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DETECTION AND DECODING OF THE INVISIBLE DATA MATRIX WITH SMART PHONE BY USING HOUGH LINES AND ONLINE LEARNING

by

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August,2015
Kayseri, Turkey

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in

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APPROVAL PAGE

This is to certify that I have read the thesis entitled “Detection and Decoding of The Invisible Data Matrix With Smart Phone by Using Hough Lines and Online Learning.” by Mahir Can UYSALTÜRK and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electrical and Computer Engineering, the Graduate Institute of Science and Engineering, Melikşah University.

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Mahir Can UYSALTÜRK

M.S. Thesis – Electrical and Computer Engineering
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Supervisor: Asst. Prof. Dr. Mahmut KARAKAYA

ABSTRACT

Today, barcode detection is everywhere in our lives, it became a common activity in many different markets. Application of the barcodes has been spread from supermarkets to factories, military industry, health industry and many other areas. In recent years, 2D Data Matrices (2D Barcodes) replaces 1D Data Matrices (Barcodes) since their data storage capacity is higher than the traditional barcodes. 2D Data Matrices are commonly used in automatic label reading of products such as books, medicine, food, security etc. In Turkey, invisible 2D Data Matrix used in alcohol beverages and tobacco products to track them from factory to market in order to prevent forgery and smuggling. The invisible 2D data matrix, printed on a special paper with pigmented ink, cannot be seen with a naked eye under day light. Under a specific wavelength light, the pigmented ink reflects the light and filtering the reflected light makes the invisible 2D data matrix as visible. In the production line, the invisible 2D data matrix on each alcohol beverages and tobacco products is scanned by a professional camera and lighting system in the factory and released to the market. In the market, inspectors use a special handheld terminals to check the authentication of the product. Due to their physical dimensions, their expensive price and requirement of special training for the use, it is not practical to use these handheld terminals for product tracking easily. Therefore, a smart phone application need is emerged.

In this thesis, an apparatus is designed and attached on a smart phone. This apparatus contains LED light which emits a red light on the invisible data matrix and a high pass filter, filters the reflected light in order to suppress the background information. An algorithm is developed to detect and decode the invisible 2D data matrix with a smart phone. The proposed method is constructed on four stages. In the first step, edge detection is applied on the 2D Data Matrix. Then, Hough Lines are used to detect the “L” shape finder pattern. At the third step, the locations of the marker point detection is applied. Finally, the online learning zig zag dot detection is carried on to the 2D Data Matrix to decode it. Experiments are conducted on different invisible 2D Data Matrices and results are obtained by high accuracy and low error rate.

Keywords: Invisible 2D Data Matrix, Data Matrix Reader, “L” shape finder pattern

GÖRÜNMEYEN KARE KODUN HOUGH ÇİZGİLERİ VE ONLİNE ÖĞRENİM YÖNTEMLERİ KULLANILARAK AKILLI TELEFON İLE BULUNMASI VE OKUNMASI

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ÖZ

Günümüzde, barkod tanıma hayatımızın heryerinde, birçok farklı pazarda günlük alışılmış işlem haline gelmiştir. Barkodların kullanım alanı süpermarketlerden, fabrikalara, askeri endüstriye, sağlık endüstrisine ve daha birçok alana yayılmıştır. Son zamanlarda İki boyutlu Karekod (İki boyutlu Barkod) sistemler, daha çok veri depolama kapasiteleri sayesinde geleneksel Tek boyutlu Karekod (Tek boyutlu Barkod) sistemlerin yerini almıştır. İki boyutlu Karekod sistemleri daha çok otomatik okunan ürünlerin tanımlanmasında kullanılmaktadır, örnek olarak kitap, ilaç, gıda ve güvenlik vs. Türkiye'de, alkol ve tütün ürünlerinde görünmez iki boyutlu karekod sahteciliği ve kaçakçılığı önlemek için ürünün fabrikadan pazara kadar olan bölümde izlenmesi için kullanılmaktadır. Görünmez İki boyutlu Karekod, özel bir kağıda pigmentli mürekkeple yazılır, gün ışığında çıplak gözle görülemez. Belirli bir dalga boyuna sahip ışık altında pigmentli mürekkep ışığı yansıtır, bir filtre işlemi sayesinde görünmez İki boyutlu Karekod görülebilir. Alkol ve tütün ürünlerinin üretim aşamasında görünmez karekod profesyonel kamera ve aydınlatma sistemi ile okunarak pazara sunulur. Pazarda müfettişler ürünlerin gerçekliğini özel olarak üretilmiş elde taşınabilir cihazlarla yapmaktadırlar. Bu cihazın boyutu, pahalılığı ve kullanımı için özel eğitim gereksinimleri sebebiyle, elde taşınabilir cihazlar pazarda çok pratik kullanıma sahip değildirler. Bu yüzden akıllı telefon uygulaması ihtiyacı doğmuştur.

Bu tezde, görünmez İki boyutlu Karekodun okunabilmesi için akıllı telefonlara takılabilen bir aparat dizayn edilmiştir. Bu aparat, belirli dalga boyuna sahip görünmez İki boyutlu Karekodu aydınlatan LED ışığa ve yüksek dalga boyunu geçiren, görünmez İki boyutlu Karekoddan yansıyan arka planı filtreleyen filtre içermektedir. Görünmez karekodun akıllı telefonlar ile algılanması ve kodun çözümlemesinin yapılması için bir algoritma geliştirilmiştir. Önerilen algoritma dört basamak üzerine kurulmuştur. Birinci aşamada, kenar taraması görünmez karekoda uygulanır. İkinci aşamada Hough çizgileri tespit edilerek karekodun "L" şekil düzlemi bulunur. Üçüncü aşamada karekodun işaretleyici noktalarının bulunması algoritması uygulanır. Son olarak, otomatik öğrenme zig zag nokta tespit algoritması ile görünmez İki boyutlu Karekodun çözümleme algoritması sürdürülmektedir. Deneyler değişik görünmez İki boyutlu Karekod verileri ile yapılmış olup, sonuçlar yüksek doğruluk ve düşük hata oranı ile tamamlanmıştır.

Anahtar Kelimeler: Görünmez Karekod, Karekod Okuyucu, "L" Şekil Düzlemi.

DEDICATION

Dedicated to my wife Derya UYSALTÜRK, my father Tarık UYSALTÜRK, my mother Nebahat Ayşe UYSALTÜRK and the rest of my family and my friends for their endless support and patience during the forming phase of this thesis.

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INTRODUCTION

1.1 DEFINITION OF 2D DATA MATRIX

Recently, it has frequently seen black-and-white modules on your magazines, clothes, boxes, medicine boxes, and all the places like a group of dots/cells without any words. These black and white dots/cells have different forms and lines with different names and data capacities. Figure 1.1 shows uniform black bars with distinct thicknesses and white blank between black bar distinct thicknesses. This universal barcodes with very little data capacity to store one-dimensional data.

With the latest advances in optics and camera technologies, barcode technology has improved rapidly and with great capabilities, different barcodes are developed. In an attempt to improve the capability of the barcode, information region storage of the barcodes is increased. As shown in Figure 1.2, two-dimensional black and white modules (2D) barcodes or data matrix codes are arisen with more information capacity as a common machine-readable barcodes. Hence, the barcode can transfer data about a product in the wink of an eye. A one-dimensional bar code data sequence indicates a black one-dimensional line.

A123456789B

Figure 1.1: 1D barcode

Figure 1.2: 2D Data Matrix is applied to medicine.

Two-dimensional barcode is designed with black and white cells every grid square-shaped, these cells are store more information into square or rectangular shapes. In order to store more information in a small region, the two-dimensional barcodes took one-dimensional barcodes place in the market.

1.2 TYPES OF DATA MATRICES

There are lots of barcodes which are composed of different combinations of dots/cells to represent characters are still used in the market. QR Code, Maxi Code, PDF417, Data Matrix are a few examples of barcode types as shown Table 1.1. For satisfy the expectations of the applications, there are quite a few numbers of symbols created. Each symbol has specific characteristics for these applications. Recently, the barcode systems are used in product labeling by some industries. There are two main issues should be considered while creating a barcode. The valid standards should be applied while creating the barcodes, is in the first place. Confusion in products may be faced unless standards are applied.

Table 1.1: Types of 2D Data Matrices

	QR Code	**Data Matrix**	**Maxi Code**	**PDF417**
Developer	Denso	RVSI Acuity CiMatrix	UPS	Symbol Technologies
Type	Matrix	Matrix	Matrix	Stacked Bar Code
Capacity: Numeric	7089	3116	138	2710
Capacity: Alphanumeric	4296	2335	93	1850
Capacity: Binary	2953	1556		1018
Capacity: Kanji	1817	773		554
Main Features	Large Capacity, small size, high speed scan	Small size	High speed scan	Large capacity
Main Usage	Logistics, Factories, automation, mobile phone	Factory automation, medicine, security systems	Logistic	Office automation
Standard	AIM, JIS, ISO	AIM, ISO	AIM,ISO	AIM, ISO

Second place is the encoding issue, the content of the barcode should be encoded. For encoding the 2D Data Matrices ASCII code standards are used. In addition, size and the coding region have crucial role for the coding a new barcode. Lastly the area issue should be taken in to consideration. For the convenience of the 2D Data Barcode, printing and scanning operations should be determined.

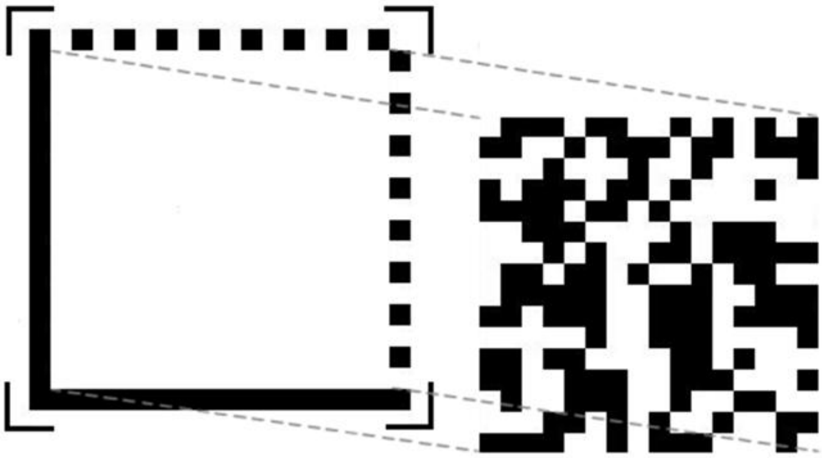


Figure 1.3: Composition of 2D Data Matrix

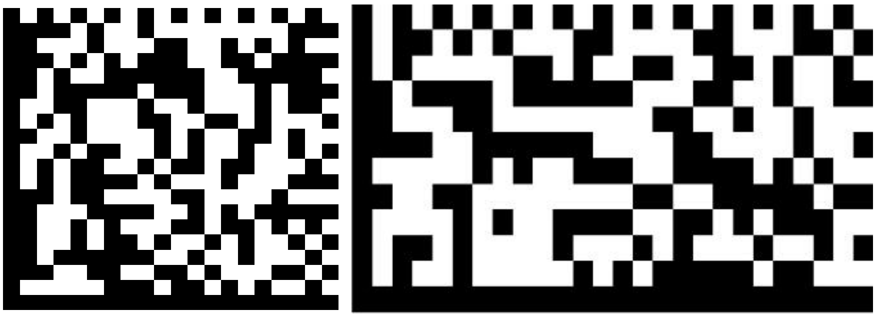


Figure 1.4: ISO/IEC Standardized Data Matrix (ECC 200)

1.3 TWO DIMENSIONAL (2D) DATA MATRIX

Two-dimensional (2D) barcodes are called Data Matrices. Data matrices can be printed as square or rectangular form and include dots or square cells. The dark-light alternating periphery of the barcode is called timing pattern. The constant dark periphery is the “L” shape finder pattern of the barcode. Detecting the barcode and finding its orientation and structure “L” shape finder pattern is used, as shown in Figure 1.3. By the help of the dark and light dots and square cells the data is encoded on the pre-determined area. The ISO/IEC certified and standardized Data Matrix is shown in Figure 1.4.

