two basic steps. First is the pixel co-ordinate transformation, which maps the co-ordinates of the input image pixel to the point in the output image. The output point co-ordinates should be computed as continuous values (real numbers), as the position does not necessarily match the digital grid after the transform. The second step is to find the point in the digital raster which matches the transformed point and determine its brightness value. The brightness is usually computed as an interpolation of the brightnesses of several points in the neighborhood. A geometric transform typically consists of two basic steps:

- **Pixel Coordinate Transform**

A pixel coordinate transform [22] is a vector function T that maps the pixel (x, y) to a new position (x',y') an illustration of the whole region transformed on a point-to-point basis. T is defined by its two component equations

$$x' = T_x(x, y)$$

$$y' = T_y(x, y)$$

- **Brightness Interpolation**

Each pixel value in the output image raster can be obtained by brightness interpolation of some neighboring non-integer samples. Brightness interpolation influences image quality. The simpler the interpolation, the greater is the loss in geometric and photometric accuracy, but the interpolation neighborhood is often reasonably small due to computational load. The three most common interpolation methods are nearest neighbor, linear, and bi-cubic.

4.1.3 Local Pre-Processing

Local Pre-processing methods use a small neighbourhood of a pixel in an input image to produce a new brightness value in the output image [23].For the pre processing two groups are common: smoothing and detection.Smoothing aims to suppress noise or other small fluctuation in the image, it is equivalent to suppressing high frequencies in the Fourier transform domain. Smoothing approaches based on direct averaging blur image edges. More sophisticated approaches reduce blurring by averaging in homogeneous local neighbourhood. Median smoothing is a non-linear operation; it reduces the blurring of edges by replacing the current point in the image by the median of the brightness in its neighborhood [24].

4.1.3 Image Restoration

Image restoration methods aim to suppress degradation using knowledge about its nature. Most image restoration methods are based on de-convolution applied globally to the entire image. Relative contrast speed movement of the object with respect to the camera, wrong lens focus, and noise are three typical image degradations with simple degradation functions [25].

I implemented some of the above-mentioned techniques to improve the BER of the Barcode Images so that a higher FRR is achieved.

4.2 IMPLEMENTATION RESULTS

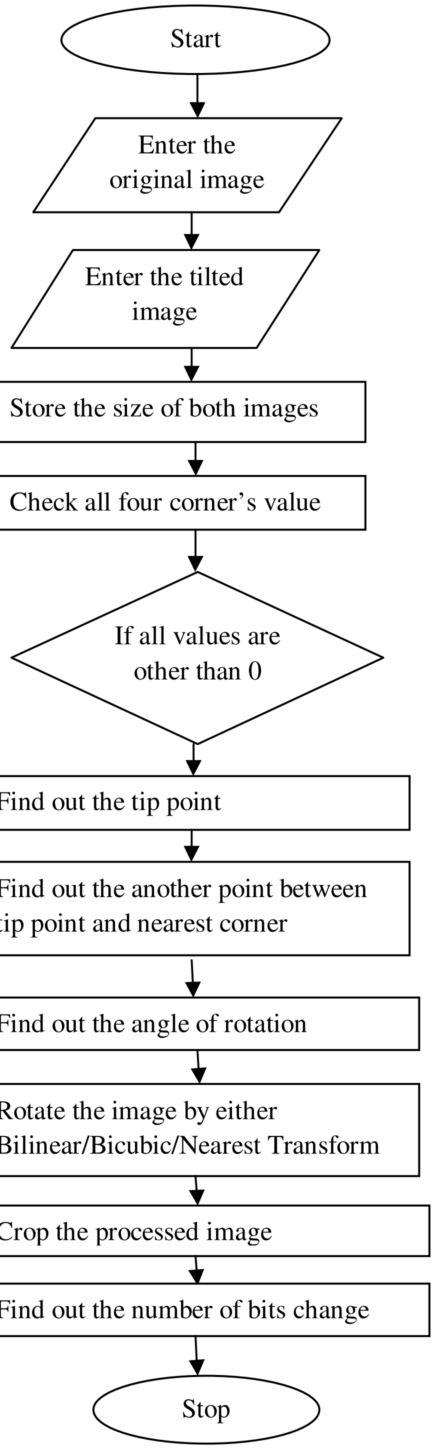


Figure 4.1: Flow Chart for Rotation of tilted image

ROTATION OF TILTED IMAGE (180X180)

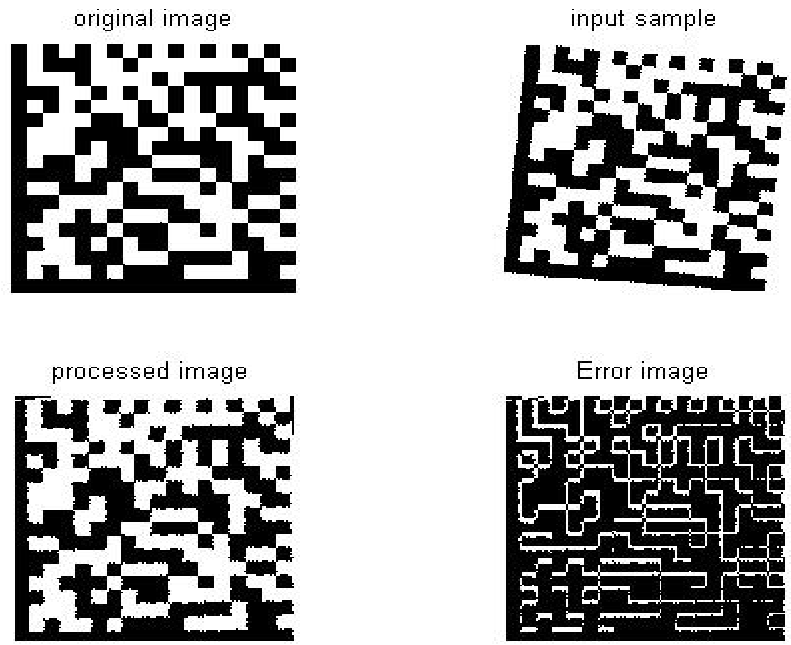


Figure 4.2: Rotation of 5 degree tilted image (Clock wise)

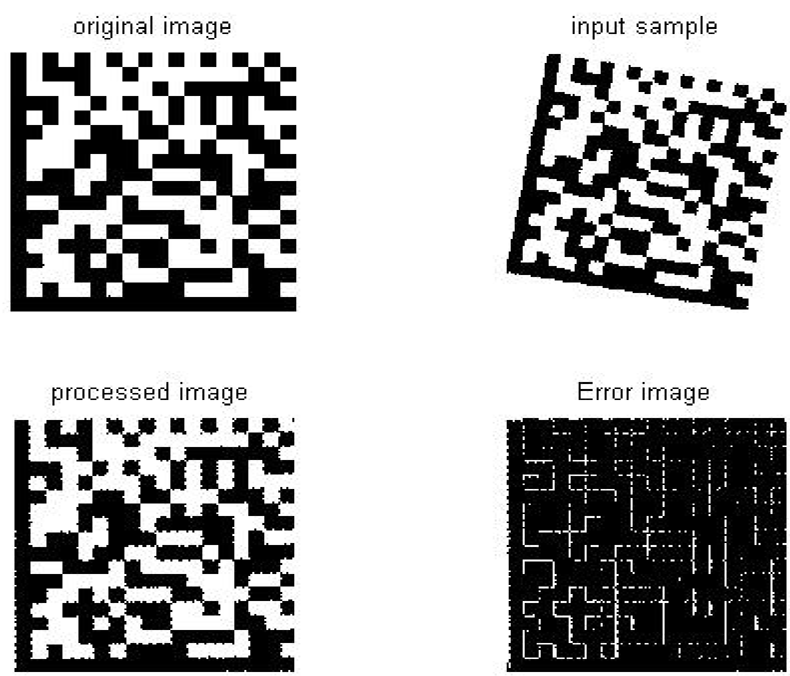


Figure 4.3: Rotation of 10 degree tilted image (Clock wise)

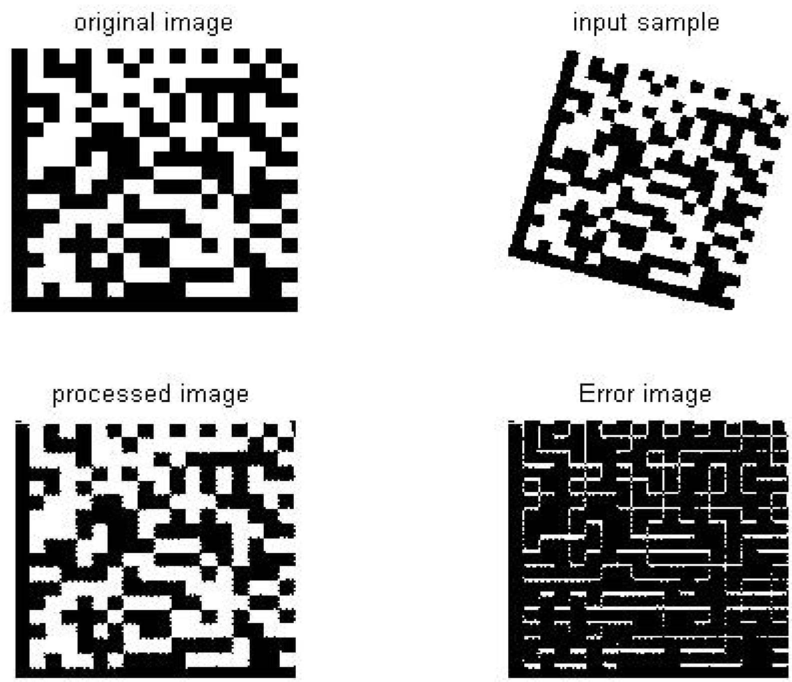


Figure 4.4: Rotation of 15 degree tilted image (Clock wise)

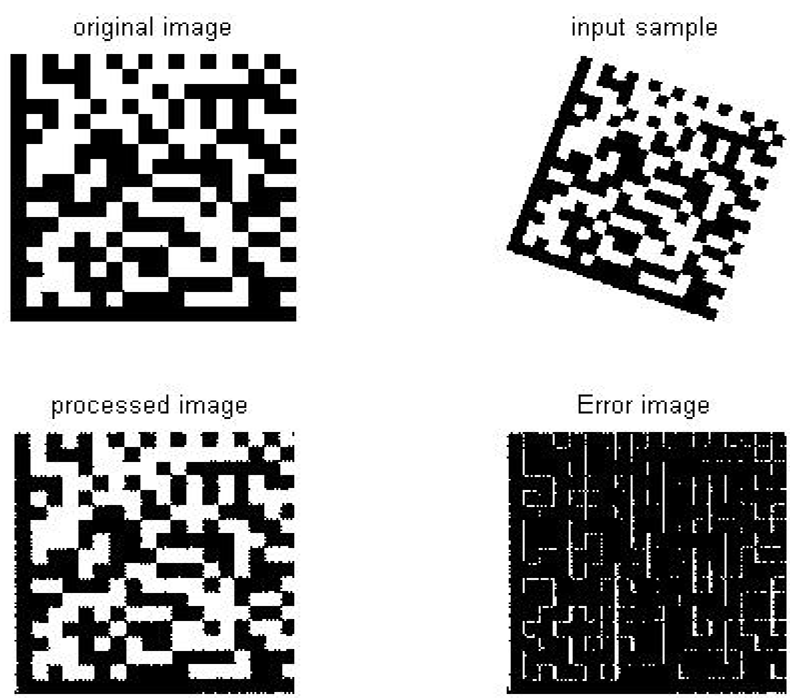


Figure 4.5: Rotation of 20 degree tilted image (Clock wise)

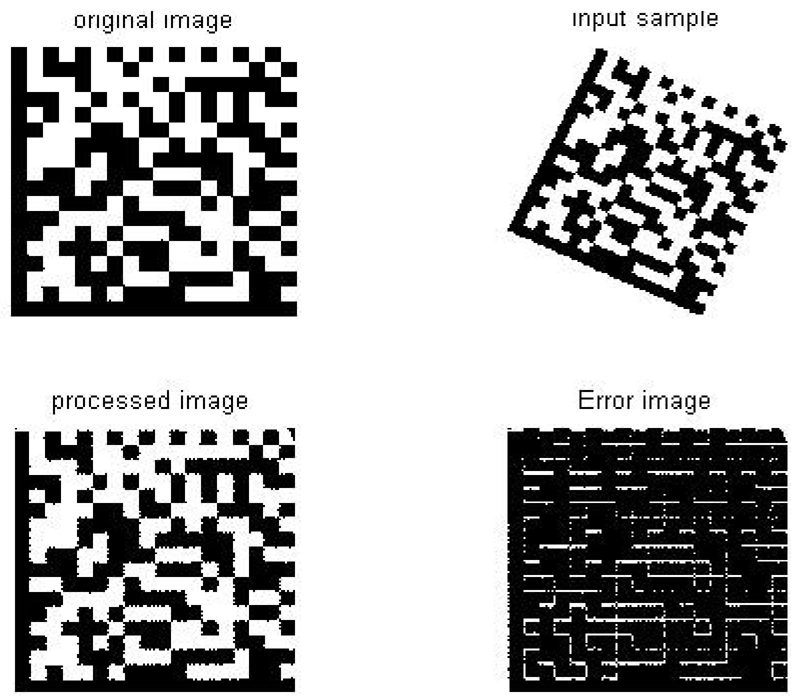


Figure 4.6: Rotation of 25 degree tilted image (Clock wise)

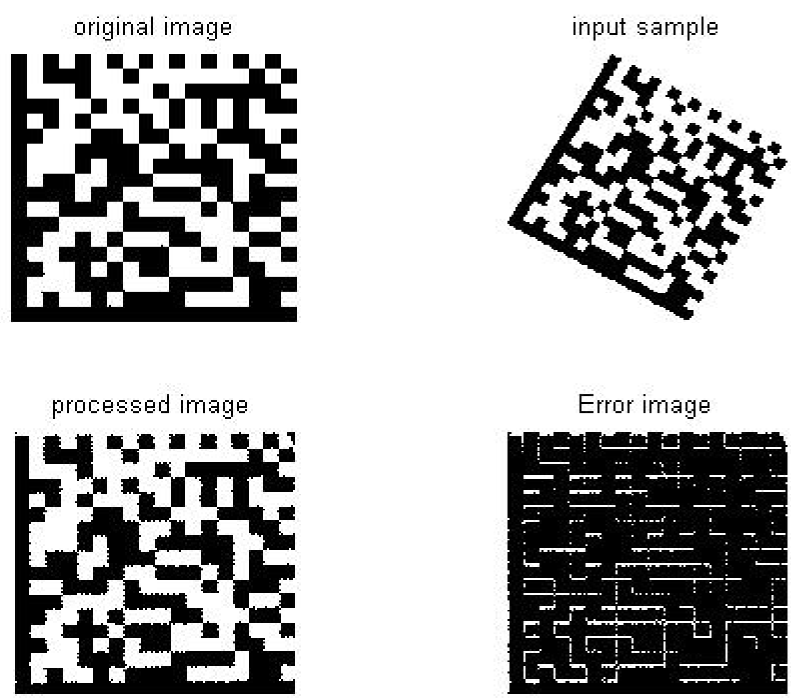


Figure 4.7: Rotation of 30 degree tilted image (Clock wise)