The size of 2D data matrix can be determined by the user. The selected size of the barcode differs the data capacity and the printing area of the barcode. Rectangular data matrices are made up of square dots which is called “the module”.

2D data matrices can be printed in rectangular or square form.

1. Square form size between 10x10 up to 144x144 modules.

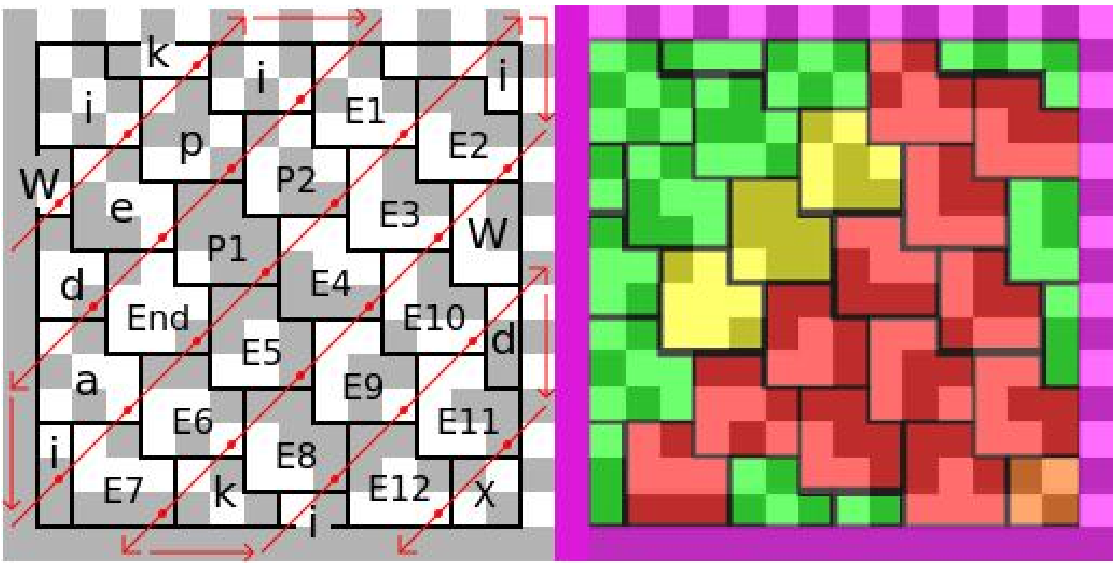


Figure 1.5: 2D Data matrix Mapping, Green Corresponds to Data, Yellow Corresponds to Padding, Red Corresponds to Error Correction, Magenta Corresponds to "L" Finder Pattern and Orange Corresponds to Not Used Area [1].

2. Rectangle form between 8x16 up to 16x48 modules.

2D data matrix barcodes capacity are up to 3116 numeric characters, 2335 alphanumeric characters and 1555 bytes.

By the truth encoding list, mapping of 2D data matrix is formalized. Encoding ASCII characters in to barcode format is more efficient than using fixed number of bytes. For instance; for encoding numeric information one byte is used for two digits. Figure 1.5 shows that the modules in the data region, each module is composed of number of dot groups by difference. These groups can divertible to padding, error correction, timing and idle modules.

For encoding a 2D data matrix; ASCII characters are used for encoding. The data is printed into a module is the aim of encoding. If the data capacity of the data matrix is fulfilled, the data is automatically rearranges the 2D data matrix's size. If the input data is included the data region, error correction modules are also added to data region in case the loss of data parts of 2D Data matrix. After all, the encoded data and the error correction parts are placed in the data region via a specified algorithm. Each bit is placed in to a certain module of the data region of 2D Data matrix. ISO standards are used for the above simplified statement.

Table 1.2: Data Capacities of the Different Matrix Sizes in ECC-200

Size	Numeric capacity	Alphanumeric capacity	Binary capacity	Max Correctable Error/Erasure
10 x 10	6	3	1	2
12 x 12	10	6	3	3
14 x 14	16	10	6	5/7
16 x 16	24	16	10	6/9
18 x 18	36	25	16	7/11
20 x 20	44	31	20	9/15
22 x 22	60	43	28	10/17
24 x 24	72	52	34	12/21
26 x 26	88	64	42	14/25
32 x 32	124	91	60	18/33
36 x 36	172	127	84	21/39
40 x 40	228	169	112	24/45
44 x 44	288	214	142	28/53
48 x 48	348	259	172	34/65
52 x 52	408	304	202	42/78
64 x 64	560	418	278	56/106
72 x 72	736	550	366	72/132
80 x 80	912	682	454	96/180
88 x 88	1152	862	574	112/212
96 x 96	1392	1042	694	136/260
104 x 104	1632	1222	814	168/318
120 x 120	2100	1573	1048	204/390
132 x 132	2608	1954	1302	248/472
144 x 144	3116	2335	1556	310/590
8 x 18	10	6	3	3
8 x 32	20	13	8	5
12 x 26	32	22	14	7/11
12 x 36	44	31	20	9/15
16 x 36	64	46	30	12/21
16 x 48	98	72	47	14/25

1.4 DATA CAPACITY OF 2D DATA MATRIX

The size of the 2D data matrix is determined by the encoded data. The characters which are encoded to a 2D data matrix are selected with respect to the data matrix's size. The possible smallest characters are chosen for encoding. Table 1.2 demonstrates broadly used data types are used for encoding instead 2D Data matrix size. Endurance of the 2D data matrix is established by the error correction modules.

1.5 IMPLEMENTATION AREAS OF DATA MATRIX

Nowadays, the barcode systems are utilized in many distinct regions for saving time from information traffic. Such systems ensure great ease for our lives in this technology era. Mostly barcodes are used in consumption economies, automatic reading systems recognize barcodes and information is taken in a blink of an eye. The simplest barcodes are 1D traditional product barcodes which have white background and black lines. 1D data matrices are the ancestors of the barcode systems they stores limited information and read by an optical reader. By the help of the developing technologies i.e. scanning, camera, printing and integrated circuit technologies, barcode systems keep step with developing technology. Storage is increased and wide range of utilization such as product security and tracing settled in industries. Marked and unmarked products in the market can easily detected. A data matrix which has a unique production information and stores in database, is placed on a product or its box. In the market, this unique info of a product can be traced easily during sales or off the rack products.

For instance, Figure 1.6.demonstrates that 2D data matrices are used to trace the product from production to the end user. The information about alcohol beverages, ingredients, production date, quantities etc. is encoded to the 2D Data matrix. The authorized dealers can take all information about the product by the help of Data Matrix scanner applications in smart phones.

1.6 INVISIBLE 2D DATA MATRIX

In Turkey, illegal trafficking and smuggling of medicine, alcohol beverages and tobacco products threatens public health and government's taxes. Hence to prevent illegal sales of these products and tracing the authentic products in the market, 2D data matrices are used as shown in Figure 1.7. Unlike visible data matrices these products' security is provided by invisible data matrices. Due to the lack of security about visible data matrices

Figure 1.6: Tobacco Product and Alcohol Beverage Banderole

these data matrices are copied easily. Invisible 2D data matrices cannot be seen with naked eye. Special pigmented ink is used to print 2D data matrices. This printed ink on a paper cannot be seen under daylight. By the help of determined wavelength light and other camera devices, printed 2D data matrix can be seen. For preventing the illegal trafficking of alcohol beverages and tobacco products, government made law for such products; these products must be traced and monitored by certificated invisible data matrix system.

In the market place, special portable devices which can read invisible 2D data matrices, are used by surveyors for tracing and monitoring. These portable devices have considerable amount of dimensions so they cannot be transferred easily. Technically expertise should be satisfied for active operations and the expensive price of the device leads that the mobile systems are needed for tracing and monitoring alcohol beverages and tobacco products.

In Figure 1.7. an invisible 2D data matrix is shown. The special pigmented ink printed on paper the invisible 2D data matrix becomes visible under 630 nm wavelength light and a high pass filter. Special ink reflects red led light which has approximately 630 nm wavelength. By means of used filter, invisible 2D data matrix has black background and white dot modules. An invisible 2D data matrix consists of two independent parts. The borders are finder patterns. The uninterrupted adjacent dot modules constitute the “L” shape finder pattern. The opposite boarders of “L” shape finder pattern, composed of alternating black and white dot modules, is timing pattern. Timing pattern helps to address the four corner points and the data area. In the

Figure 1.7 Invisible 2D Data Matrix

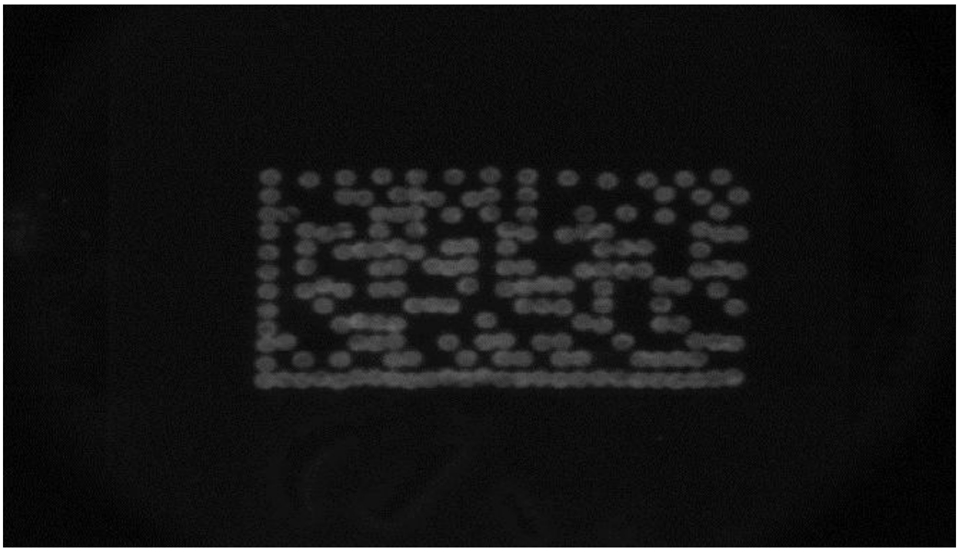
middle of this area is the second part of the invisible 2D data matrix; data area. The data area is used to indicate information.

The location of the 2D Data Matrix is determined by “L” shape finder pattern. In addition “L” Shape finder pattern gives the information about the shape of the data matrix whether it is square or rectangle. The first step for detecting a 2D data matrix is to find the “L” shape finder pattern and the timing pattern. These finder patterns give clues about the taken image of the 2D data matrix if the matrix is distorted or not.

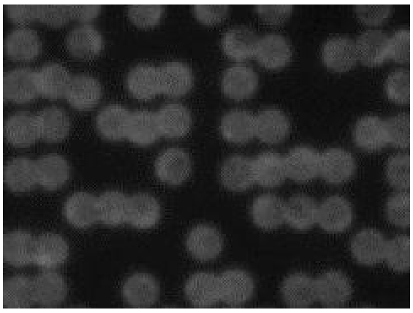
The inkjet printer is used for printing the invisible 2D data matrix. While printing the Data Matrix ink can be spread and the needle of the printer cannot stamp on the paper properly or vice versa. As a result, the printing quality of the invisible 2D data matrix is shown in Figure 1.8. The faced problems and errors are listed below:

- Noise caused by background.
- Orientation of the rows and columns are alternating.
- Ink can be spread out of the region.
- Needle cannot press as hard as needed.

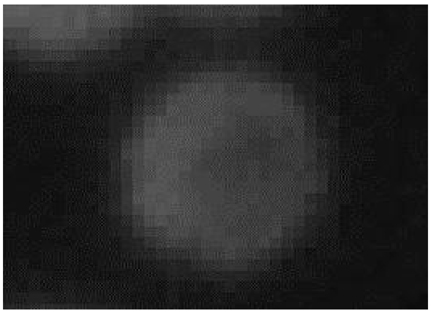
As discussed above the invisible 2D data matrix capture has more tough process than the visible 2D data matrix capture.



(a) Invisible 2D Data Matrix



(b) A section of a data part



(c) Single Dot Module

Figure 1.8: Printing Quality of Invisible 2D Data Matrix, (a) Full data matrix, (b) zoom-in of the full data matrix (c) Single Dot Module of a data matrix.

1.6.1 Hardware Problems in Smart Phone

The capturing the invisible 2D data matrix via smart phones is more difficult than capturing industrial cameras. Since the hardware difference between the industrial cameras and the camera of smart phone causes this problem.

There are two main reasons for this problem. First is the quantum efficiency of the devices and the other is the pixel size. The quantum efficiency shows the absolute amount of incoming light. If the quantum efficiency is high, the incoming light is absorbed more. For the best explanation, the quantum efficiency plots of the near infrared and color industrial camera shown in Figure 1.9 and Figure 1.10. [2]

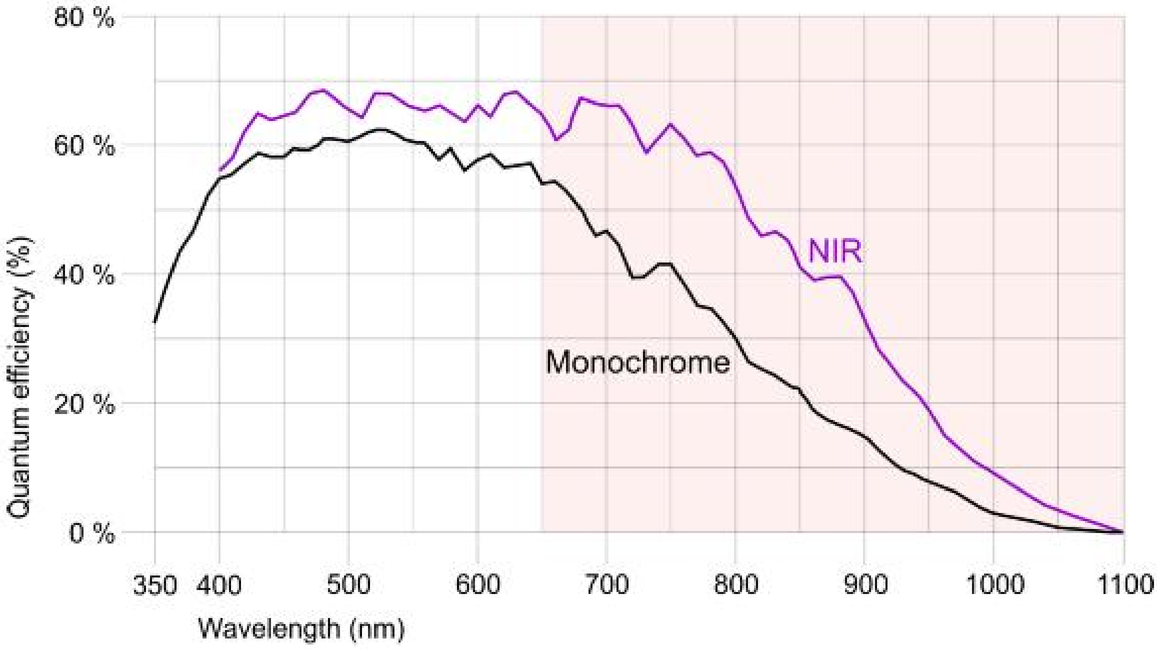


Figure 1.9 Quantum Efficiency of Near Infrared IDS-1240 ML-NIR-GL Camera [2]

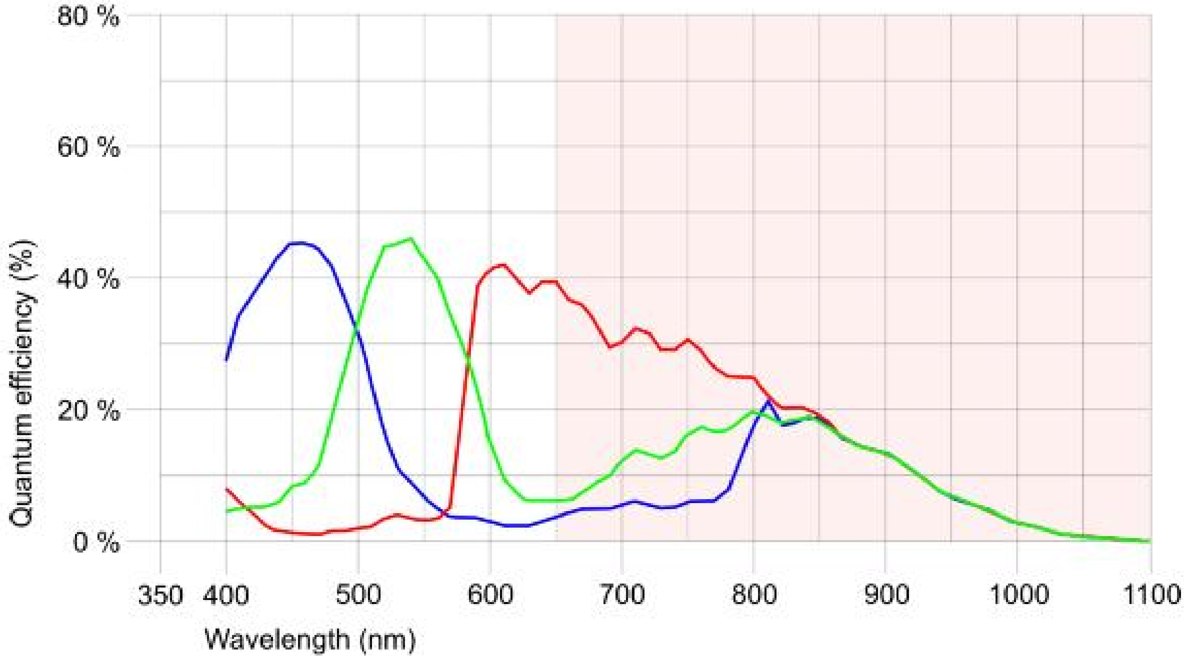


Figure 1.10 Quantum Efficiency of Color IDS-1240 ML-C-HQ Camera [2]

The difference between color and near infrared IDS camera is obvious by the help of the below figures. Even if there are two monochrome cameras on the hand. One is NIR and the other one is monochrome. Their quantum efficiencies around 700 nm wavelength differs by 20%. In the increasing number of the wavelength NIR camera's quantum efficiency doubles the monochrome camera. Consider the color IDS camera, the quantum efficiencies of the blue and green channels are around 10% of so they cannot be considered in the range of 650-800 nm wavelength. As considered that, the used filter which is high pass filter, has 695 nm permeability. The efficiency difference between color IDS camera and near infrared IDS camera is very distinct. This sensor efficiency is a huge problem from the smart phone camera aspect. While taking the images for tests near infrared IDS camera is used. This provides that, the reflected red light is obtained more efficiently nearly 60% of the reflected light compose the image. On the other hand, if the image was taken with the color IDS camera, around 40% reflected light would compose the data.

The second reason of difficulty by capturing invisible data matrix by smart phone is the pixel size. The pixel size of the industrial camera is 5,3 µm this size also affects the quantum efficiency. Unlike industrial cameras, smart phone cameras pixel size is 1,12 µm. That is nearly 25 times smaller pixel area that the smart phones have. It means that industrial camera absorbs 25 times more light than the camera of the smart phone. This difference causes that the quality of smart phone cameras is worse than the industrial camera. These basic properties directly affects the image quality. The data loss or the noisy background problems are caused by the pixel size.

1.6.2 Invisible 2D Data Matrix with Different Filters

In order to show the effect of the filter, invisible data matrix is captured with different filters. There are invisible 2D data matrices are shown below, these samples are taken by different wavelength permeable high pass filters (680 nm, 695 nm, 720 nm, 850 nm and 950 nm) by industrial camera. The filter affect can be seen clearly by these samples. In Figure 1.11 680 nm permeable high pass filter image can be seen. Shiny dots and a background noise can be perceptible easily. The reflected light couldn’t be eliminated by 680 nm high pass filter. In Figure 1.12 695 nm high pass filter image can be seen, the background effect is broken and the shiny dots are obtained. 695 nm high pass filter is the ideal range for capturing invisible 2D data matrix. Since In Figures 1.13, 1.14 and 1.15 there are 720 nm, 850 nm and 950 nm high pass filter images are demonstrated. Not only the background effect broken but also the data loss is faced. The quantum efficiency of the NIR camera is decreasing so the shiny dots disappear around 700-900 nm high pass filter wavelength band.