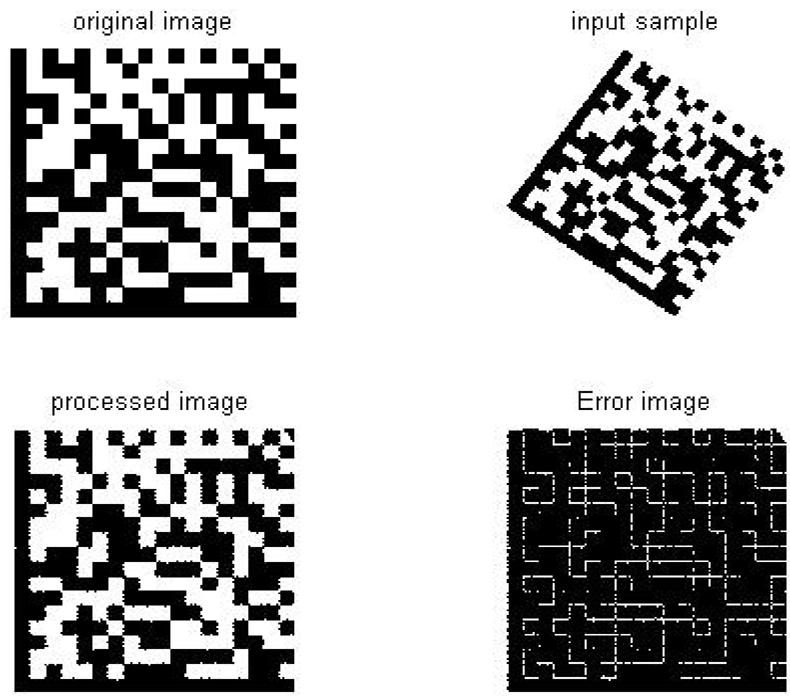


Figure 4.8: Rotation of 35 degree tilted image (Clock wise)

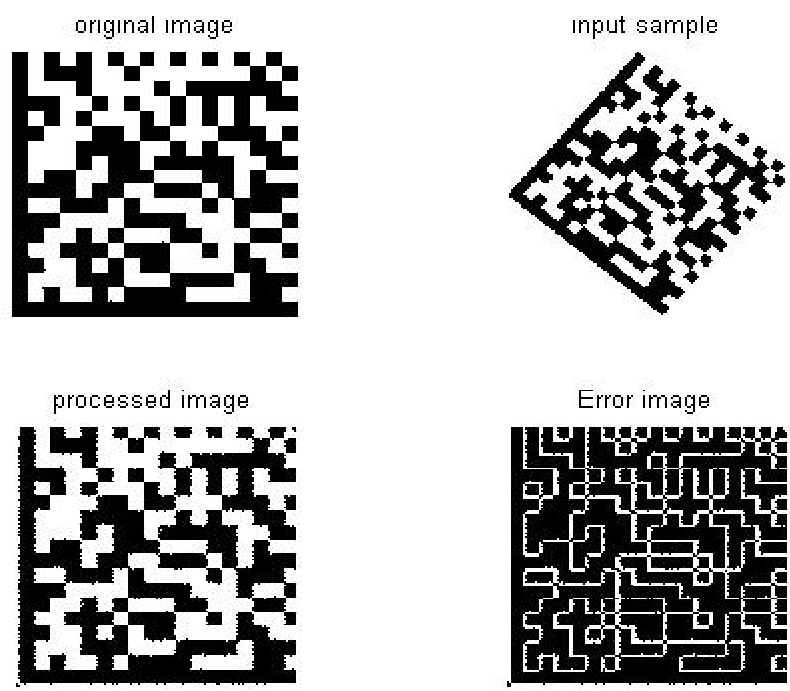


Figure 4.9: Rotation of 40 degree tilted image (Clock wise)

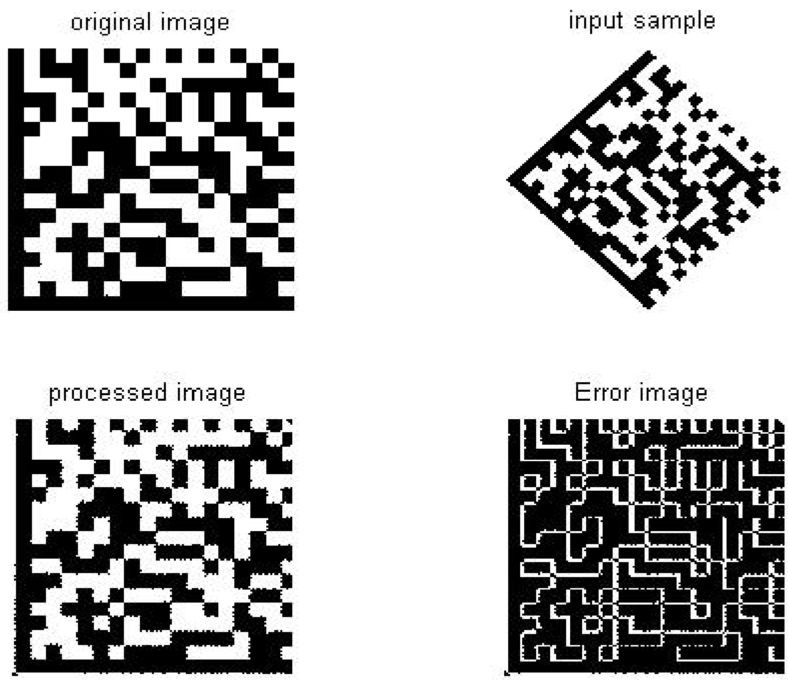


Figure 4.10: Rotation of 45 degree tilted image (Clock wise)

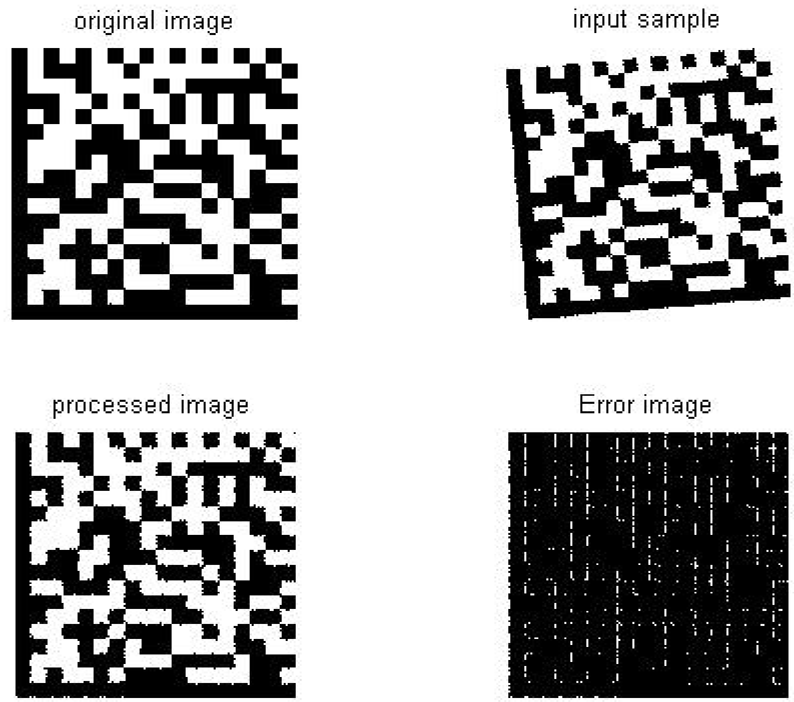


Figure 4.11: Rotation of 5 degree tilted image (Anticlock wise)

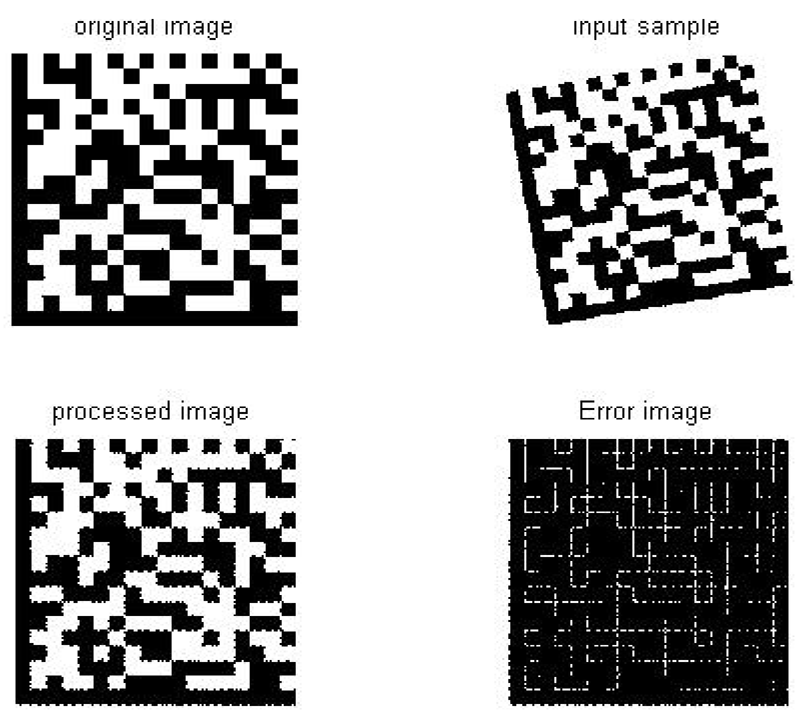


Figure 4.12: Rotation of 10 degree tilted image (Anticlock wise)

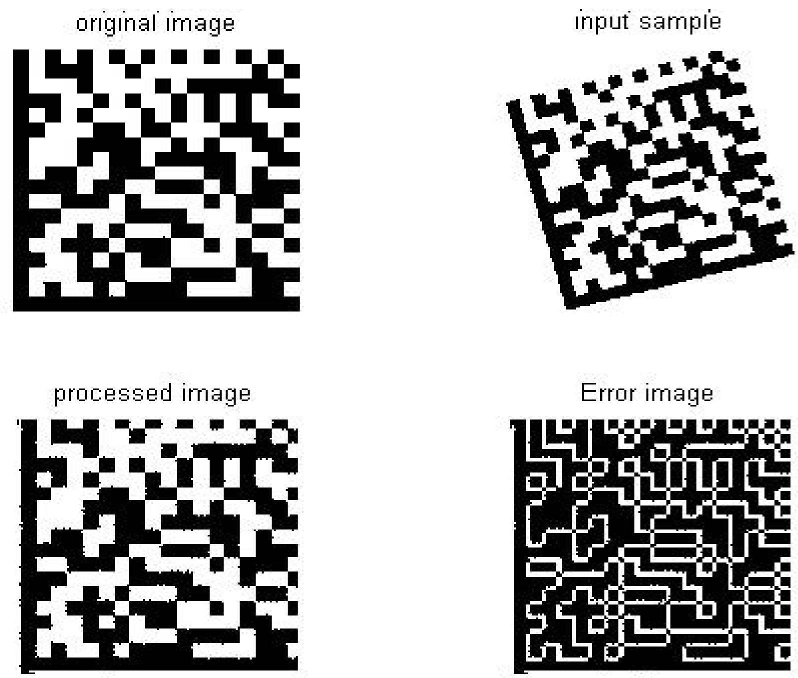


Figure 4.13: Rotation of 15 degree tilted image (Anticlock wise)

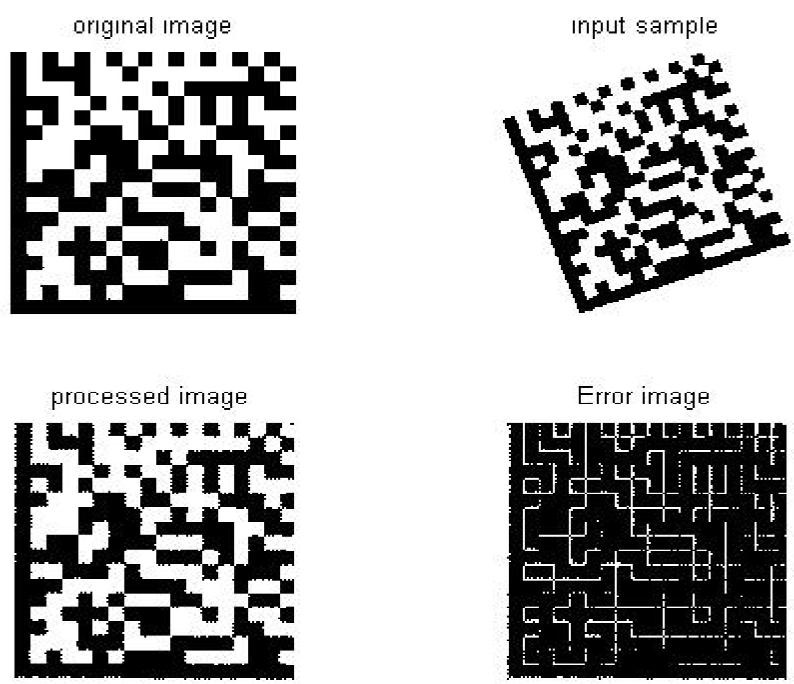


Figure 4.14: Rotation of 20 degree tilted image (Anticlock wise)

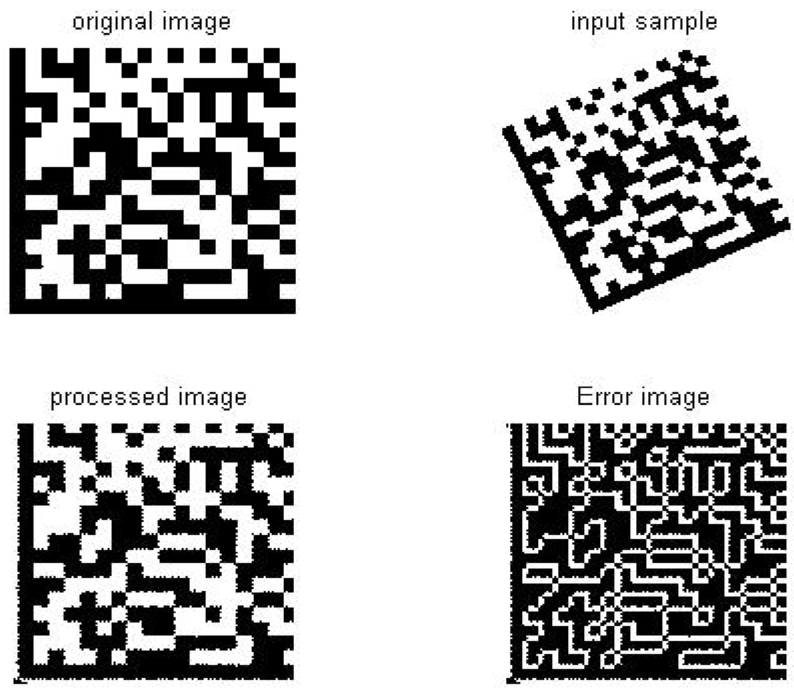


Figure 4.15: Rotation of 25 degree tilted image (Anticlock wise)

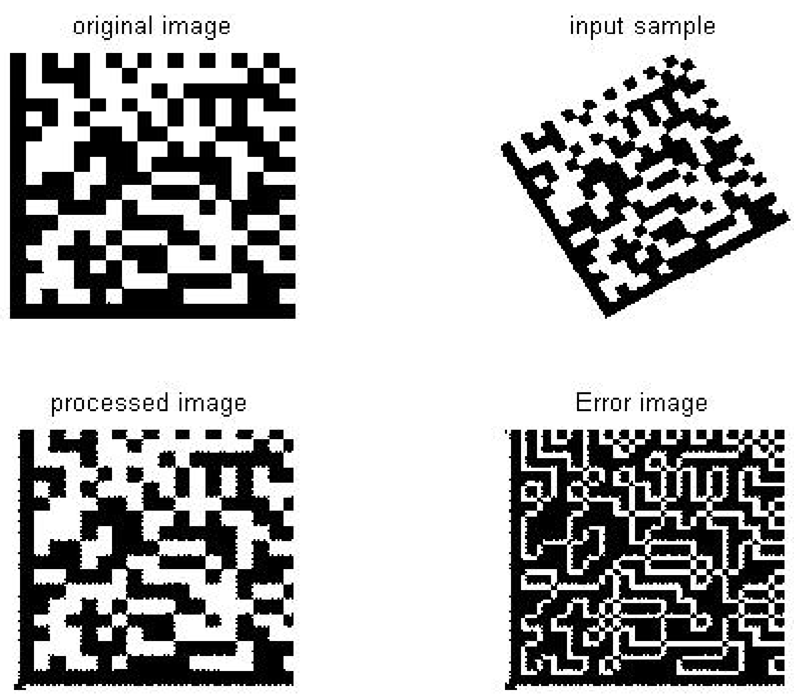


Figure 4.16: Rotation of 30 degree tilted image (Anticlock wise)