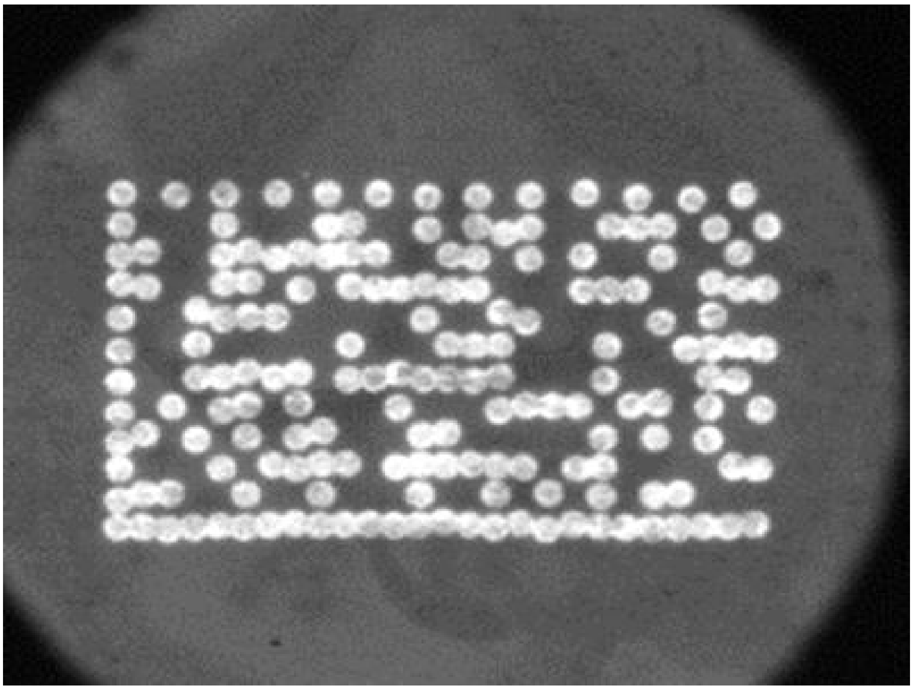


Figure 1.11 680 nm High Pass Filter Image

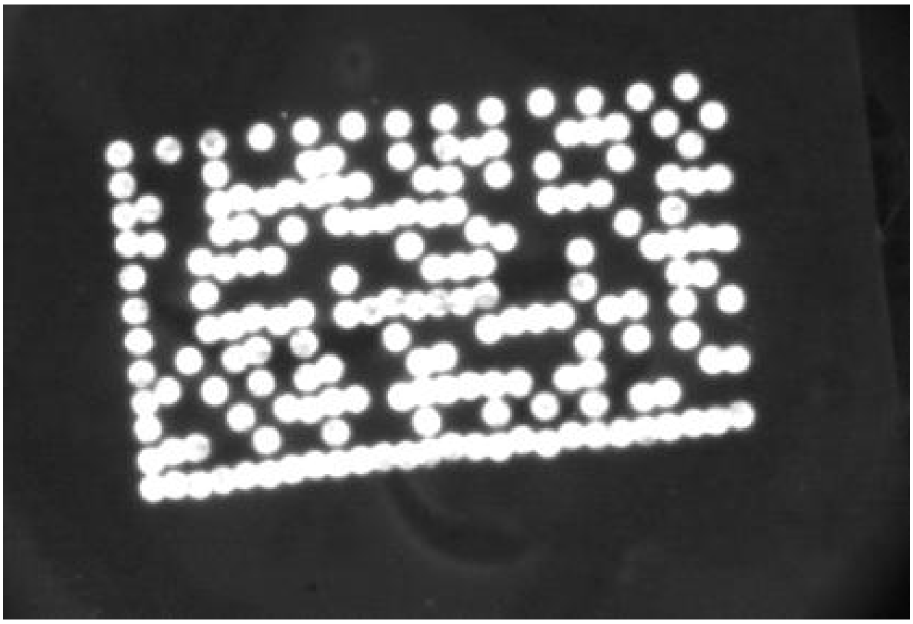


Figure 1.12 695 nm High Pass Filter Image

Figure 1.13 720 nm High Pass Filter Image

Figure 1.14 850nm High Pass Filter Image

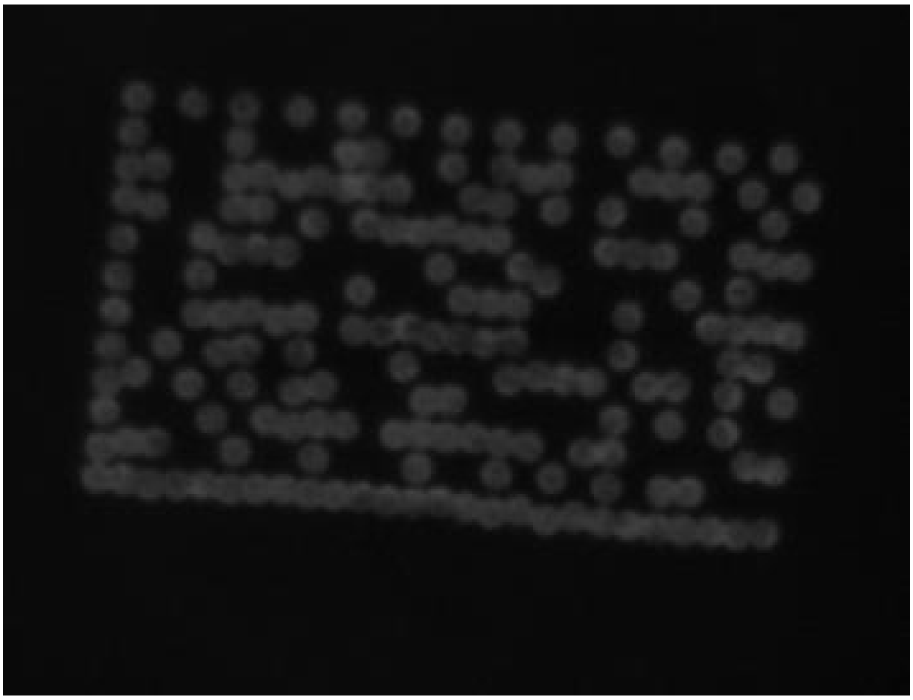


Figure 1.15 950 nm High Pass Filter Image

As seen on above Figures when the permeability of the filter increases the invisible 2D data matrix images' quality and the reflected light density are decrease. The reason of the small pixel size and inadequate quantum efficiency which the smart phone cameras have, the reflected light can be disappeared. The loss of the density of the pixel indexes in the image causes noise, blur and low sharpness between modules. Unlike smart phone cameras, industrial cameras have bigger pixel size, the filter utilization can provide options for the image qualities. This condition warns that the invisible 2D data matrix capturing by smart phones needs extra sensitive efforts. Unlike visible 2D data matrices, invisible 2D data matrix capturing, detecting and decoding processes are more complex. In addition to that, capturing the invisible 2D data matrix by smart phones doubles the difficulty of the process. In this thesis, these problems are tried to be solved.

CHAPTER 2

BACKGROUND AND RELATED WORKS

Studies on data matrix systems generally concentrate on detecting, decoding and encoding of these systems. The very first important issue is about detection of the data matrix. After locating the data matrix decoding stage begins for the detected data matrix. Various methods are developed for decoding systems. Studies on encoding and mapping systems hypervariable according to types of data matrices. Although there are many works related on data matrices, most of these about “visible” data matrix systems. This leads us to present studies on visible data matrix systems generally in this chapter.

2.1 DETECTING THE FINDER PATTERN

The location of the 2D data matrix is determined by “L” Shape finder pattern. By the help of the timing pattern which has alternating dark and light dots/cells, row and column sequences are determined. The finder pattern which enclose the data part of the data matrix gives way to decoding part.

Detection of the “L” Shape finder pattern is crucial step of the algorithms. For detection of “L” shape, Hough Transform is used. Thanks to the high printing quality of the visible data matrices, “L” shape can be detected easily. On the other hand, detecting the “L” shape finder pattern in the invisible data matrix is not as easy as visible ones. Because of the distortion, noise and printing quality of the invisible data matrix make this detection more difficult. The advantages and disadvantages or lacks of the methods between visible and invisible data matrix are considered in this chapter.

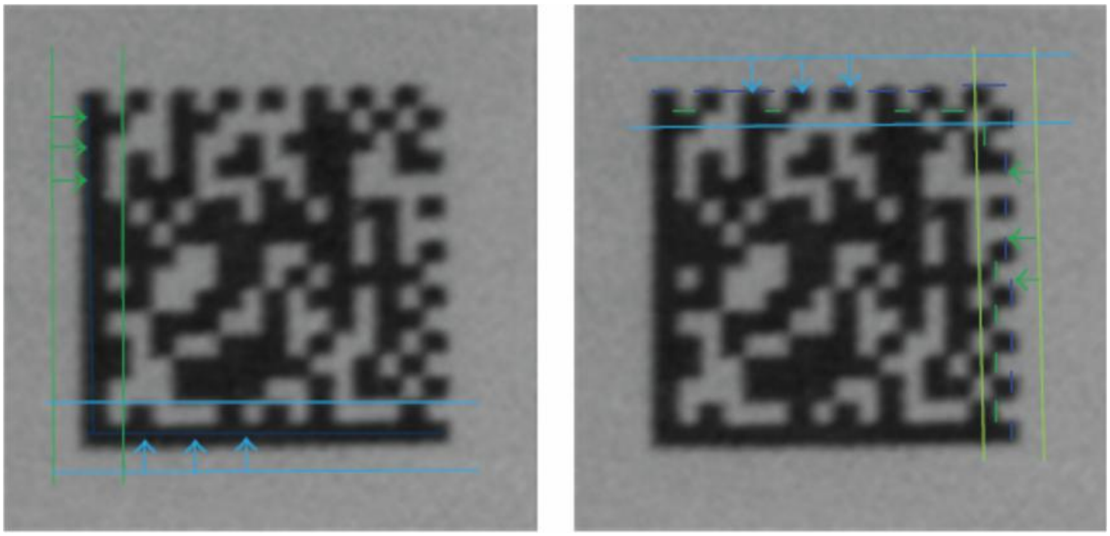


Figure 2.1: Determine the Finder Pattern Borders

The Radon Transform is used to find the “L” shape finder pattern and the timing pattern of the data matrix by Donghong at al. [2]. However, this algorithm is very practical for high-sensitive and high density 2D data matrices, high rate of time consumption while detecting the “L” shape finder pattern makes this algorithm adequate for fast applications.

Hough Transform based placement algorithm is composed by Chenguang et al. [3]. The time consumption and the large memory request are decreased with second Hough Transform by this algorithm. The foremost disadvantage of this algorithm is the low accuracy for complex background. Wenting and Zhi [4] used convex hull property for detection of the “L” shape finder pattern but this algorithm needs a clear background.

The detection algorithms which are considered in [5, 6] are operable under less than stellar setting. For instance; clean background, well illumination of the data matrix etc. Often barcodes are printed on complex background. In addition to that, barcodes can be perished. Under these conditions algorithms consumes more memory and need more time for processing. That is, such kind of algorithms are not suitable for real time activities.

The Line Segment Detector (LSD) algorithm is proposed by Huang et al [7]. The Line Segment Detection algorithm is based on detect and fit the 2D data matrix to the “L” shape finder pattern frontier. The approximation technique is used to fit the barcode to the “L” shape finder pattern by a region called support line. The range of the support line can be seen in Figure 2.1.

Pseudo algorithm is presented by Liu et al [8]. “L” shape finder pattern is a very crucial element of 2D data matrix, in the beginning the algorithm. The 2D data matrix is detected on edge image. After that point, three steps of filtering will not wipe out the 2D data matrix. Firstly, thanks to the Roberts’ operator is used to edge detection. This solution technique has high validity and strength for destroyed “L” shape finder pattern. Secondly, for the detection of the corners of the 2D data matrix Grammar Convex Hull algorithm is applied. Finally pixel density gives the “L” shape finder pattern on the image if the computed convex hull edge exceeds the threshold value.

2.2 2D DATA MATRIX DECODING

The “L” shape finder pattern is detected and the 2D data matrix is located in the image. The next step is to decode the data region. There are several studies are conducted about this task.

‘Bidirectional centripetal run length method’ is proposed by Rathod and Ladhake [9] to detect 2D data matrix by mixture of detection directions and bit by bit detection. The Hough Transform is used to determine the four corners of the 2D data matrix. Only the peripheral coordinates are kept for the next detection step. By the help of the cells which are close to the boarders of the 2D data matrix, lead the centripetal detection route. The data region is divided into four sectors, each row and column of the data area are scanned from outside to inside. While scanning the previous scan is used to predict the next scan.

After acquisition of the four corners of the 2D data matrix, Pârvu and Bălan [10]’s method which is based on binarization of the elements in the image, starts. If there is no 2D data matrix is found in the selected region, the algorithm turns back to select another region in the image to detect a 2D data matrix. Their method is robust for 2D data matrix detection. Distinct components are located by contour tracing algorithm. With the original background which has noise and distortions, the found longest two pieces of the contour tracing algorithm provide us “L” shape finder pattern. The corners of the 2D data matrix is located by two sequential adjusting and re-adjusting steps, starting from the maximum deviation of fourth corner detection analysis with respect to the found elements.