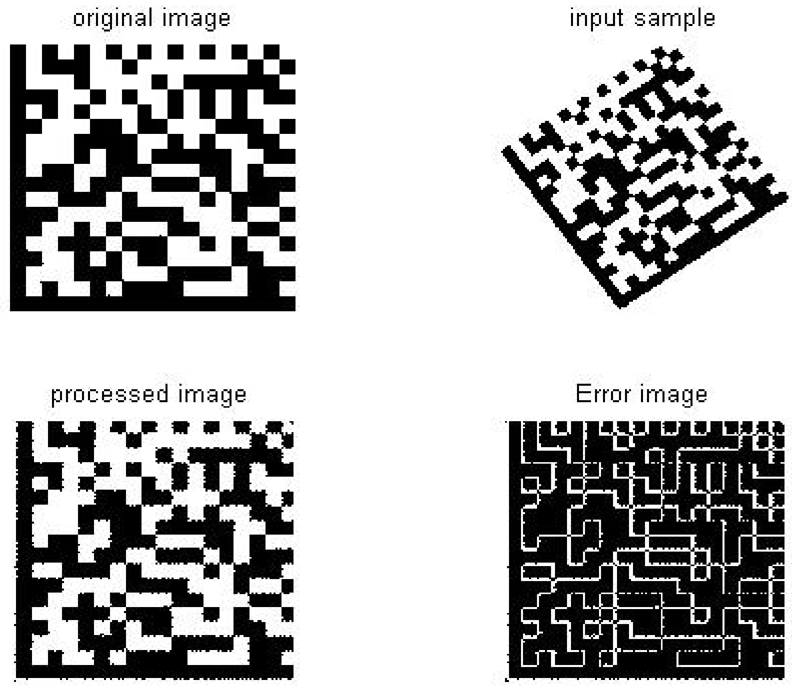


Figure 4.17: Rotation of 35 degree tilted image (Anticlock wise)

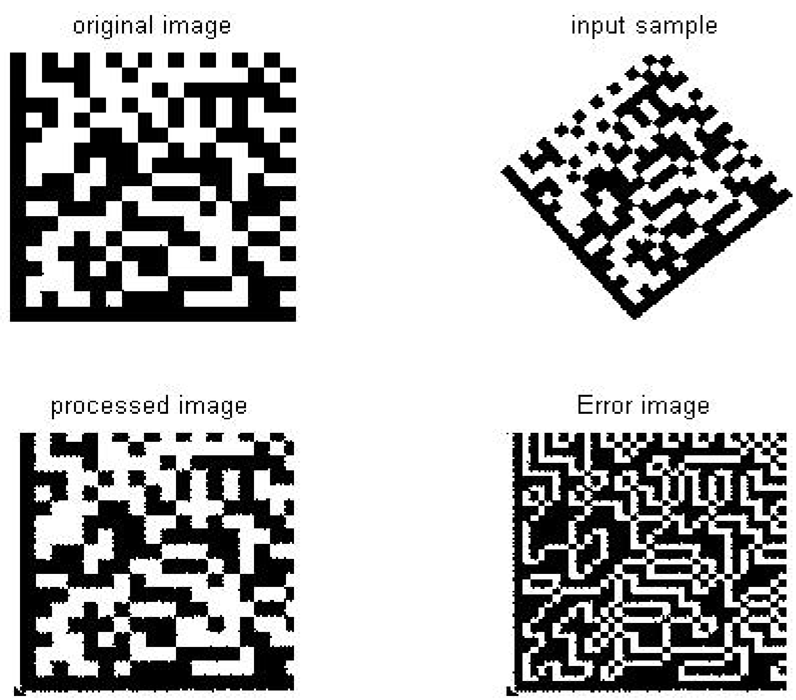


Figure 4.18: Rotation of 40 degree tilted image (Anticlock wise)

Table 5.1

BER For Tilted Image (180x180) By Using Bilinear Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	38.6543	19.3704	32.6358	32.0401	11.0102	28.8981	6.6260	3.6790

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	19.7099	7.0679	14.5123	9.0401	10.0802	9.1790	8.6451	22.8781	22.9938

b) Clockwise Rotation

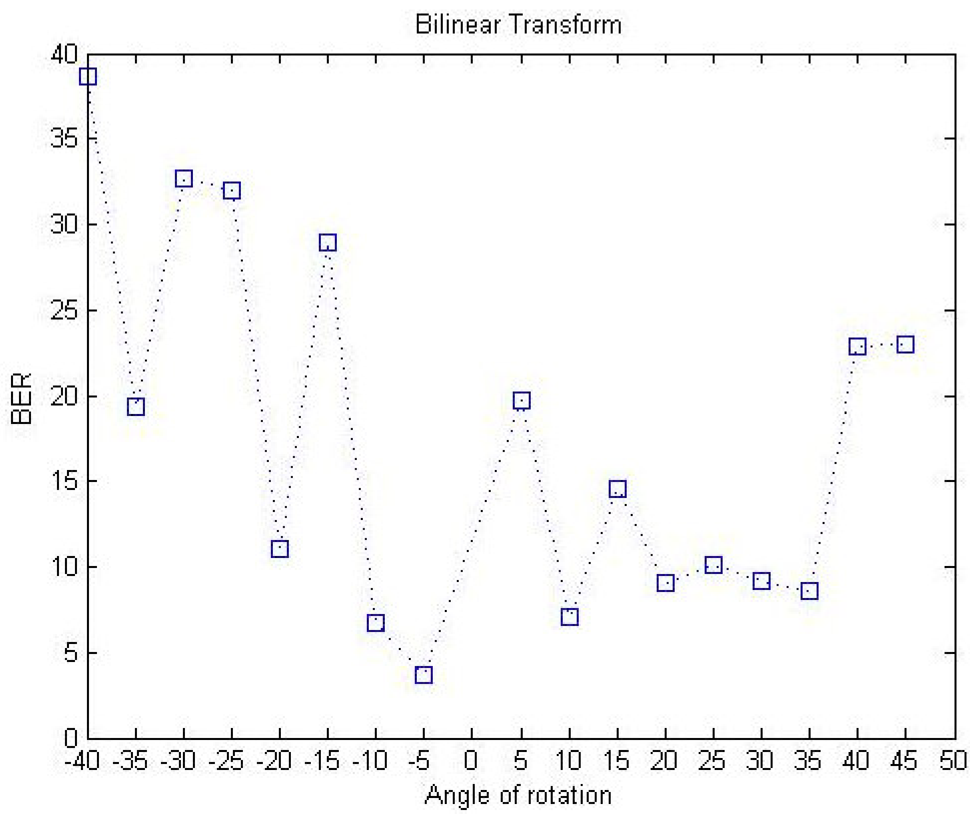


Figure 4.19: BER Plot For Tilted Image (180x180) By Using Bilinear Transformation

Table 5.2

BER For Tilted Image (180x180) By Using Nearest Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	38.6727	19.4136	32.8179	32.3241	11.0523	28.9394	6.6758	4.1049

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	19.7593	7.2377	14.5462	9.1759	10.2809	9.3889	8.6827	22.9099	23.8426

b) Clockwise Rotation

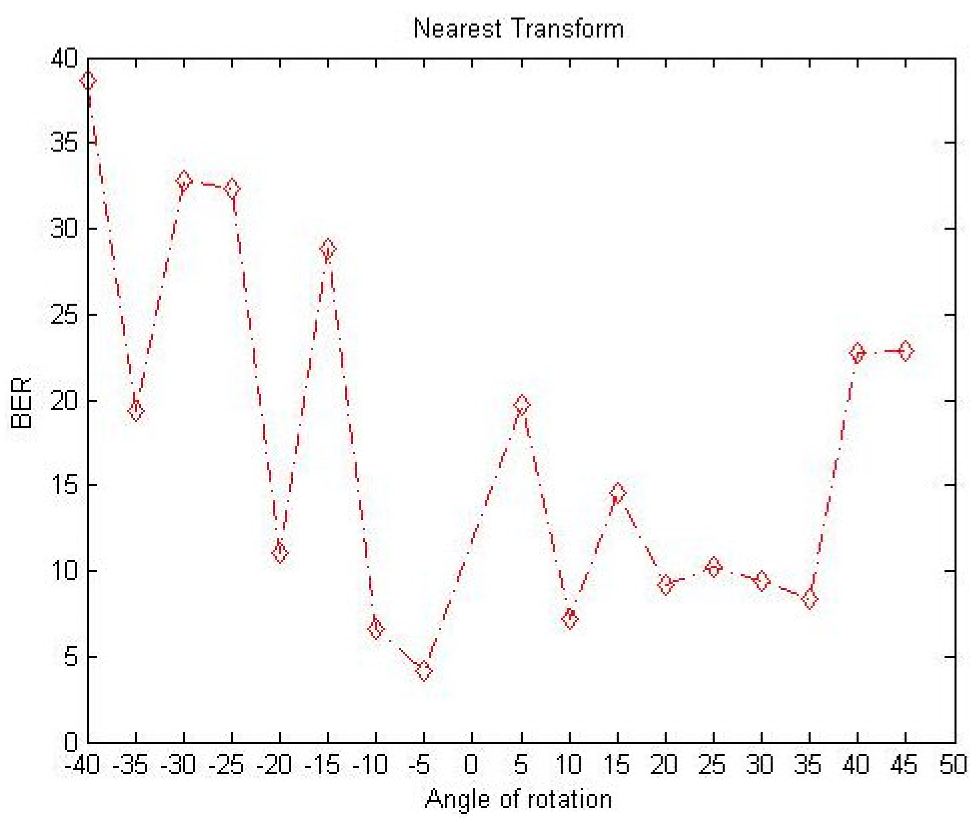


Figure 4.20: BER Plot For Tilted Image (180x180) By Using Nearest Transformation

Table 5.3

BER For Tilted Image (180x180) By Using Bicubic Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	38.6636	19.3889	32.6728	32.0586	11.0486	28.9136	6.6667	3.8765

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	19.7332	7.1420	14.5001	9.0556	10.1142	9.2469	8.6680	22.8935	23.0617

b) Clockwise Rotation

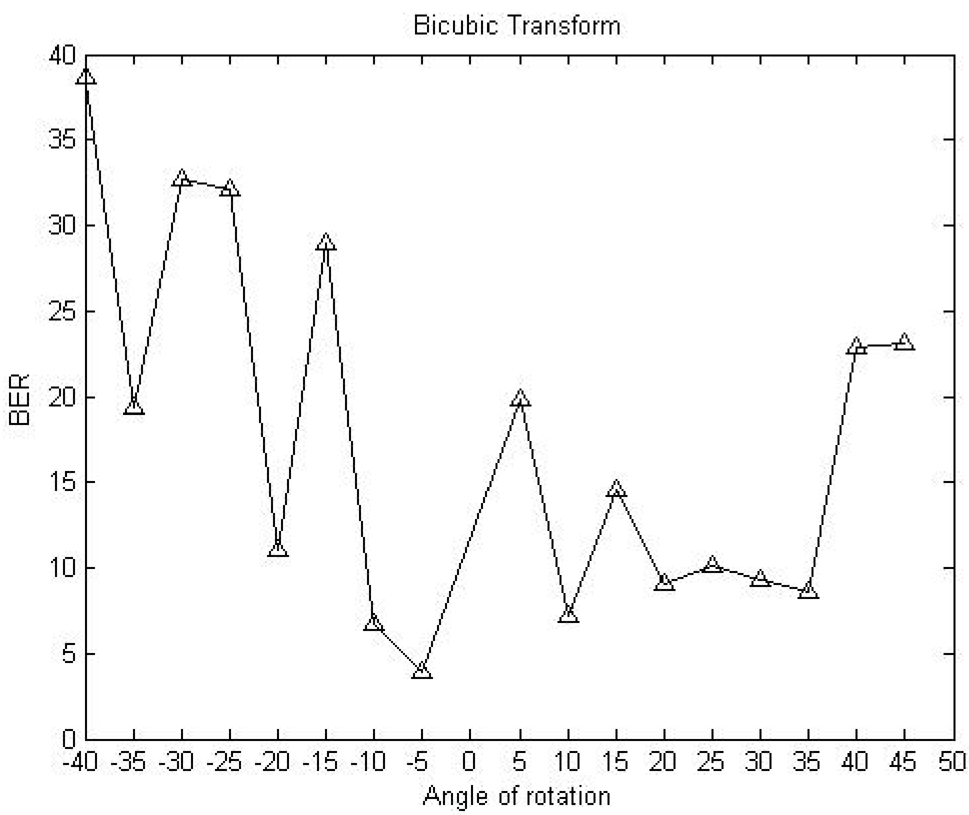


Figure 4.21: BER Plot For Tilted Image (180x180) By Using Bicubic Transformation

ROTATION OF TILTED IMAGE (140X140)

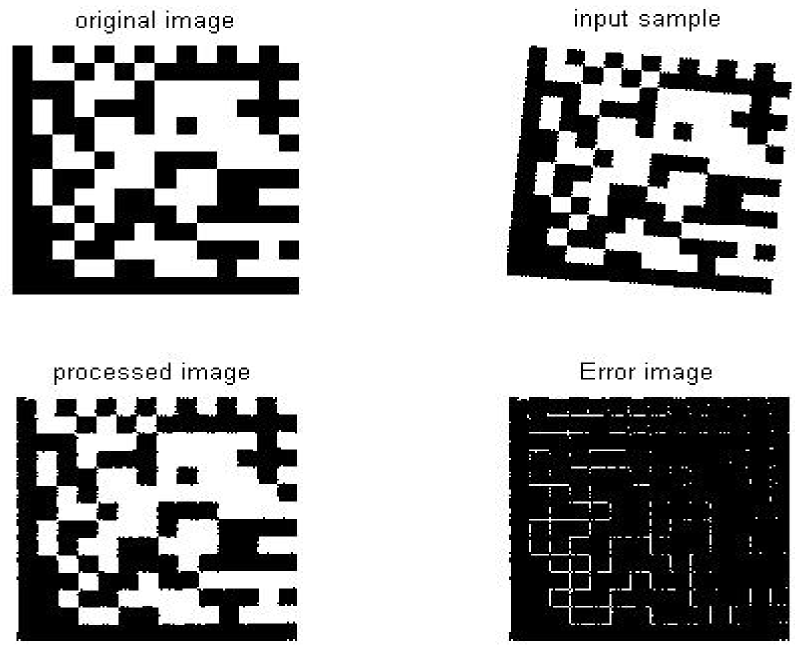


Figure 4.22: Rotation of 5 degree tilted image (Clock wise)

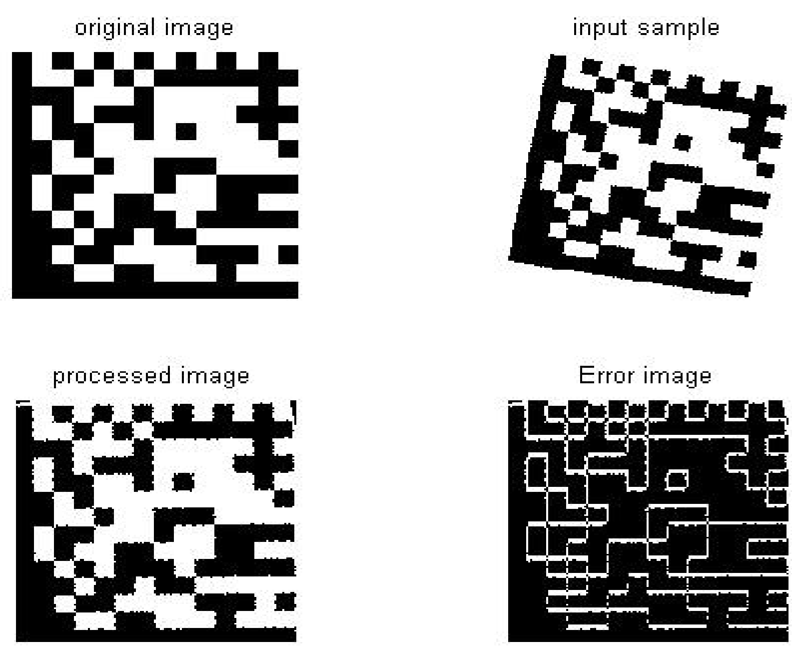


Figure 4.23: Rotation of 10 degree tilted image (Clock wise)