The above briefly described related works are proposed for visible data matrix. The only work on invisible data matrices is presented by Halit Sun [11]. In this method the invisible 2D data matrix is captured and detected in the image by Hough Transform. Then, the detected invisible data matrix’s orientation is fixed. The process continues on the binary image mostly. According to the pixel list of the image, the four corners of the 2d data matrix are found. Due to the printing failures the 2D data matrix is rearranged as it should be in rectangular shape by geometric transform. After detection and rearrangement of the 2D data matrix, the dots are traced row by row. Unlike Sun’s study in this thesis, the Hough Transform usage is more effective for the location of the invisible 2D data matrix. In Sun’s algorithm Hough Transform captures only the longest frame of the “L” shape finder pattern. In this thesis by the help of the edge function the complete “L” shape finder pattern diagnosed by Hough Transform. While detecting the modules of the invisible 2D data matrix, the zig zag algorithm runs and also keeps the local thresholding information in the matrix. This brings the online learning thresholding in other words local thresholding is used for detection.

As discussed above, the one of the most important difference between visible vs invisible data matrix is printing procedure. Printing visible data matrix is easier than invisible data matrix. Generally, white clean background and a high quality printers are used to print visible data matrices. The cells of the data matrices are square shaped and uniformly printed. On the other hand, inkjet printers are used to print invisible data matrices by using special pigmented ink. While printing procedure inkjet printer repels the pigmented ink through a needle on to the paper. As a result of this procedure the cells of the invisible data matrix are not printed uniformly. Since the invisible data matrix cannot be seen under daylight, determined wavelength LED light and a high pass filter is used. For obtaining effective image from invisible data matrix the illumination should be adjusted very carefully. The pigmented ink reflects determined wavelength light and also under well-lit paper can reflect light, it causes noisy background even if high pass filter is used.

Therefore, the image quality issue and the technical needs are critical between detection of visible data matrices and invisible data matrices. As described above, the visible 2D data matrix detection and detecting methods are cannot be applied as they are to the invisible 2D data matrix algorithms.

CHAPTER 3

DETECTION AND DECODING OF THE INVISIBLE DATA MATRIX WITH SMART PHONE BY USING HOUGH LINES AND ONLINE LEARNING

3.1 THE INVISIBLE 2D DATA MATRIX CONCEPT

Based on the special pigmented ink and the paper, the invisible 2D data matrix cannot be seen under daylight by bare eyes. There should be some components to make invisible 2D data matrix visible. Determined wavelength which is around 630 nm LED light. Under this illumination the reflected light has to be filtered to be chosen the invisible 2D data matrix. If the illumination is high above the determined wavelength or the filter is not properly selected for the wavelength, the invisible 2D data matrix cannot be detected or detected invisible 2D data matrix has noisy background. On the contrary the standard visible 2D data matrices, invisible 2D data matrices' cells are composed of dots which have not determined dimensions. That is, the algorithms which are designed for visible 2D Data Matrices are not properly applied on the invisible 2D data matrices.

The printing issue is the one of the important disadvantage for invisible 2D data matrix. The inkjet printer has unsustainable printing quality. For instance, the pigmented ink disturbs the modulation so the alignment of the rows and columns is alternating. The spread of the pigmented ink brings us an uncertain cell boarders.

The capabilities of the smart phone cameras are incomparable between standard hand cameras. The elements and the software of these devices are distinct according to the utilization areas. Therefore, capturing an invisible 2D data matrix is extremely challenging compared to a visible 2D data matrix. The proposed algorithm struggles above challenges.

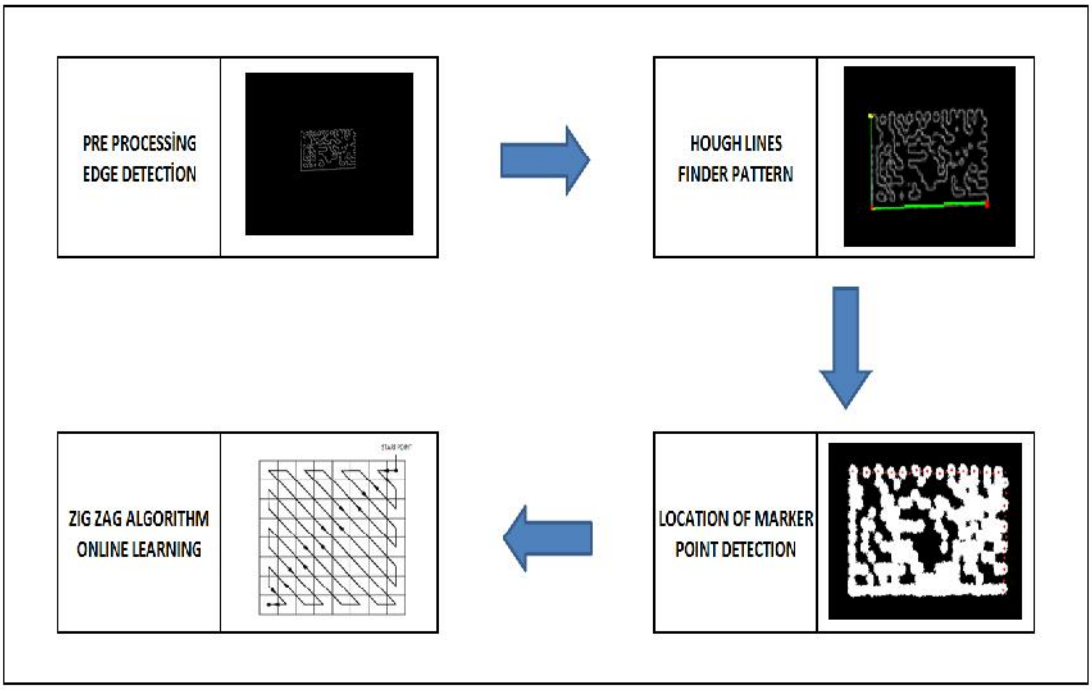


Figure 3.1: Flow Chart

3.2 PROPOSED ALGORITHM

Similar to the visible 2D data matrix detection algorithms, recommended algorithm is started by detecting the “L” shape finder pattern and the timing pattern. After determining the location and the corner points of the invisible 2D data matrix the algorithm focuses on the decoding of the invisible 2D data matrix.

In the related works chapter we have discussed about advantages and disadvantages of “L” shape finder pattern detection algorithms. By the reason of difficulties between invisible and visible 2D data matrices, the discussed algorithms cannot be directly applied on invisible 2D data matrix decoding. These algorithms need to be developed to decode the invisible 2D data matrix. The recommended algorithm is demonstrated above in Figure 3.1.

The construction of the algorithm is described by the flow chart. At the beginning, the image is obtained. Later on a threshold which is based on global image thresholding using Otsu’s method is applied to the image. After using global thresholding, the edges of the image is obtained via edge function. At that moment the noise and other distortions in the image are eliminated, only the edges of the invisible 2D data matrix is expected to acquire. The time for locate the 2D data matrix in the image. The traditional method

Hough Transform is applied to detect where these edges in the image. That is “L” shape finder pattern is the target to this pursuit. The “L” shape finder pattern is expected to found after Hough Transformation, and the next step is to identify the founded information. The Hough Lines in the image gives us the “L” shape finder pattern which is composed of two adjacent perpendicular lines. These two lines needed to be identified that the longest and the other edge of the “L” shape finder pattern. The other properties of these lines will be discussed. The timing pattern have the key role on decoding so the next step is to access the timing pattern of the invisible 2D data matrix. At this stage of the algorithm the expected datum of invisible 2D data matrix are; location of the matrix, “L” shape finder pattern and timing pattern elements are completely designated. By the help of the four corner center points, the data tracing in the invisible 2D data matrix shall be started. The zig zag tracing algorithm detects and states the dots of the invisible 2D data matrix. The detailed explanation will be presented in the following subtitles.

3.2.1 PREPROCESSING

A- Global Thresholding

The recommended algorithm starts with detection of the invisible 2D data matrix in the image. As discussed before the most important distinguishing property of the 2D data matrices is “L” shape finder pattern. As a beginning, the algorithm focuses on pick up the 2D data matrix from whole image. That is, the background and the other elements in the image should be eliminated. For this purpose, the global image thresholding using Otsu’s method is applied to the image. This method provides an automatic threshold selection. Histogram based method maximizes the distinguishability of the image in gray levels [12]. After elimination of the background and other distortions, the image of the invisible 2D data matrix becomes a binary image.

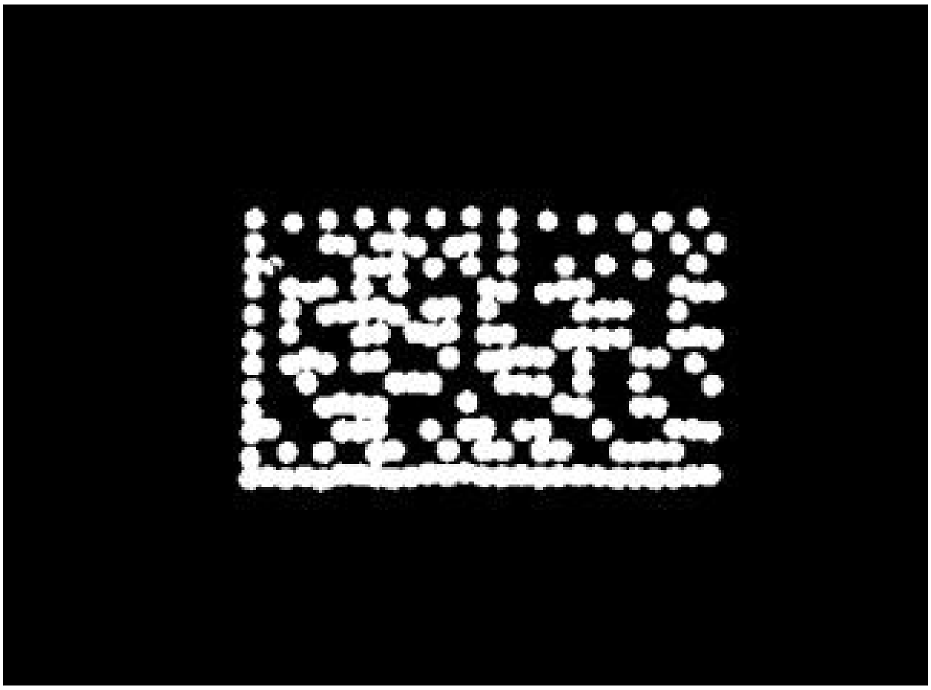


Figure 3.2: The graythresh method is applied to an Invisible 2D Data Matrix.

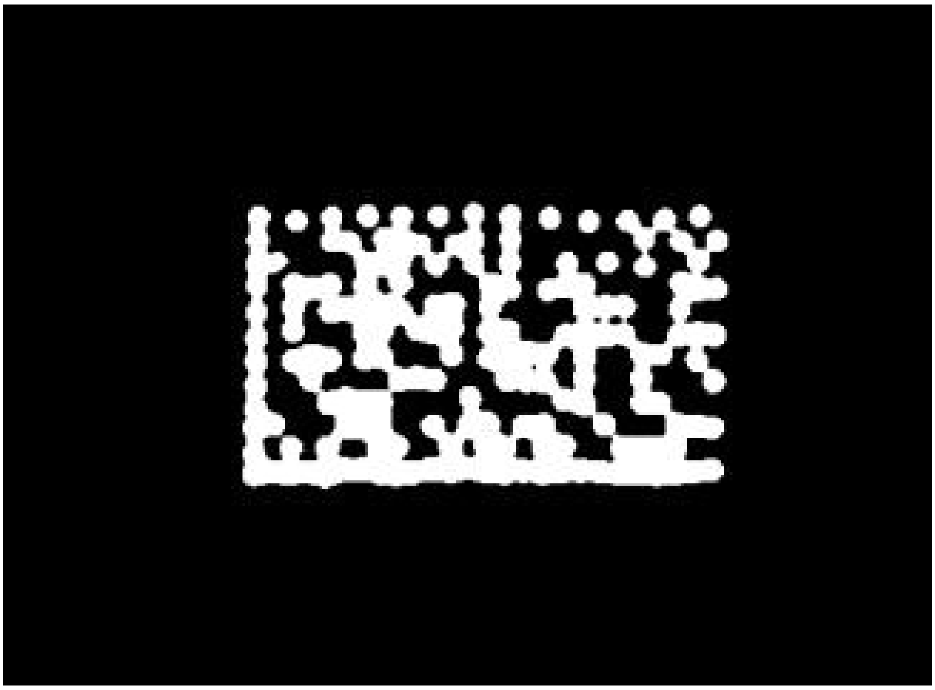


Figure 3.3 Applied Gaussian Filter to Threshold Image

The obtained threshold image is used for determining the edges of the 2D data matrix. According to the printing distortions like untouched dots and discrete printed dots may cause loss of “L” shape finder pattern. For elimination of the losses on “L” shape finder pattern the image is blurred by Gaussian filter. The filtered image can be seen on Figure 3.3.

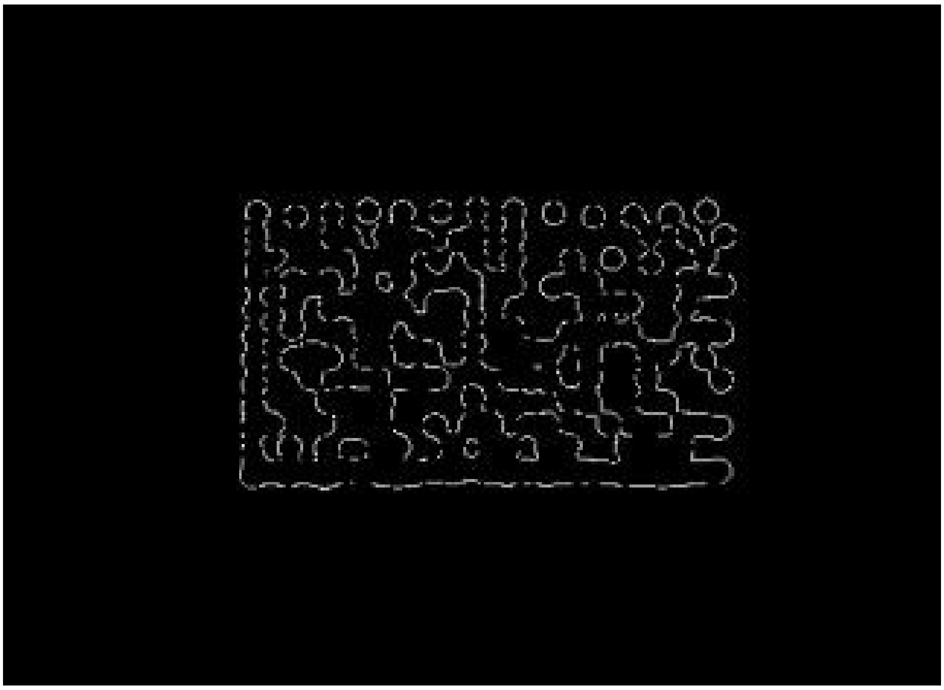


Figure 3.4. The edge function is applied to 2D Data Matrix

By the canny edge detection algorithm, the edges of the invisible 2D data matrix can be detected. The canny method of edge function uses local maximum point of gradient of the Image and this gradient is obtained from the derivative of Gaussian filter. There are two thresholds are consisted by this method. The intense and lean edges are detected and only the lean edges which are bonded to the intense edges are demonstrated at the output image. The edge detection applied image can be seen on Figure 3.4.

B- Hough Lines and Detection of Finder Pattern

After achieving the edge of the invisible 2D data matrix, the next step should be locating the data matrix in the image. In order to locate the data matrix in the image, “L” shape finder pattern detection have to be done. As the Figure 3.7 illustrates that the longest two lines on the image belong to the “L” shape finder pattern. Hough Transformation is utilized for detection of the longest two lines. Hough Transform’s purpose is to catch the lines and others like circular and elliptical shapes. Hough Transform algorithm searches for any proof of line or other shapes in the image. If there are any proof for any shape, algorithm increments the existence variable and looks for the maximum value of this variable. The maximum value of this variable is called Hough Peaks. Hough Transform algorithm brings us two dimensional array about found

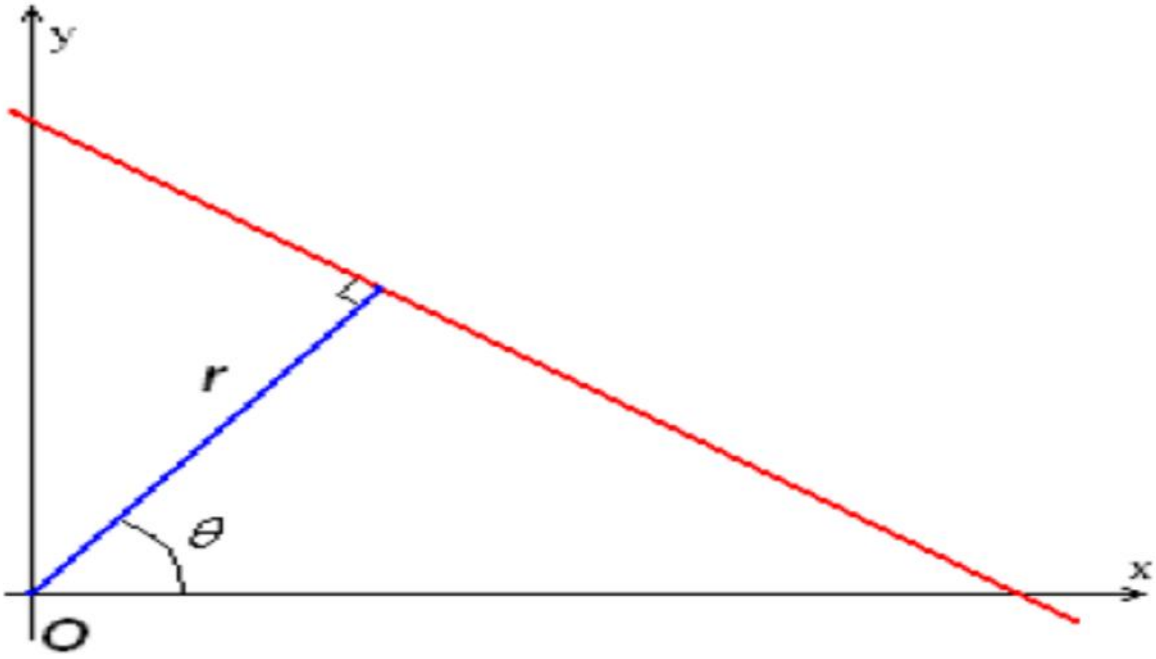


Figure 3.5 Angle θ and Distance r Relation [13].

line or other shapes. One of the array is the angle θ and the other is distance from the origin. The line equation is y = mx+b, according to the slope of the line "m" Hough Transform computes the angle of the line with respect to origin and the distance from the origin. Though, if the range of θ is limited 0 to π the vertical lines which are the x and y axis the normal parameters are unique. For solve this issue the equation is transformed to sinusoidal curves. That is the equation becomes; $r = x_i \cos\theta + y_i \sin\theta$. The Houghpeaks function of Matlab brings us the densities of the peaks in the image on an r-θ plane [13].

By using the Hough Transform, the "L" shape finder pattern's location is determined. Figure 3.6 demonstrates the Hough Peaks of the Image. The perpendicular lines which are composing the "L" shape finder pattern, Hough Peaks of these lines have 90 degrees between each other and the Figure 3.7 demonstrates the Hough Lines of the transformation algorithm.