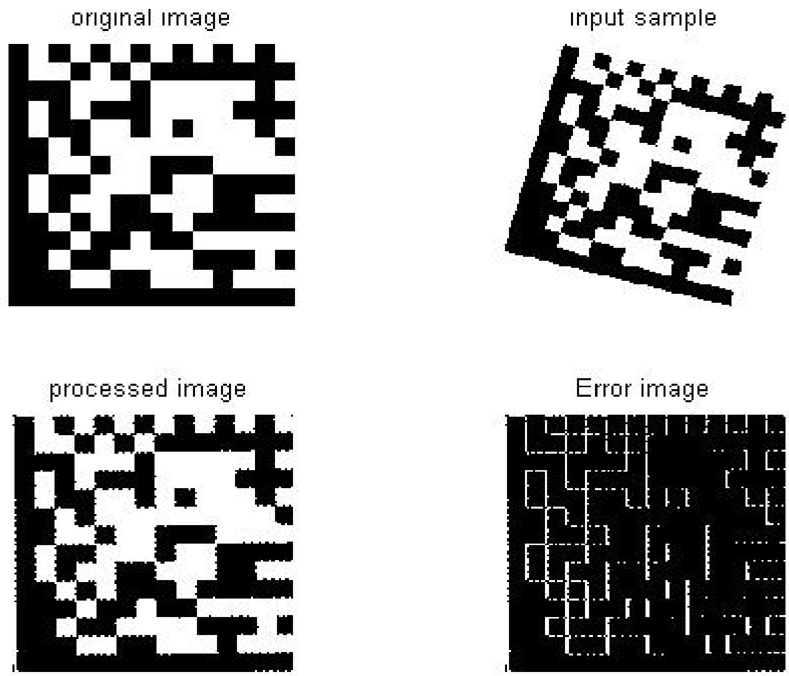


Figure 4.24: Rotation of 15 degree tilted image (Clock wise)

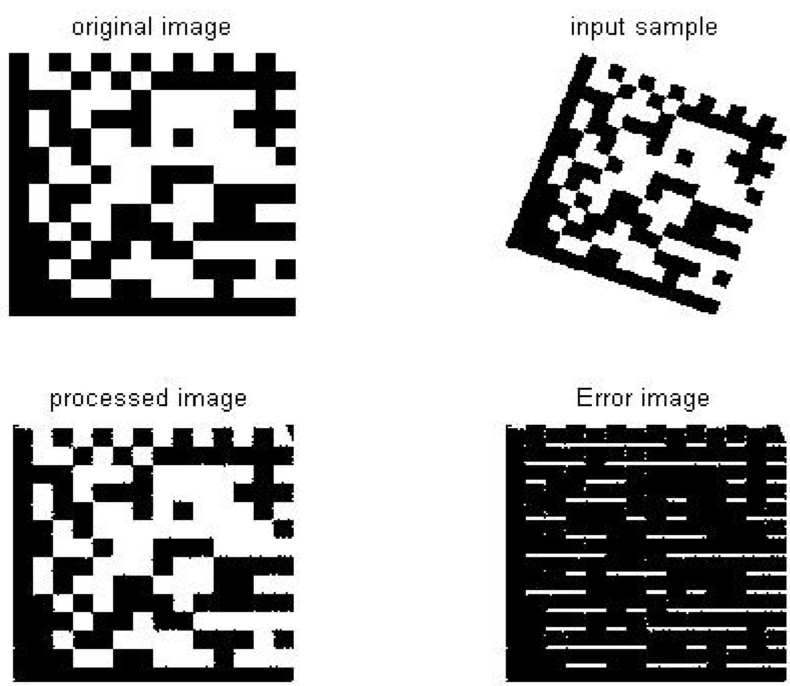


Figure 4.25: Rotation of 20 degree tilted image (Clock wise)

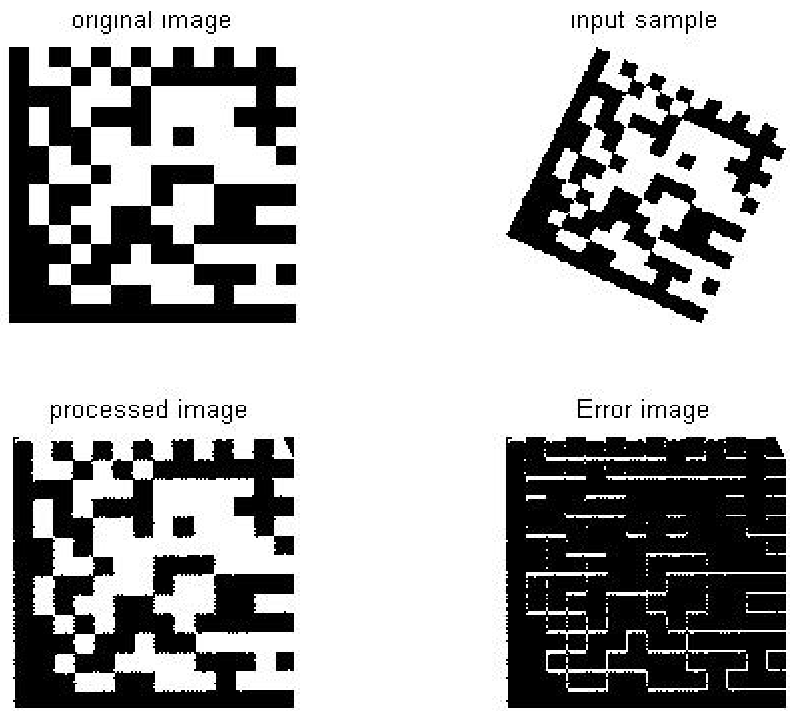


Figure 4.26: Rotation of 25 degree tilted image (Clock wise)

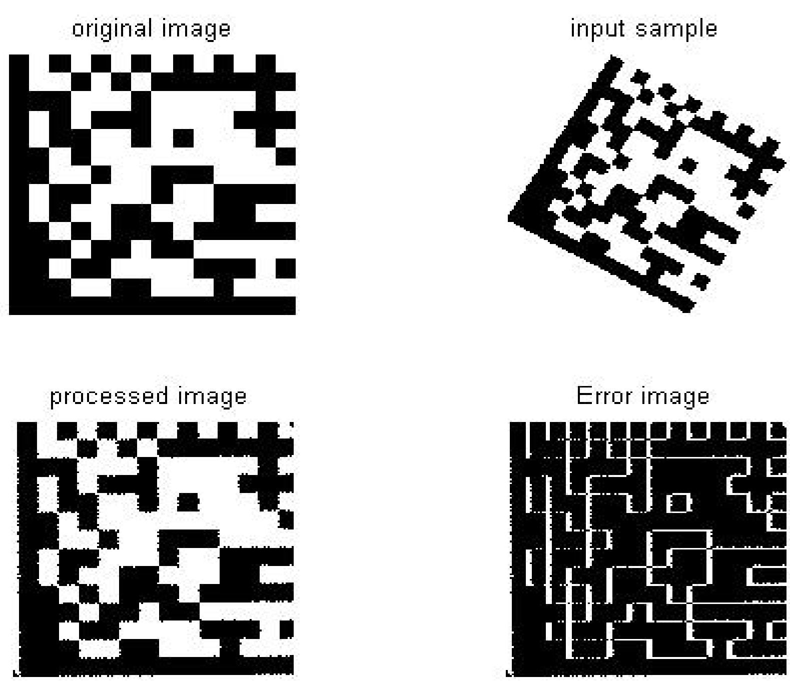


Figure 4.27: Rotation of 30 degree tilted image (Clock wise)

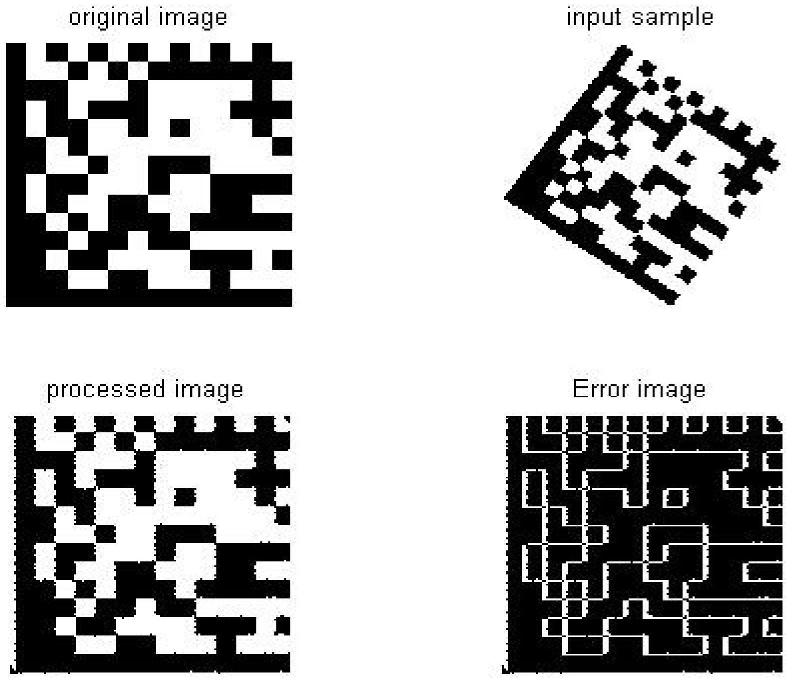


Figure 4.28: Rotation of 35 degree tilted image (Clock wise)

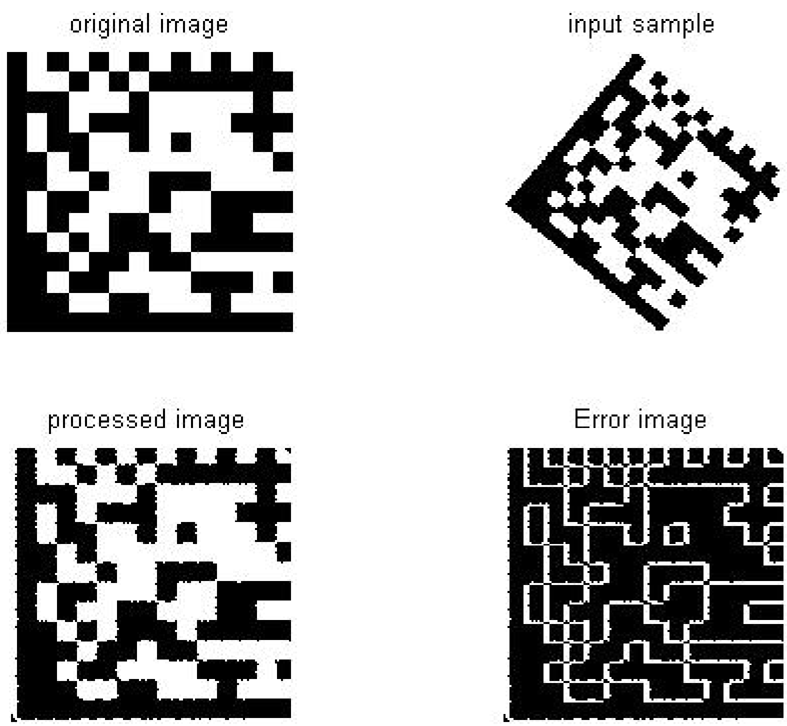


Figure 4.29: Rotation of 40 degree tilted image (Clock wise)

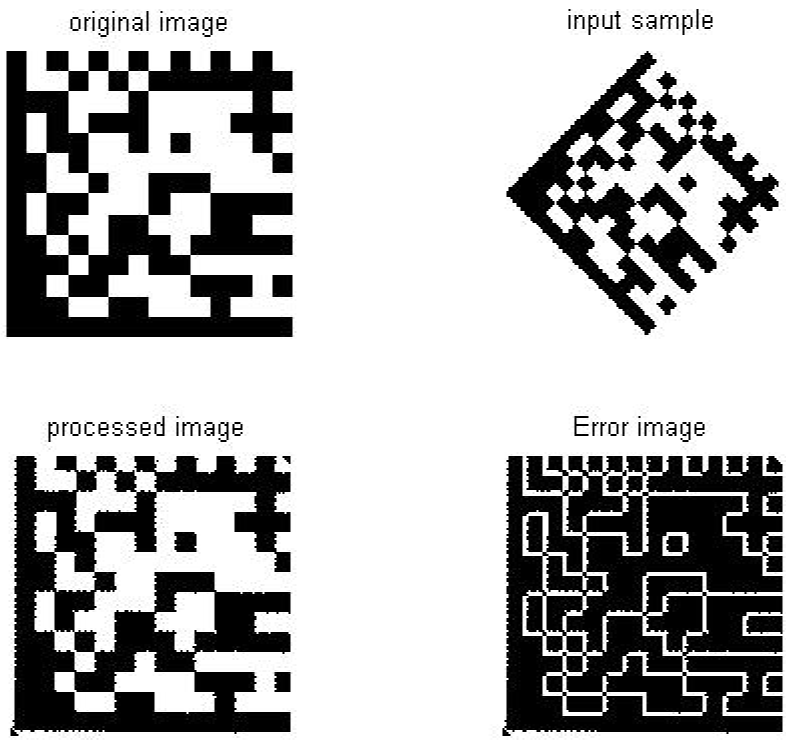


Figure 4.30: Rotation of 45 degree tilted image (Clock wise)

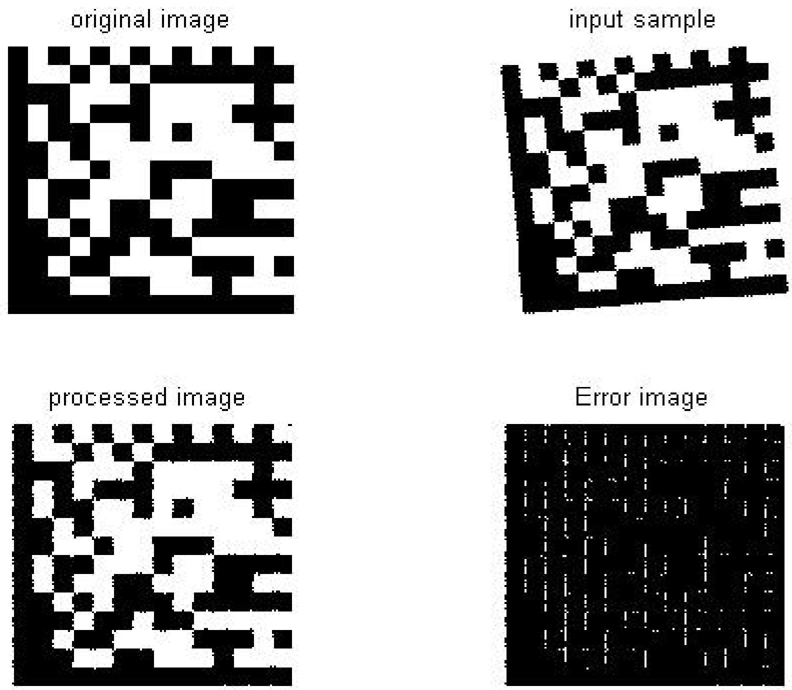


Figure 4.31: Rotation of 5 degree tilted image (Anticlock wise)

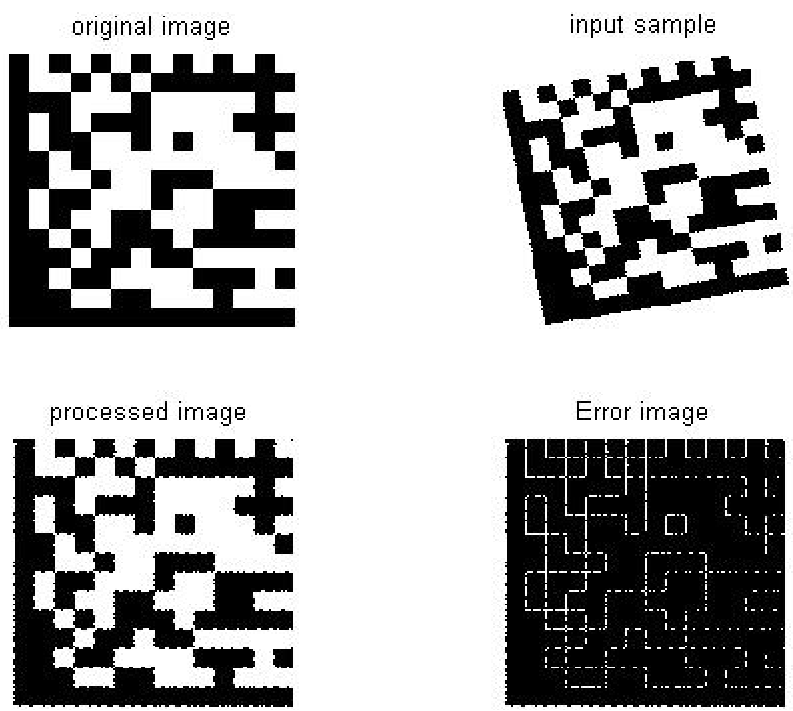


Figure 4.32: Rotation of 10 degree tilted image (Anticlock wise)