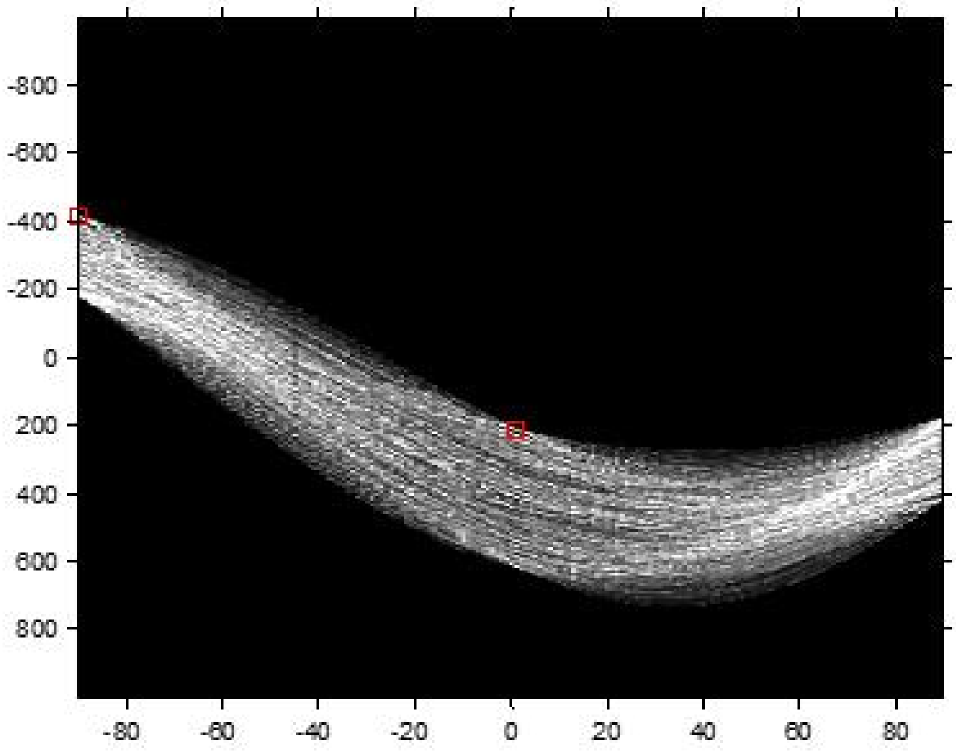


Figure 3.6 Hough Peaks

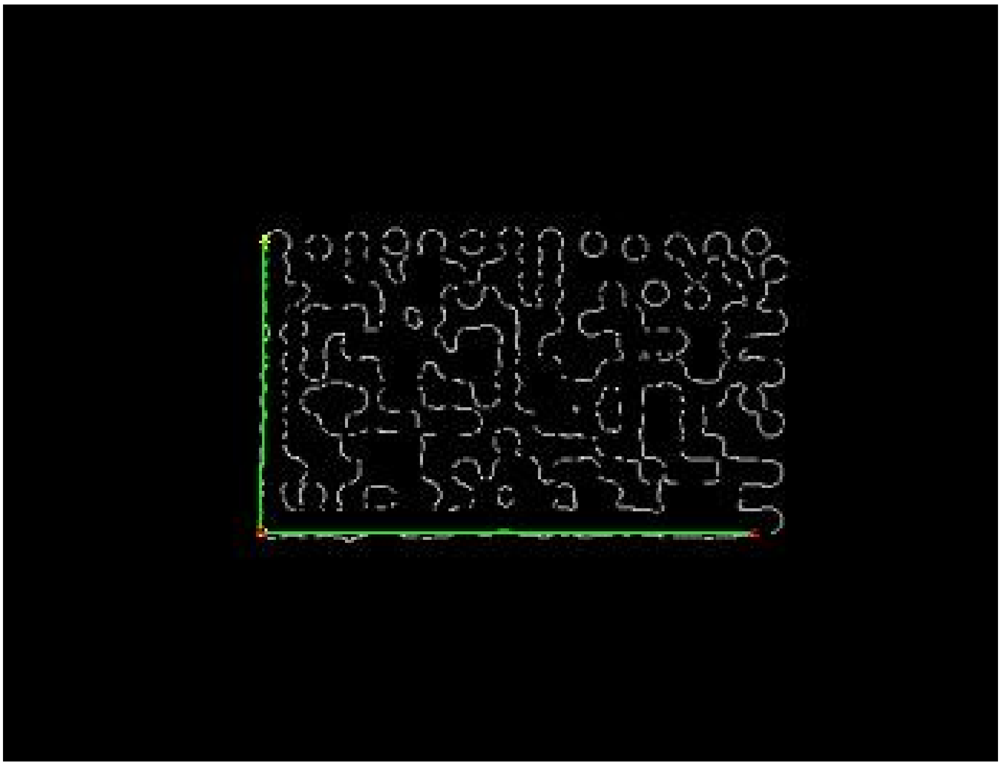


Figure 3.7 Hough Lines

C- Identification of the “L” Shape Finder Pattern Parameters

The “L” shape finder pattern is found and the location information in the image is obtained by the Hough Transformation. Yet, the obtained lines should be identified for the following purposes in the next sections. The longest line and the other adjacent line of the “L” shape finder pattern is determined by the help of the Hough Lines. For the orientation of the 2D data matrix the slopes of these lines are calculated. In the following sections the slopes are going to be the crucial data for the line equations. In consequence of the modules of invisible 2D data matrix are dots, Hough Transform mostly cannot find the intersection point of the “L” shape finder pattern. The intersection point is evaluated as a reference point for the invisible 2D data matrix. Due to the resolution of the image, the number of pixels composing the invisible 2D data matrix’s modules should be estimated. The estimated dimensions of the modules are going to be used in the detection of the modules which are 1 or 0.

D- Center Detection of the “L” Shape Finder Pattern

After, the identification of the “L” shape finder pattern is completed, the exact size of the “L” shape finder pattern should be found. That is; the exact lengths, location and the centers of the “L” shape lines should be designated. By the help of the slope information the Hough Lines and the location information comes from identification, the “L” shape finder pattern traced along two modules range in the original image. The pixel values and the uninterrupted “L” shape line is detected on both adjacent corners. The tracing image is shown in Figure 3.8. Every parallel line to the “L” shape finder pattern center line is tested after this algorithm’s process. The peak point of the pixel values during tracing is stored for determining the center line of the long frame and short frame. Figure 3.9 demonstrates the pixel values on the tracing line. Figure 3.11 shows the center line for the long frame of the “L” shape finder pattern. In Figure 3.12, 3.13, 3.14 and 3.15 demonstrate the short frame tracing.

Figure 3.8 Tracing the Long Frame of the L Shape

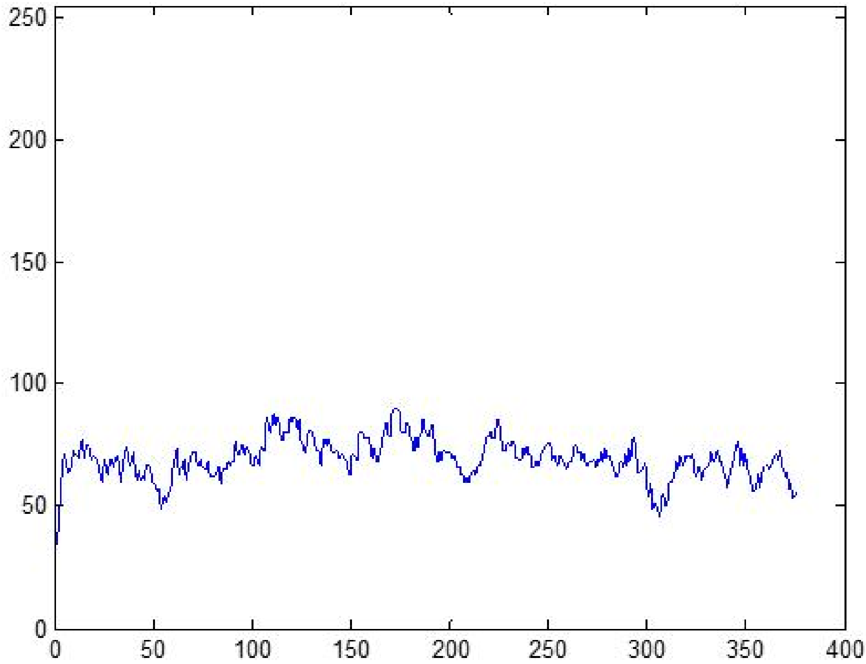


Figure 3.9 Pixel Values on the Long Frame Tracing Line

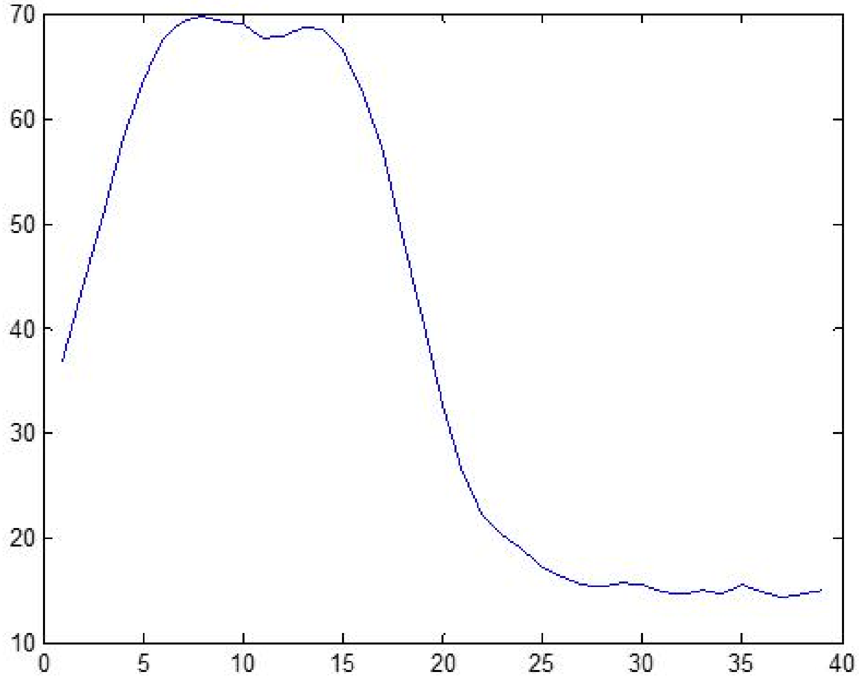


Figure 3.10. The Peak Point of The Long Frame Determines the Center Line

Figure 3.11. Long Frame Centers of L Shape Finder Pattern

Figure 3.12. Tracing the Short Frame of the L Shape

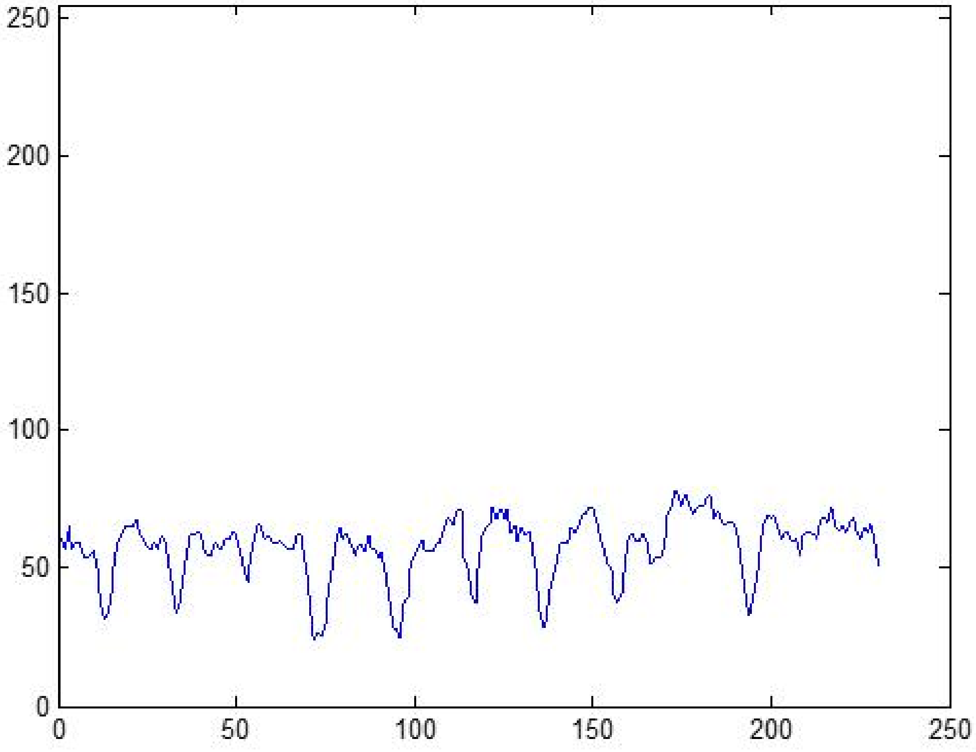


Figure 3.13. Pixel Values on the Short Frame Tracing Line

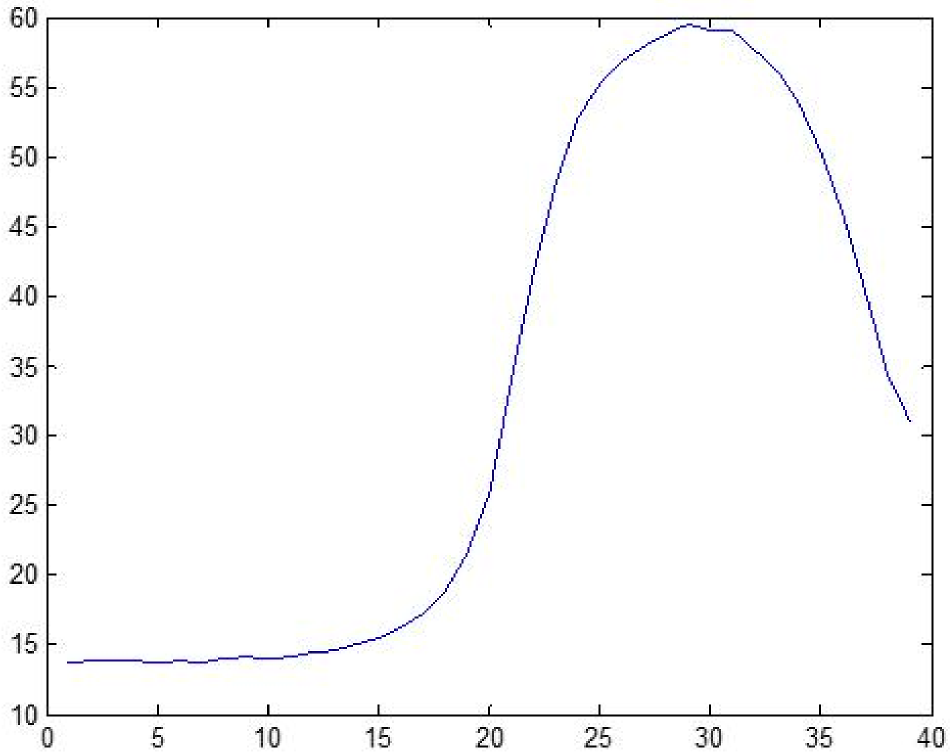


Figure 3.14. The Peak Point of The Short Frame Determines the Center Line

Figure 3.15 Short Frame of L Shape Finder Pattern

E- Center Detection of the Timing Pattern

The “L” Shape finder pattern is found, that brings us the limits of the invisible 2D data matrix in the image perceptibly. From now on, the location of the 2D data matrix is found and the coordinates of the “L” shape finder pattern is obtained. At this stage, the focus should be on the timing pattern. Timing pattern is important for the data area locations. The alternating 1 and 0’s addresses the modules in the 2D data matrix. By the help of the long and the short frame of the “L” shape finder pattern, the timing pattern trace can be done. The trace process is progressed in the binary image. Since the timing pattern has alternating 1-0 modules, the connected components of the timing pattern of the invisible 2D data matrix are labeled easily. The tracing steps of long timing pattern and short timing pattern are shown in Figures 3.16, 3.17, 3.18, 3.19, 3.20 and 3.21.