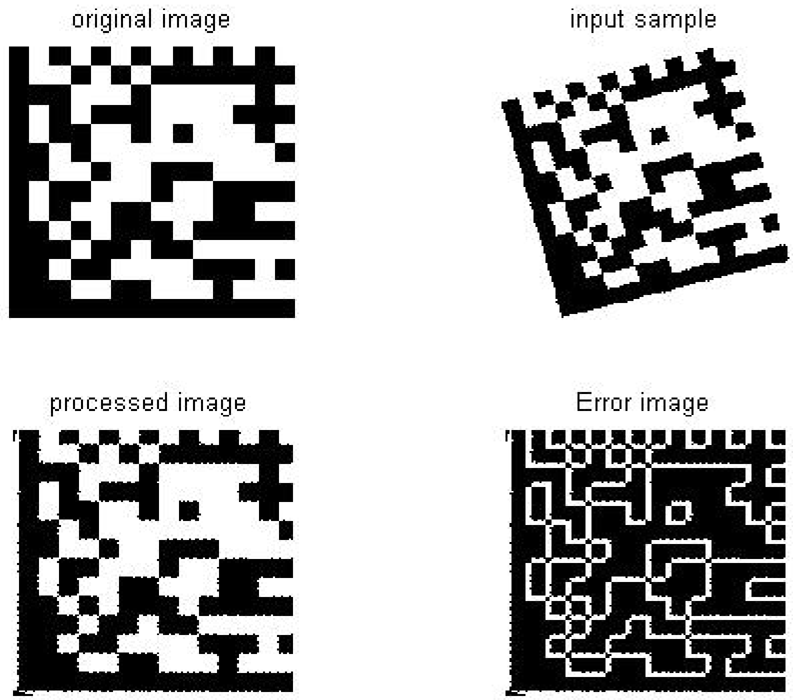


Figure 4.33: Rotation of 15 degree tilted image (Anticlock wise)

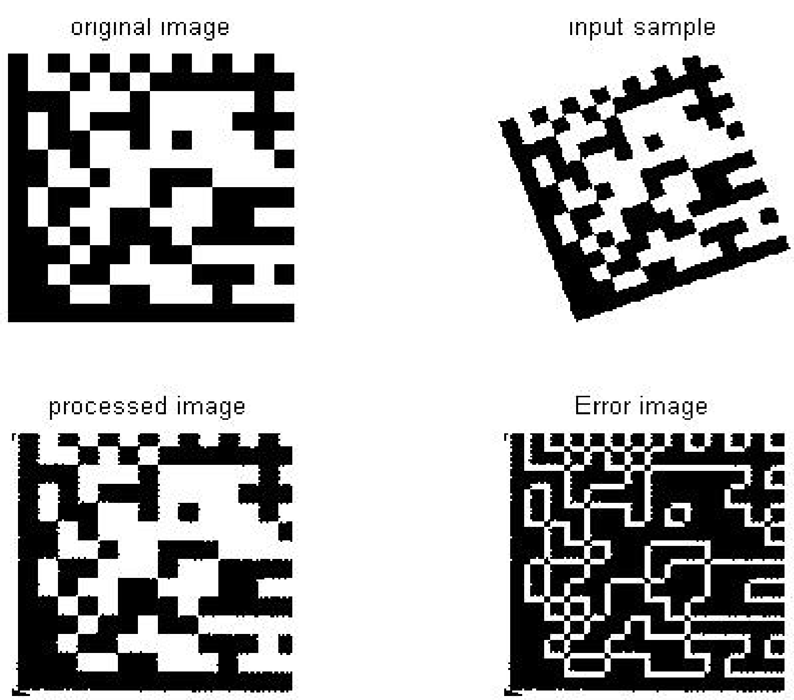


Figure 4.34: Rotation of 20 degree tilted image (Anticlock wise)

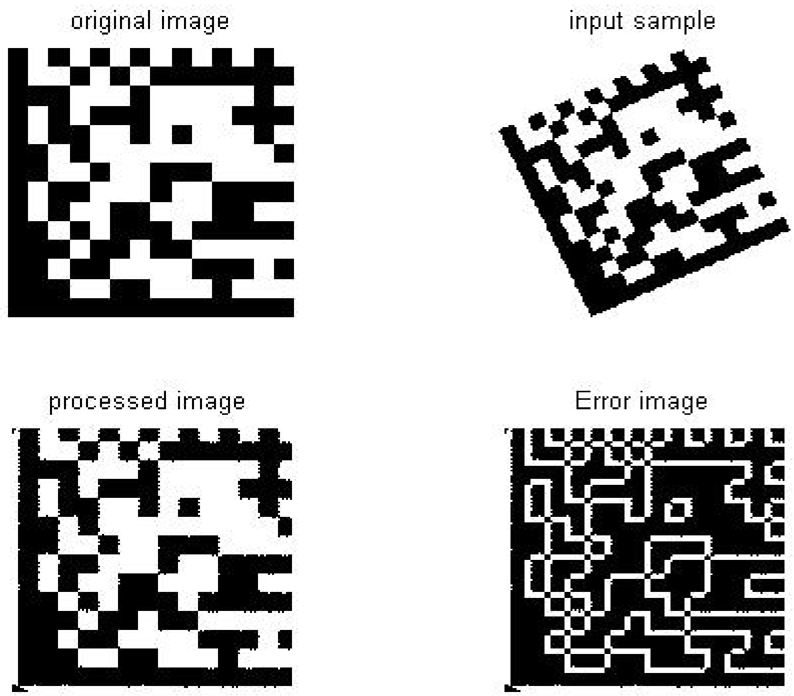


Figure 4.35: Rotation of 25 degree tilted image (Anticlock wise)

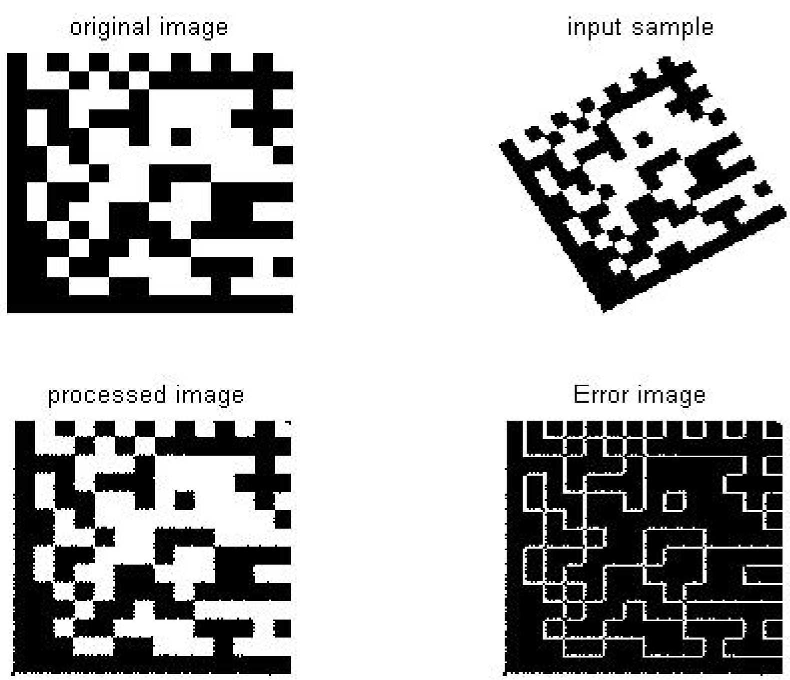


Figure 4.36: Rotation of 30 degree tilted image (Anticlock wise)

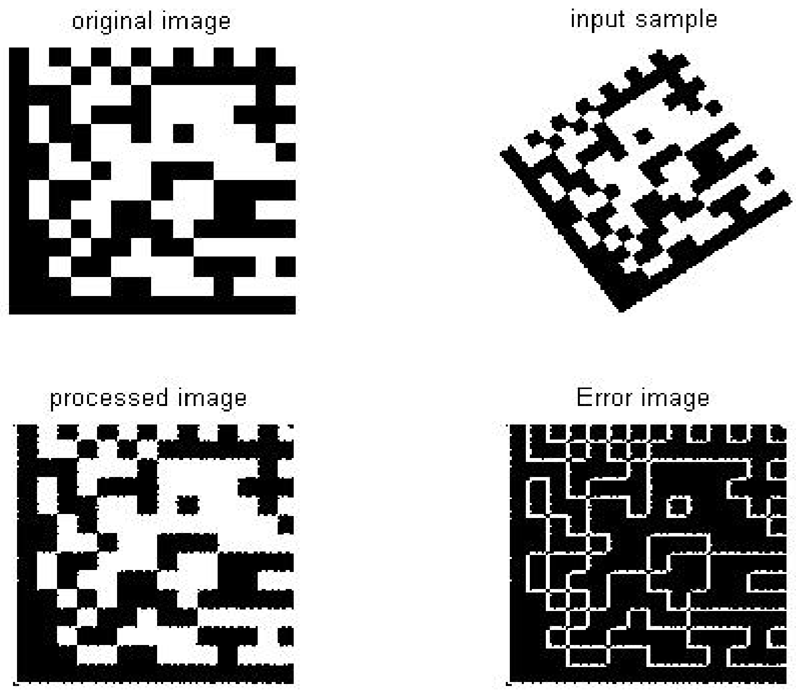


Figure 4.37: Rotation of 35 degree tilted image (Anticlock wise)

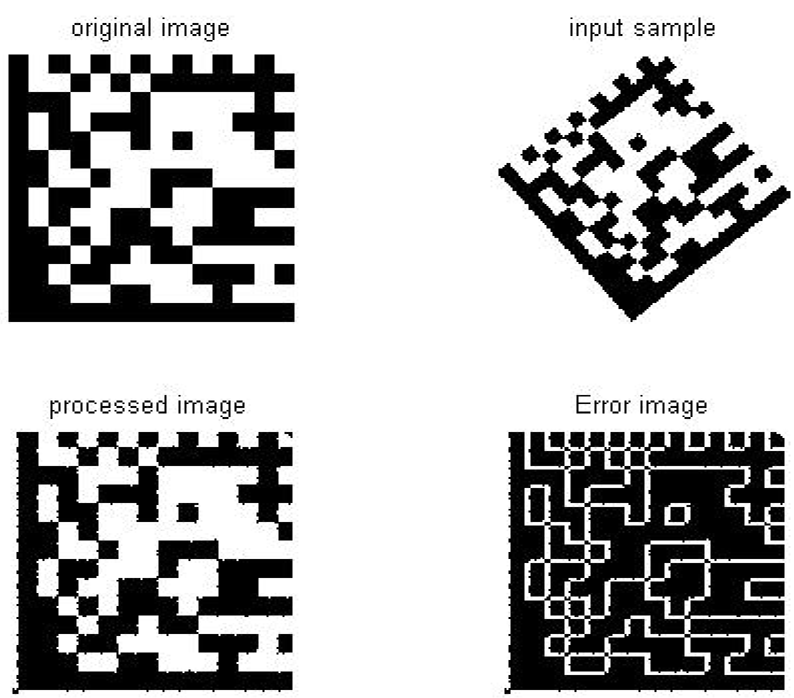


Figure 4.38: Rotation of 10 degree tilted image (Anticlock wise)

Table 5.4

BER For Tilted Image (140x140) By Using Bilinear Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	22.4541	18.3571	14.6837	28.3163	27.8473	24.8724	6.3623	3.1633

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	4.6531	16.6013	8.5408	11.0408	9.8214	17.0102	17.6027	21.2039	21.5459

b) Clockwise Rotation

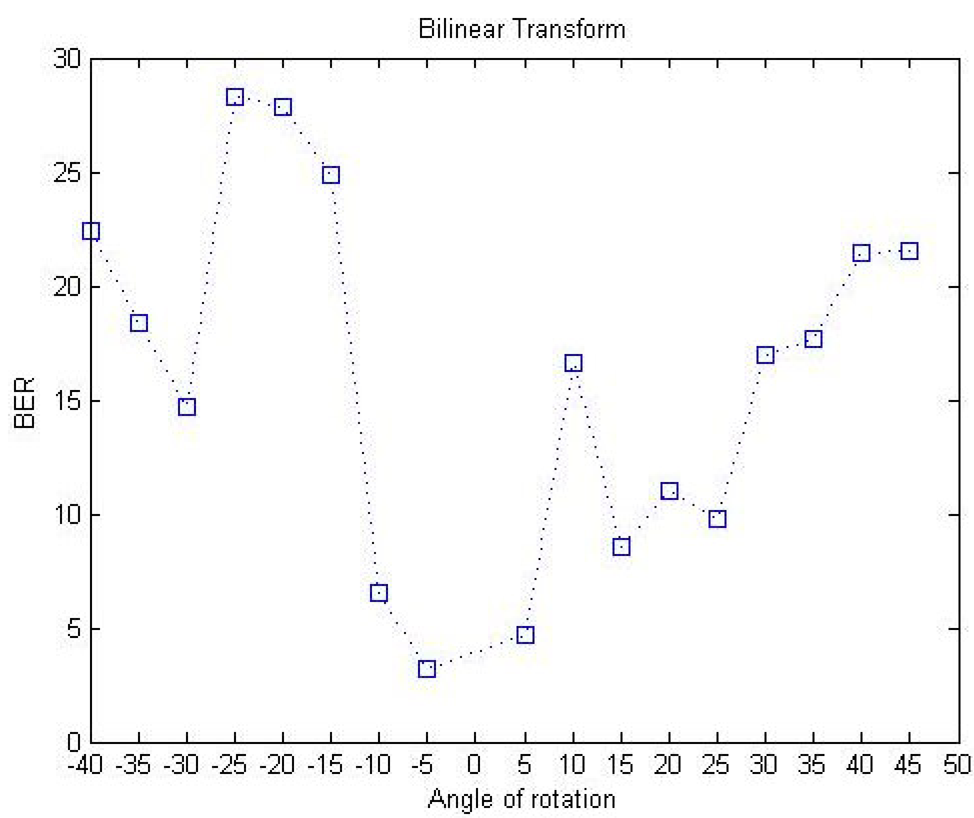


Figure 4.39: BER Plot For Tilted Image (140x140) By Using Bilinear Transformation

Table 5.5

BER For Tilted Image (140x140) By Using Nearest Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	22.4684	18.3673	14.7653	28.3214	27.8776	24.9337	6.3827	3.5816

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	4.9643	16.6071	8.6633	11.1990	9.9847	17.1378	17.6122	21.2143	21.7653

b) Clockwise Rotation

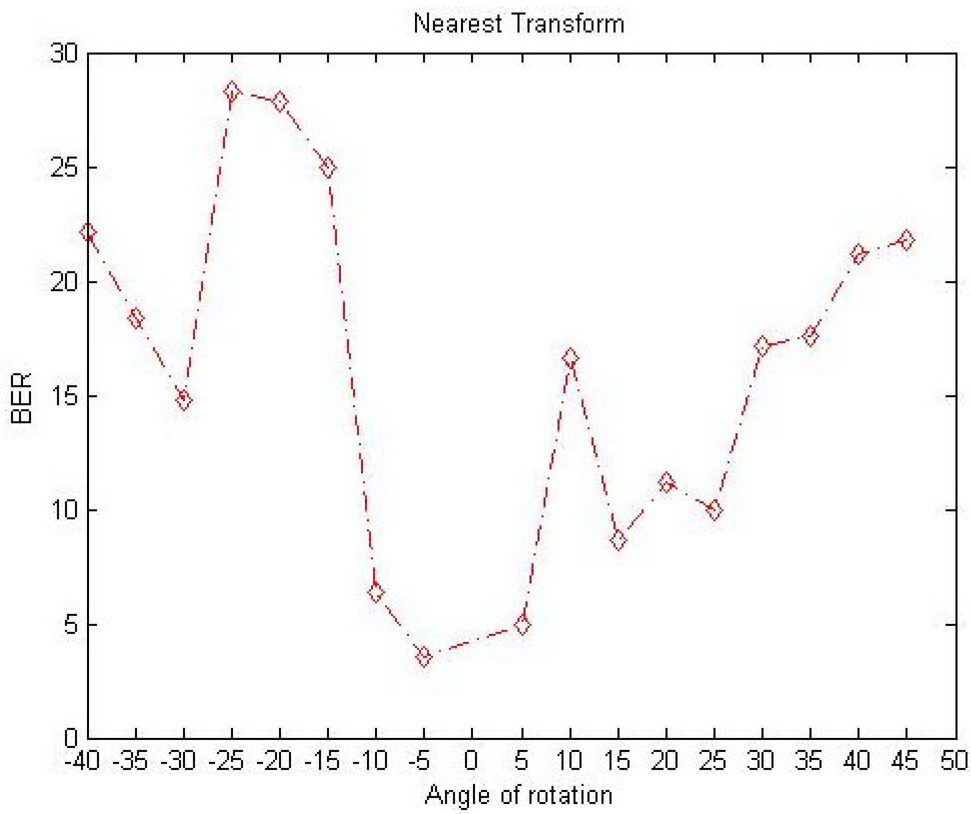


Figure 4.40: BER Plot For Tilted Image (140x140) By Using Nearest Transformation

Table 5.6

BER For Tilted Image (140x140) By Using Bicubic Transformation

Angle(in degree)	-40	-35	-30	-25	-20	-15	-10	-5
BER	22.4531	18.3668	14.7194	28.3210	27.8571	24.8827	6.3728	3.2551

a) Anticlockwise Rotation

Angle(in degree)	5	10	15	20	25	30	35	40	45
BER	4.7398	16.6031	8.6173	11.0765	9.8929	17.0510	17.6117	21.2140	21.5561

b) Clockwise Rotation

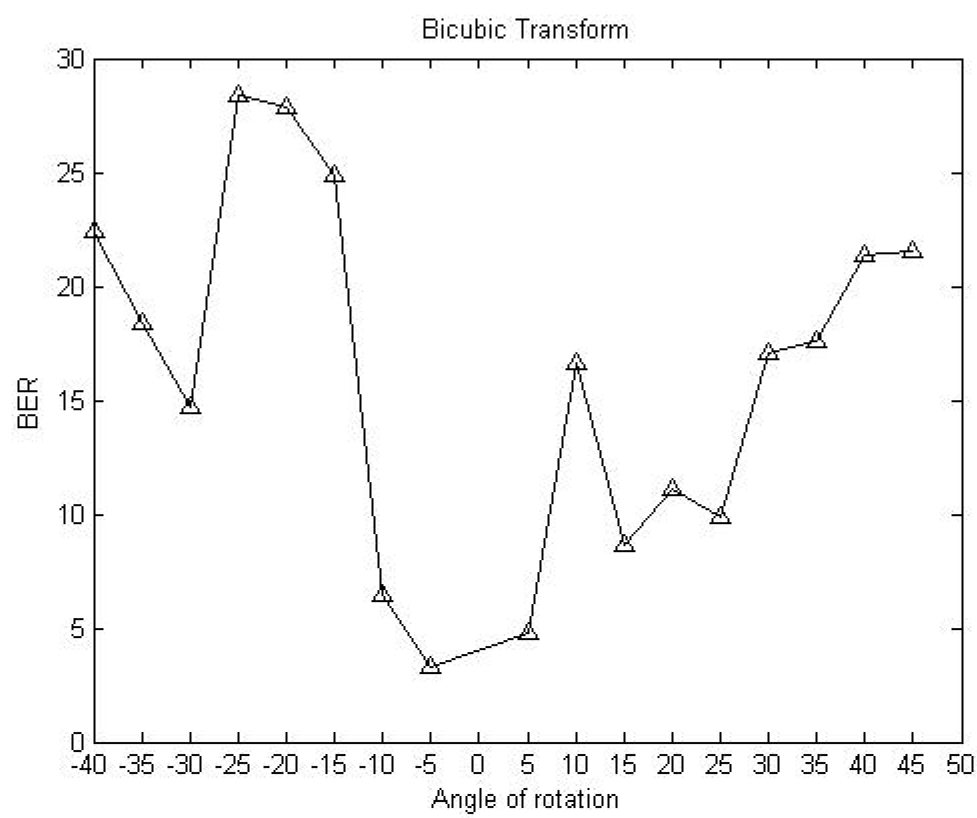


Figure 4.41: BER Plot For Tilted Image (140x140) By Using Bicubic Transformation

FOR IMPROVE AXIAL NON-UNIFORMITY

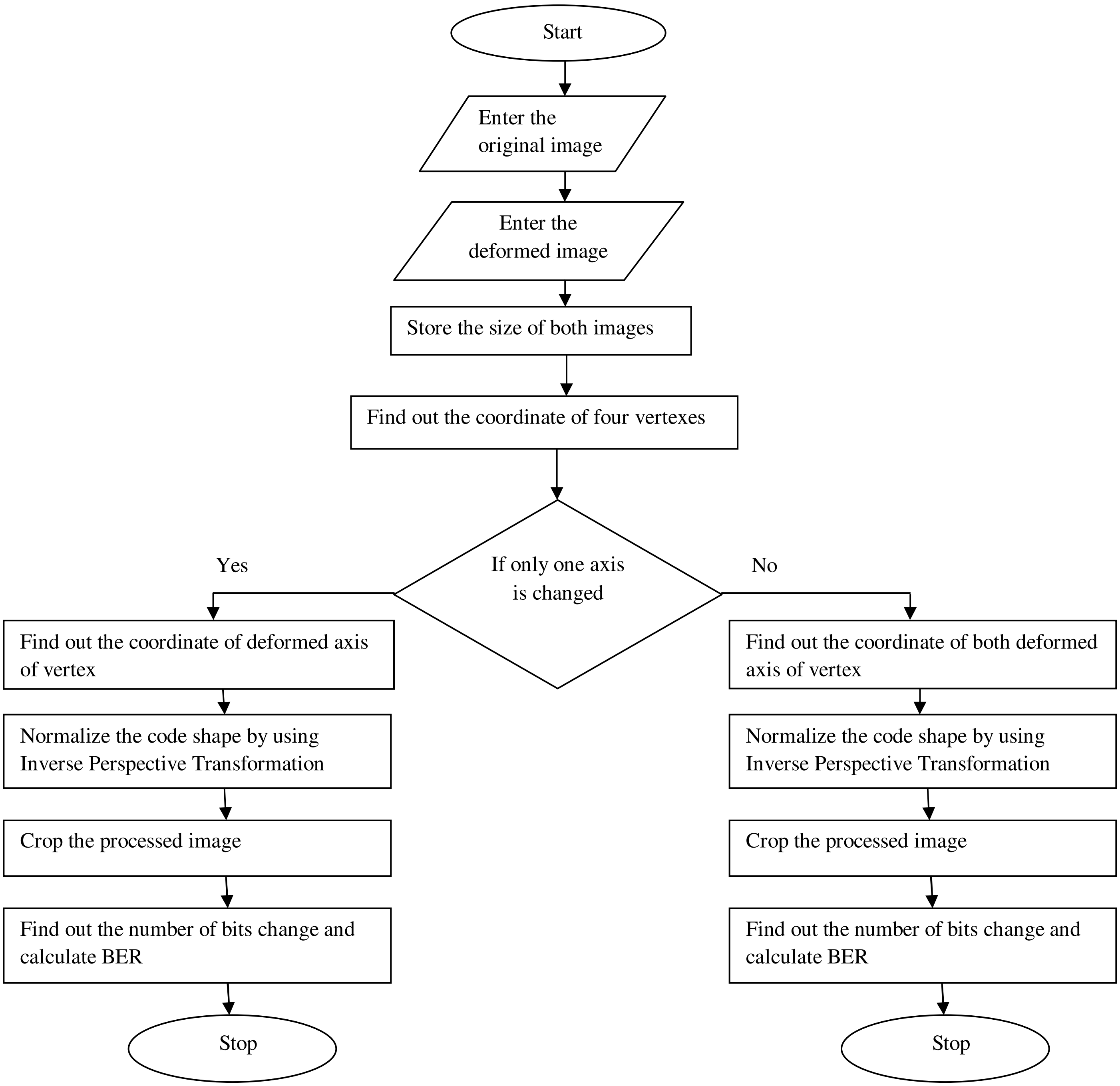
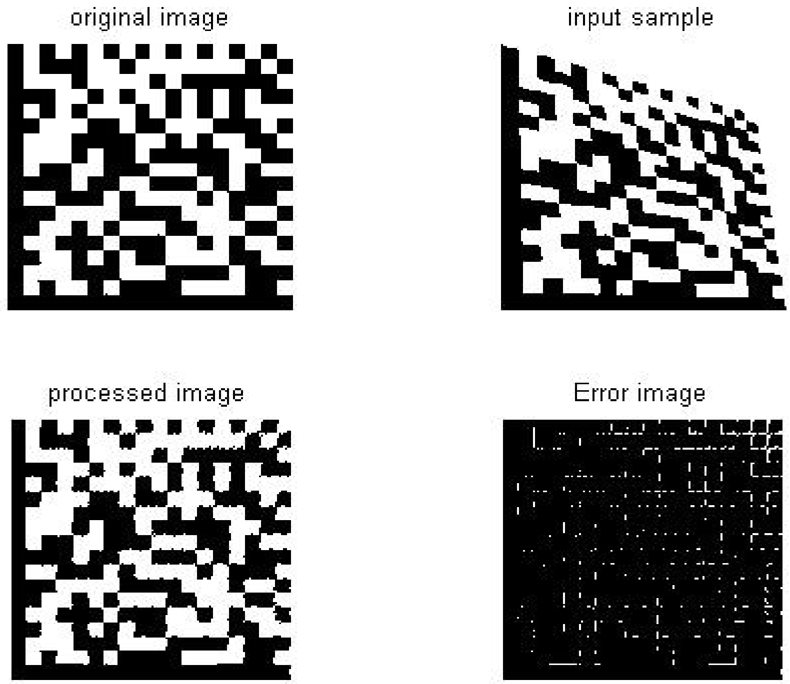
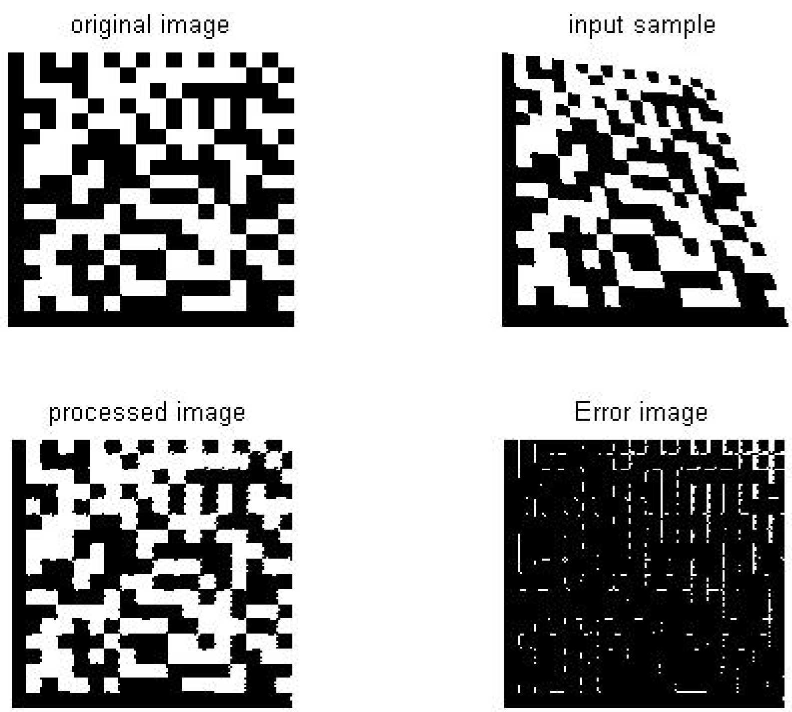


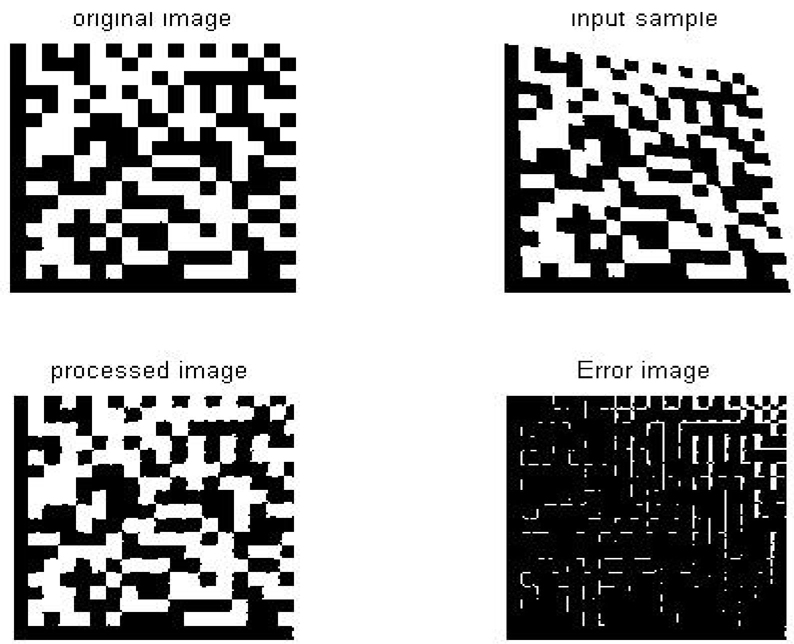
Figure 4.42: Flow Chart for Improve Axial non-uniformity


original image
input sample
processed image
Error image

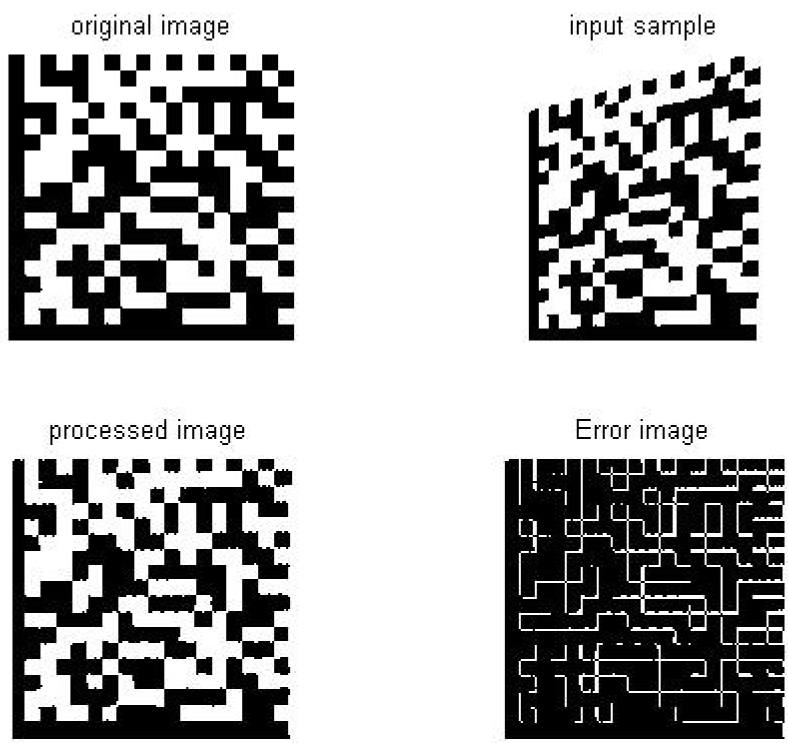
a)


original image
input sample
processed image
Error image

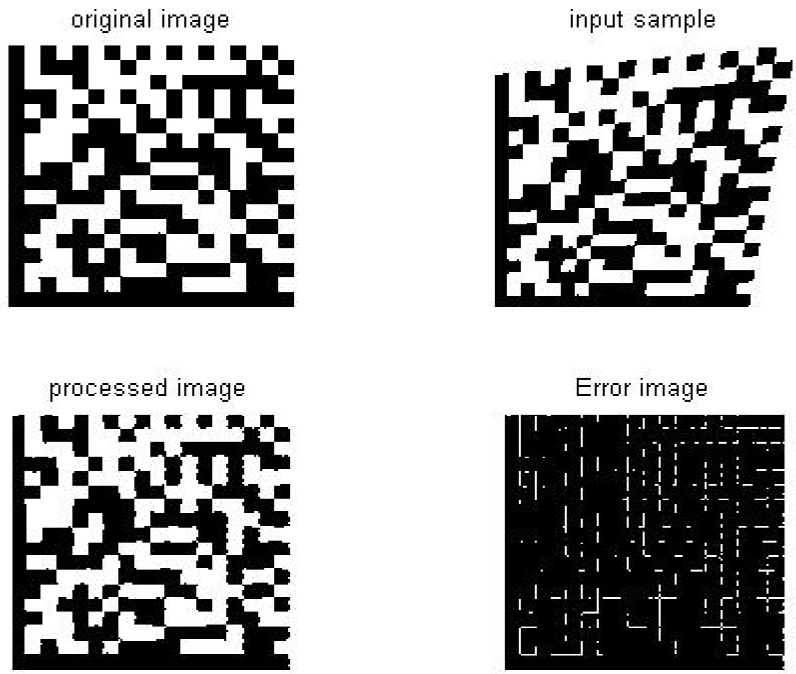
b)


original image
input sample
processed image
Error image

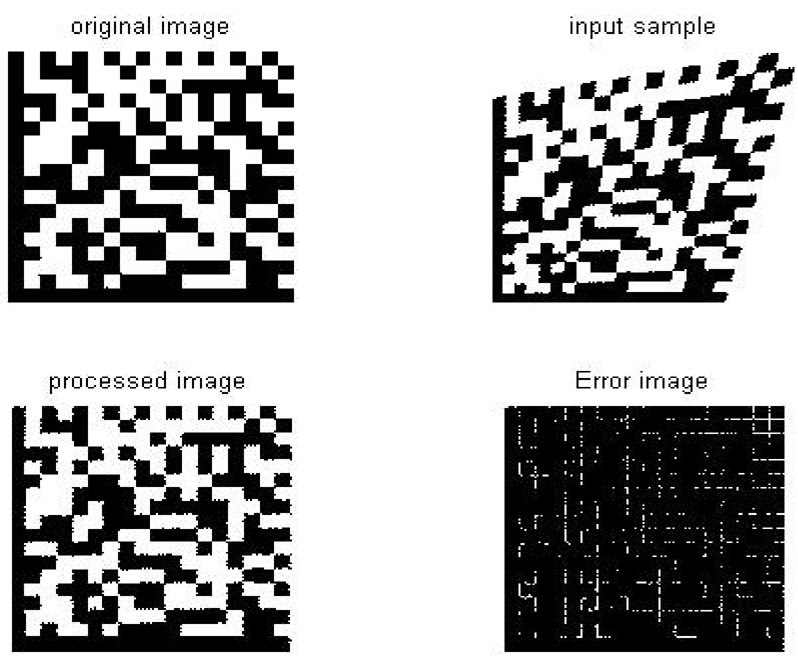
c)


original image
input sample
processed image
Error image

d)



e)



f)

Figure 4.43: Processing for Axial Non-Uniformity

Table 5.7

BER For Deformed Image due to Axial Non-Uniformity

Angle (in degree)	115.7804	112.1659	108.6773	75.9638	72.6409	59.8916
BER	3.5247	5.1574	7.2562	12.4722	4.7315	4.0062

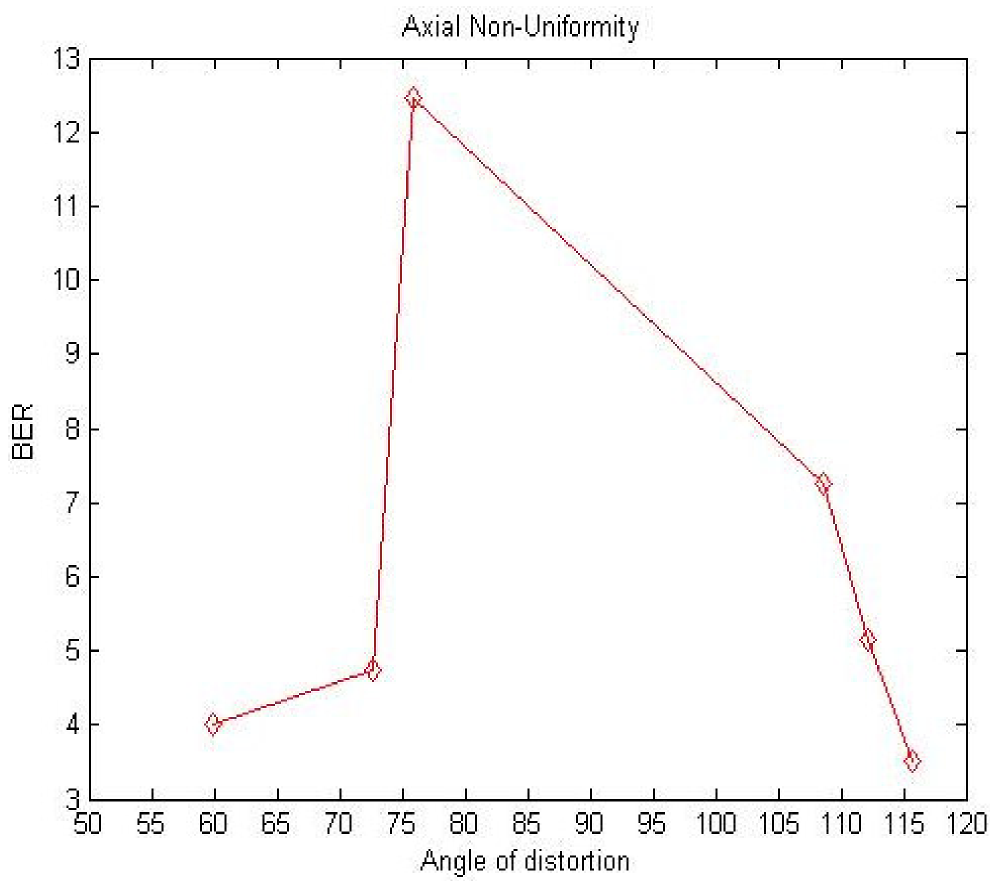


Figure 4.44: BER Plot For Deformed Image due to Axial Non-Uniformity

FOR IMPROVE GRID NON-UNIFORMITY

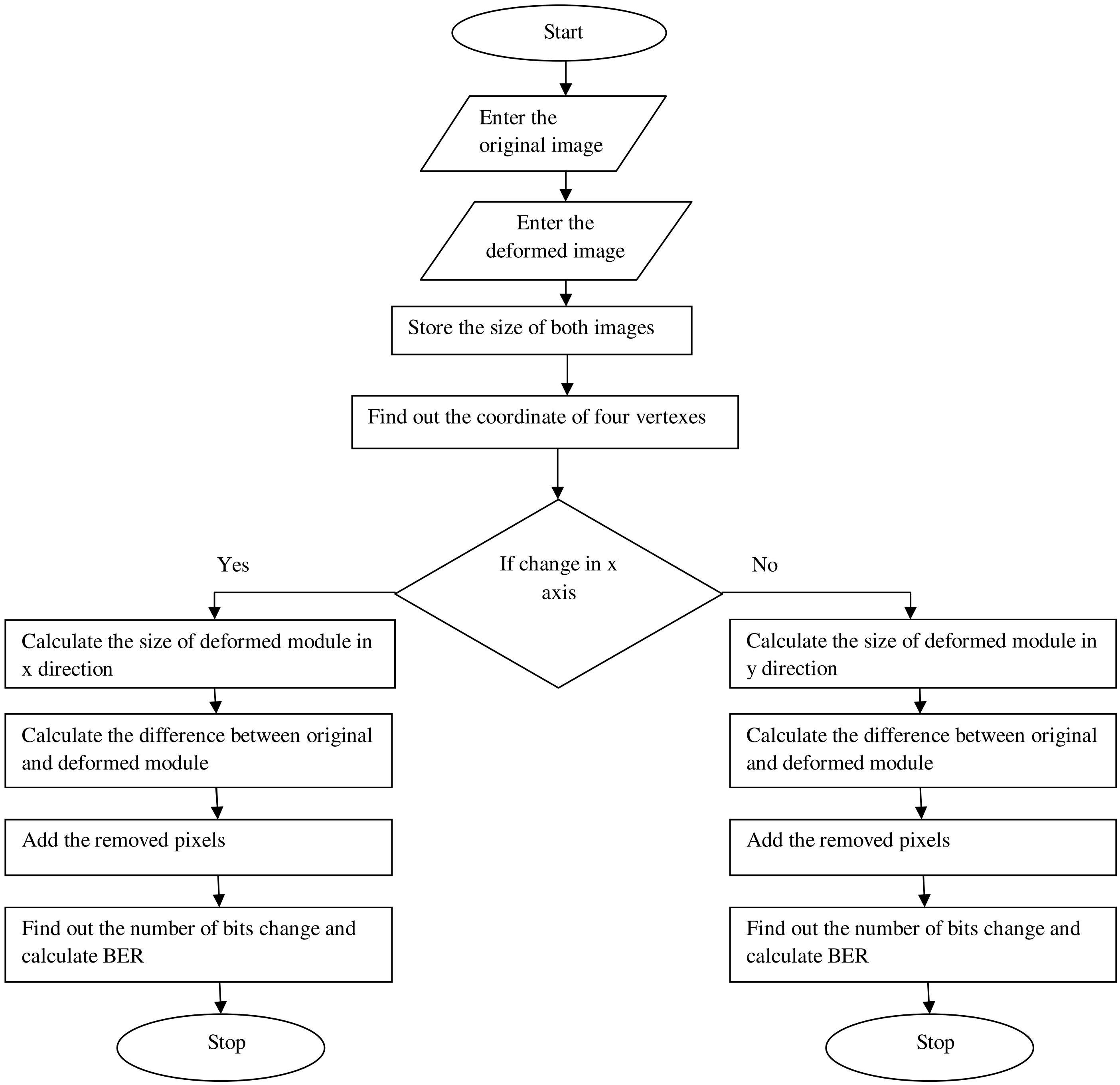
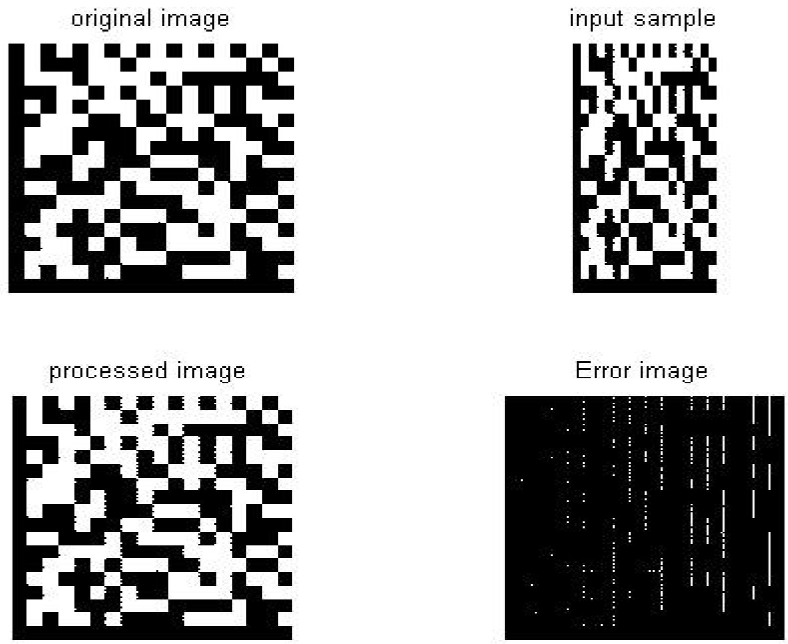
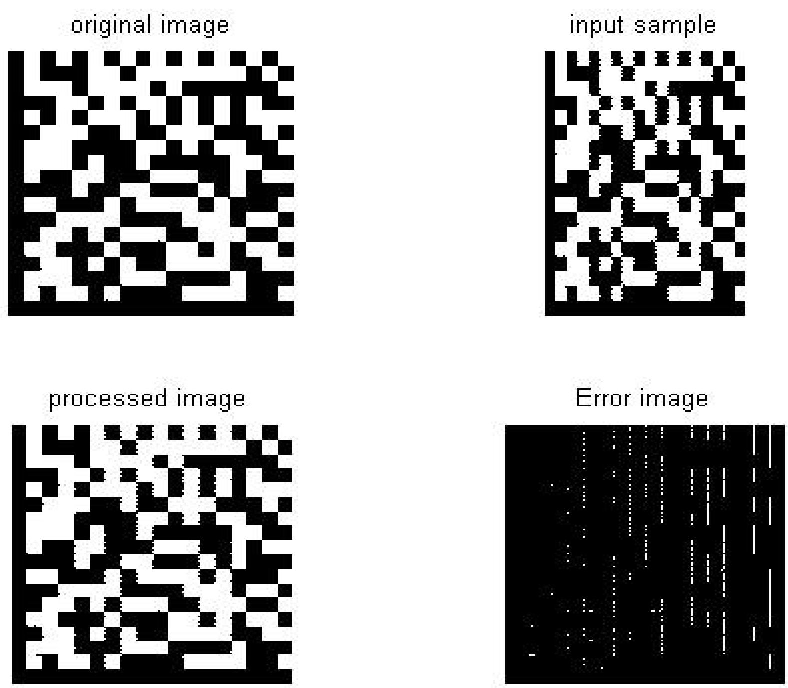


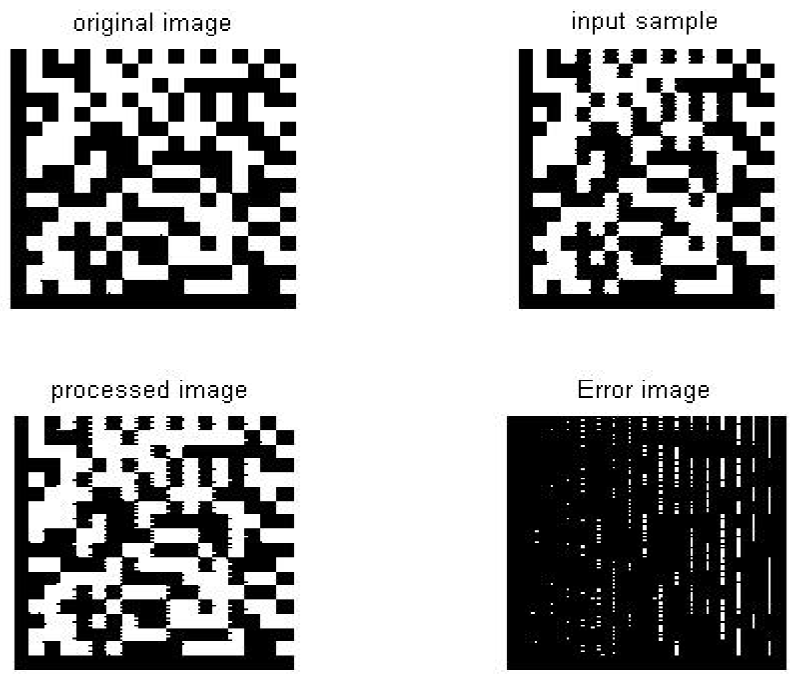
Figure 4.45: Flow Chart for Improve Grid non-uniformity


original image
input sample
processed image
Error image

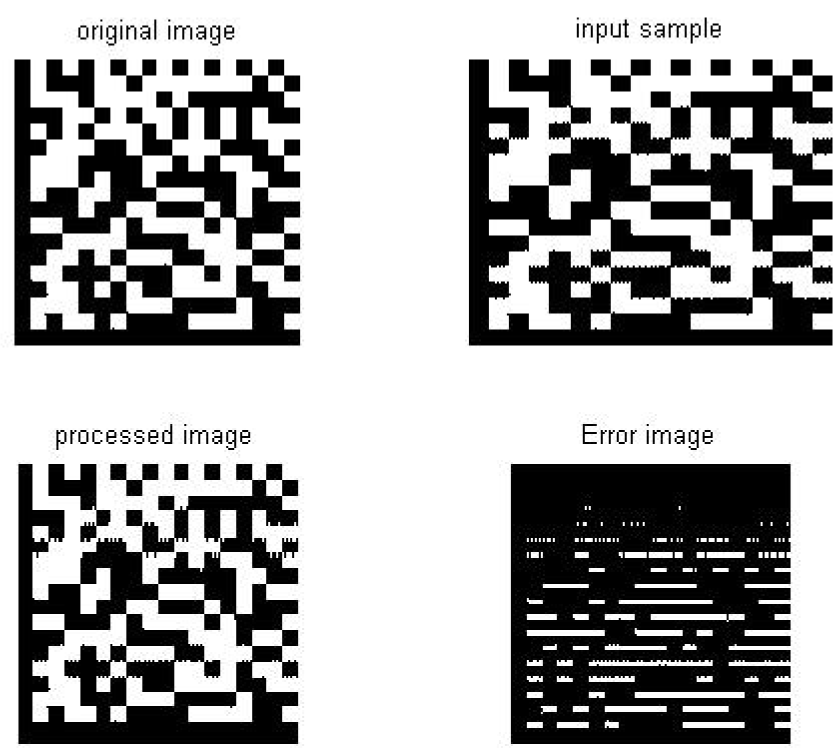
a)


original image
input sample
processed image
Error image

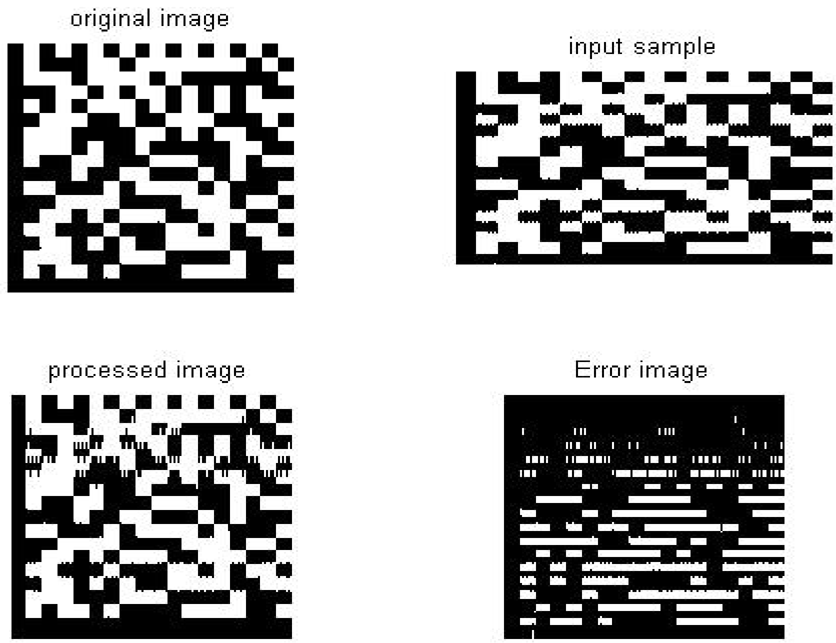
b)


original image
input sample
processed image
Error image

c)


original image
input sample
processed image
Error image

d)



e)

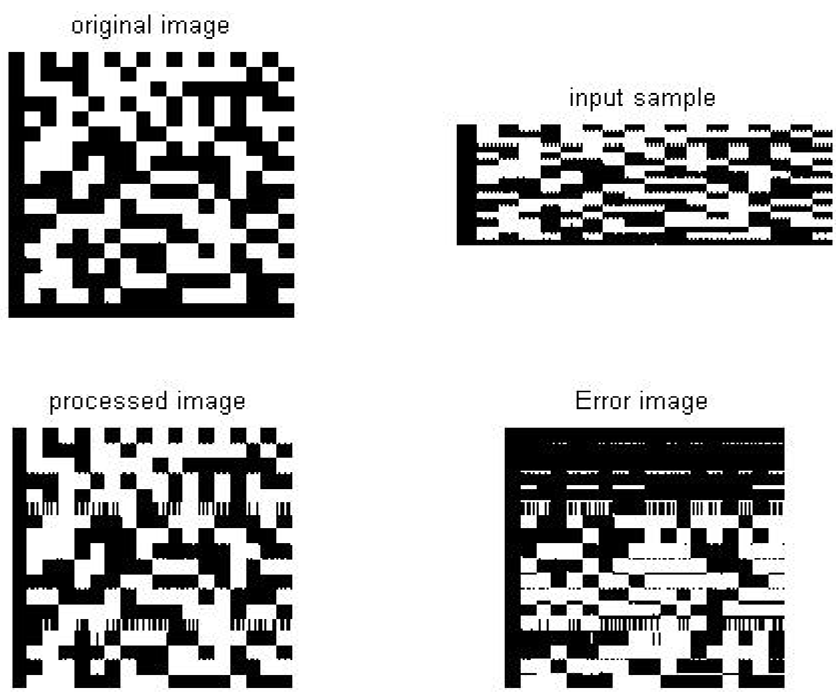


Figure 4.46: Processing for Grid Non-Uniformity

Table 5.8

BER For Deformed Image due to Grid Non-Uniformity

Ratio of Dimensions (x/y)	1.9780	1.4173	1.1180	0.7888	0.5888	0.3444
BER	2.4846	2.4691	2.1625	13.2840	21.2963	38.5772

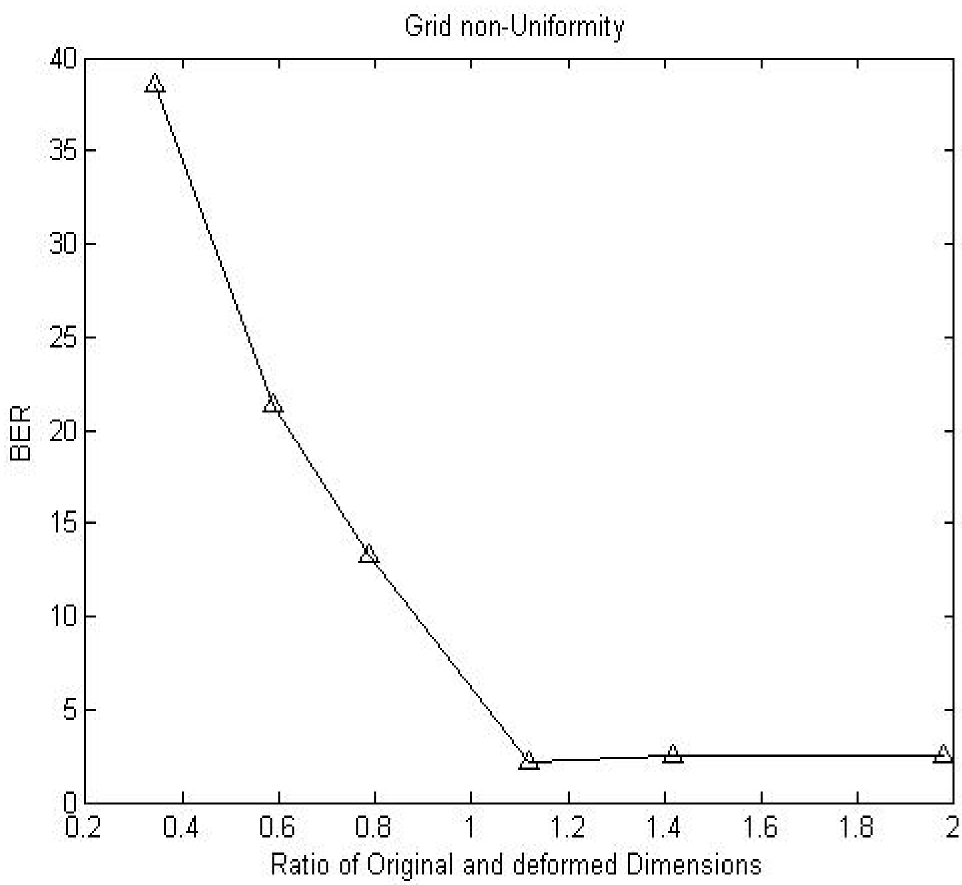


Figure 4.47: BER Plot For Deformed Image due to Grid Non-Uniformity

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

I believe 2D barcodes such as Data Matrix, QR Code and Visual Code will find important applications in manufacturing, medical records management, military logistics management and certification of valuable items as Diamonds etc other than using them for mobile applications. Therefore its necessary to have a higher FRR in that case. This can only be achieved when the grade of these 2D barcodes can be maintained.

This thesis provides a better FRR for Low Parameter Grade Two 2D Barcodes, by achieving a low BER. The BER is decreased by using different transforms available in image processing as mentioned in previous chapter.

I implemented above-mentioned techniques for same low parameter grade barcodes, which are enhanced using image processing techniques in Matlab. This gives a comparative analysis of decreased Bit Error Rate of low parameter grade barcodes.

On the basis of experimented results, I can say that BER for low size (140x140) image is low than large size image (180x180). Here, I have implemented three transforms for rotation of tilted image, i.e. Bilinear Transform, Nearest-Neighbor Transform, and Bicubic Transform. Among three given transforms, bilinear transform provides better results in terms of BER performance. While Nearest-Neighbor transform provides poor BER performance. Thus Bilinear Transform gives higher FRR for low parameter grade 2D barcodes.

I have improved the axial non-uniformity by use of inverse perspective transformation. The experimented results show that when distorted angle is acute and it is decreased BER also decreased. While for the obtuse angle, BER decreases for increasing angle.

I have also improved the grid non-uniformity. The experimented results show that if image size is decreased either in x direction or y direction, BER is increased. Thus I can say that the size of image approaches towards the original size of image, BER decreases.

5.2 FUTURE WORKS

As the fast advance of 2D barcode enabling technology, people have found its great value and diverse applications in M-commerce because 2D barcodes support a new interactive and efficient approach between mobile customers and wireless application systems.

- **Wireless advertising and marketing:** Using a mobile camera phone, a customer can easily input a 2D barcode on a product advertisement (posted everyone), found more product information from the barcode. When the customer likes the product, only a very few clicks can lead to a trading transaction with the backbone M-commerce application system.

- **Wireless trading (pre-sale/sale-and-buy/ post-sale):** Using mobile camera phones, consumers can easily input a 2D barcode of a product by scanning product barcodes in the store, and found more detailed information about each product, including producers, harvest date, shipping date, and agricultural chemicals in each found. In addition, 2D barcodes are also very useful in post-sale, including product tracking, shipping, and delivery

- **Mobile security:** most security solutions are developed based on some kinds of encoding and decoding cryptographic algorithms, clearly it is easy to use a 2D barcode technology to embed diverse security data (or code) into a 2D barcode by an encoding and a decoding process.

- **Mobile customer and product verification:** Using 2D barcodes delivery man can easily perform various verifications using mobile scanner devices (or mobile devices) to scan 2D barcodes on a movie (or train/flight/sport) ticket, a coupon, a good, or an invoice.

Consumers also are able to carry out product verification by accessing the 2D barcode of a product/package to check its detailed product information, track its shipping and transaction history.

- **Wireless payment:** I believe that 2D-barcode technology provides a new way to develop mobile e-card based payment systems that allow customers to make payments using mobile phones with 2D barcode technology.

- **Product information tracking and checking:** This technology used the embedded cameras in the mobile devices for decoding the 2D barcode tags – Cyber Codes. This technology can be used for indoor navigation or indoor guidance. For instance, Cyber Code tags can be printed on the items inside a museum. Visitors can retrieve the relating information by scanning the Cyber Code tags on the items.

At last I can say that, 2D barcode's main application field is advertising. Advertiser can include one or more tags in their ads or TV commercials in order to deliver rich, appealing, branded content related to the product or the service advertised. Users can take advantage from scanning tags and access valuable content usually for free, being the content paid by the advertiser. Additionally, users can easily download and/or purchase multimedia branded content and mobile applications, and subscribe value added services Barcodes can bring several benefits to the end users who can easily access valuable content and information wherever they are.

CHAPTER 6

REFERENCES

[1] H. Kato and K.T. Tan, "2D Barcodes for Mobile Phones," Proc. 2nd Int'l Conf. Mobile Technology, Applications and Systems (MTAS 05), IEEE, 2005, pp. P1A–4.

[2] Tasos Falas and Hossein Kashani, "Two-Dimensional Bar-code Decoding with Camera-Equipped Mobile Phones", Fifth Annual IEEE International Conference on PerComW'07, 2007.

[3] Milan Sonka, Vaclav Hlaavac and Roger Boyle, "Image Processing and Machine Vision", Third Edition.

[4] Aidong Sun, Yan Sun and Caixing Liu "The QR-code Reorganization in Illegible Snapshots taken by Mobile Phones", Fifth International Conference on Computational Science and Application, 2007.

[5] Jerry Zeyu Gao, Lekshmi Prakash, and Rajini Jagatesan, "Understanding 2D-BarCode Technology and Application in M-Commerce–design and Implementation of a 2D Barcode Processing Solution" ,1st Annual International Computer Software and Application Conference (COMPSAC), 2007.

[6] H. Kato and K. T. Tan, "First Read Rate Analysis of 2D-Barcodes for Camera Phone Applications as a Ubiquitous Computing Tool", IEEE, 2007.

[7] E.Ottaviani, A.Pavan, M.Bottaz, E.Brunclli, F.Casclli, and M.Guerre, “A Common Image Processing for 2D Barcode Reading”, Image Processing and its Applications, Conference, IEE 1999.

[8] Jose Rouillard,” Contextual QR Codes “, IEEE International Conference,2008.

[9] Dimensional Symbologies Handbook, Keyence Corp., May 2005; www.keyence.co.jp/ req/info/2jigenpdf/show.jsp [in Japanese.].

[10] Understanding 2D Symbologies: Detailed Information on Barcodes, Japan Automatic Identification Systems Assoc., 2004.

[11] Information Technology—Automatic Identification and Data Capture Techniques—QR Code 2005 Bar Code Symbology,ISO/IEC 18004, Int’l Organization for Standardization,2006

[12] Leng Biao,” A Data Matrix-based Mutant Code Design and Recognition Method Research”, IEEE, 2007.

[13] Automatic Identification and Data Capture Techniques—Data Matrix Bar Code Symbology Specification, ISO/IEC 16022, Int’l Organization for Standardization, 2006

[14] Hiroko Kato and Keng T. Tan,” Pervasive 2D Barcodes for Camera Phone Applications” IEEE Computer Society, 2007.

[15] M. Rohs, “Real-World Interaction with Camera-Phones,” Proc. 2nd Int’l Symp.Ubiquitous Computing Systems (UCS 04), LNCS 3598, Springer, 2005, pp. 74–89.

[16] David Chen," Shape-Based Identification of Visual Code Marker", IEEE, 2007.

[17] Understanding 2D Verification, Microscan Systems, Inc. Rev *B*, 2007.

[18] R C Gonzalez and R E Woods. Digital Image Processing. Addison-Wesley, Reading, MA, 1992.

[19] A K Jain. Fundamentals of Digital Image Processing. Prentice-Hall, Englewood Cliffs, NJ, 1989.

[20] W M Morrow, R B Paranjape, R M Rangyyan, and J E L Desautels. Region-based contrast enhancement of mammograms. IEEE Transactions on Medical Imaging, 11(3): 392-406, 1992.

[21] J F Canny. Finding edges and lines in images. Technical Report AI-TR-720, MIT, Artificial Intelligence Laboratory, Cambridge, MA, 1983.

[22] J Cooper, S Venkatesh, and L Kitchen. Early jump-out corner detectors. IEEE Transactions on pattern Analysis and machine intelligence, 15:823-828, 1993.

[23] R Mehrotra and S Nichani. Corner detection. Pattern Recognition Letters, 23(11):1223-1233, 1990.

[24] T S Huang, G J Yang, and G Y Tang. A fast two-dimensional median filtering algorithm. IEEE Transactions on Acoustics, Speech and Signal Processing, ASSP-27(1):13-18, 1979.

[25] H C Andrews and B R Hunt. Digital Image Restoration. Prentice-Hall, Englewood Cliffs, NJ, 1977.