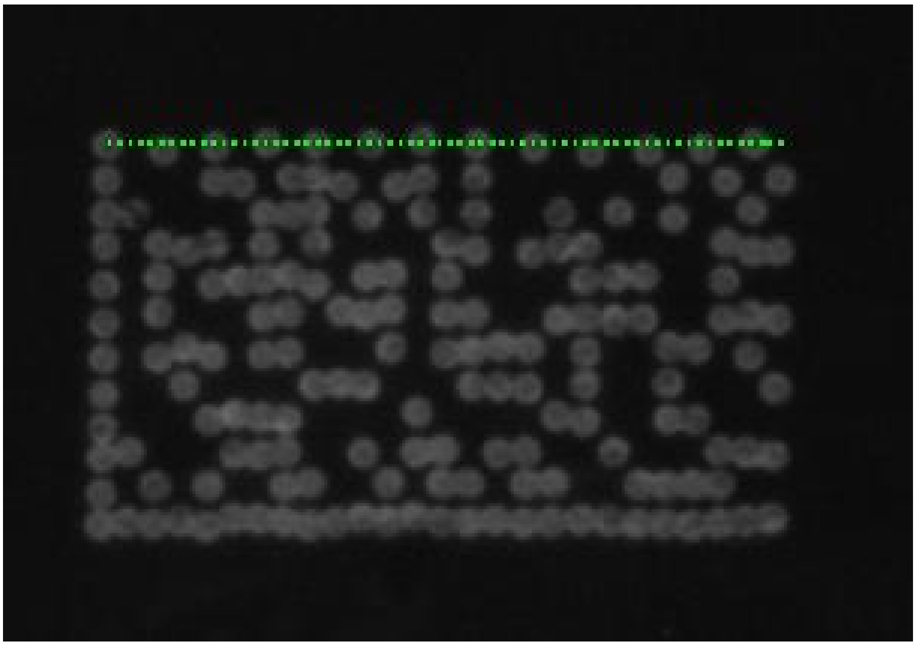


Figure 3.16. Long Frame of Finder Pattern Tracing

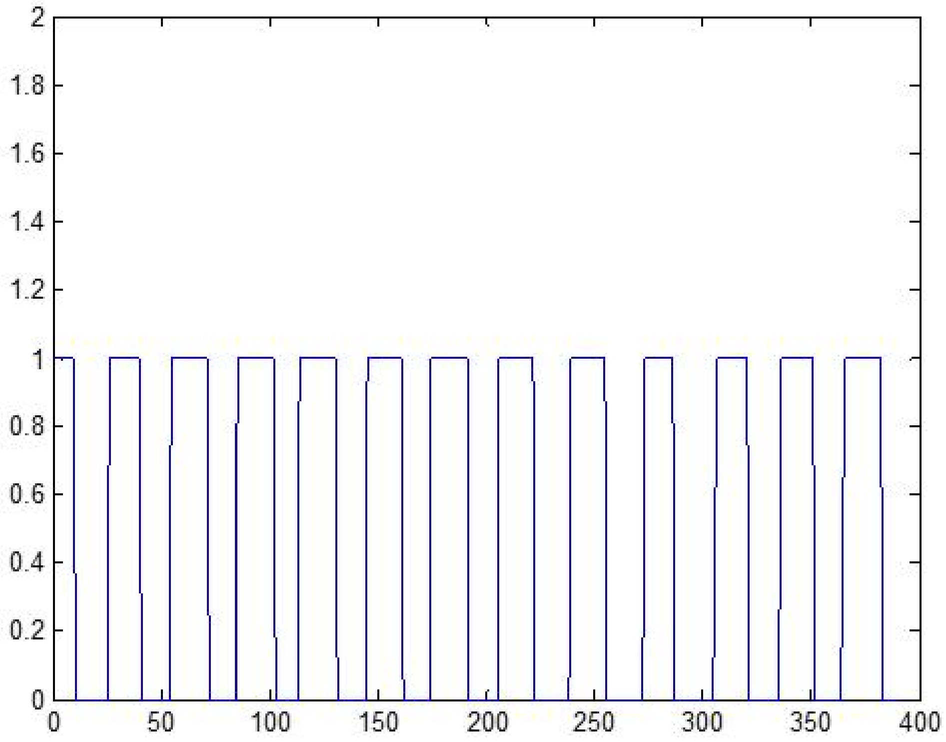


Figure 3.17 Long Frame of Finder Pattern Tracing Line on Binary Plane

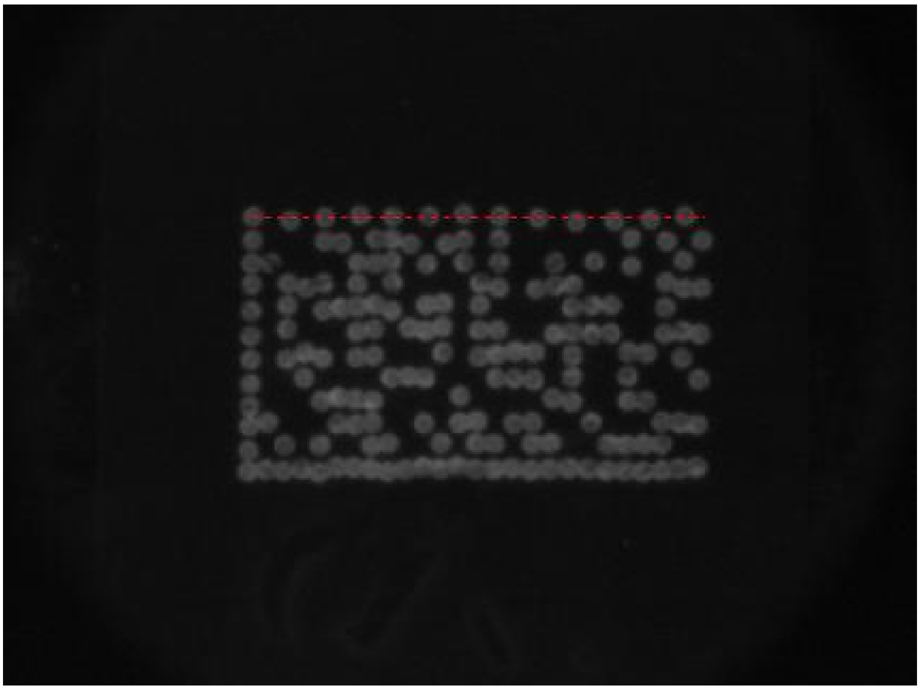


Figure 3.18 Long Frame of Timing Pattern

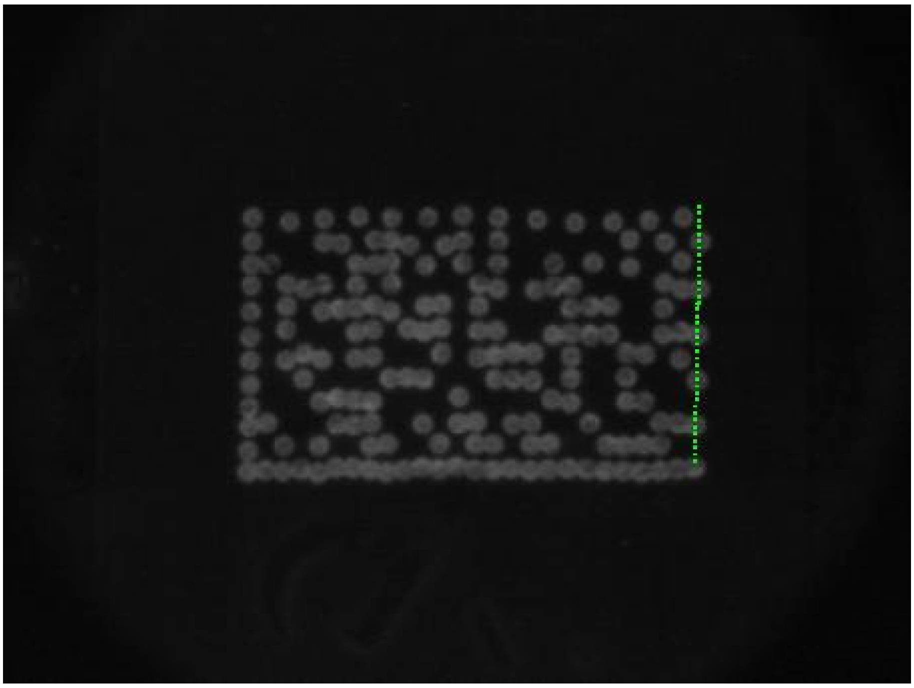


Figure 3.19. Short Frame of Finder Pattern Tracing

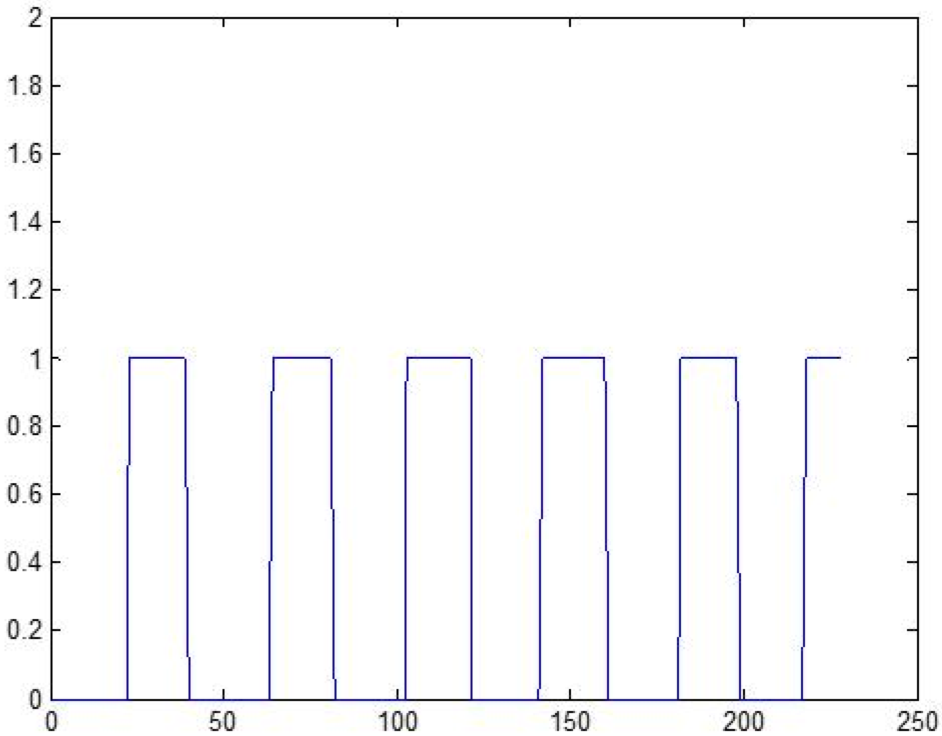


Figure 3.20 Short Frame of Finder Pattern Tracing Line on Binary Plane

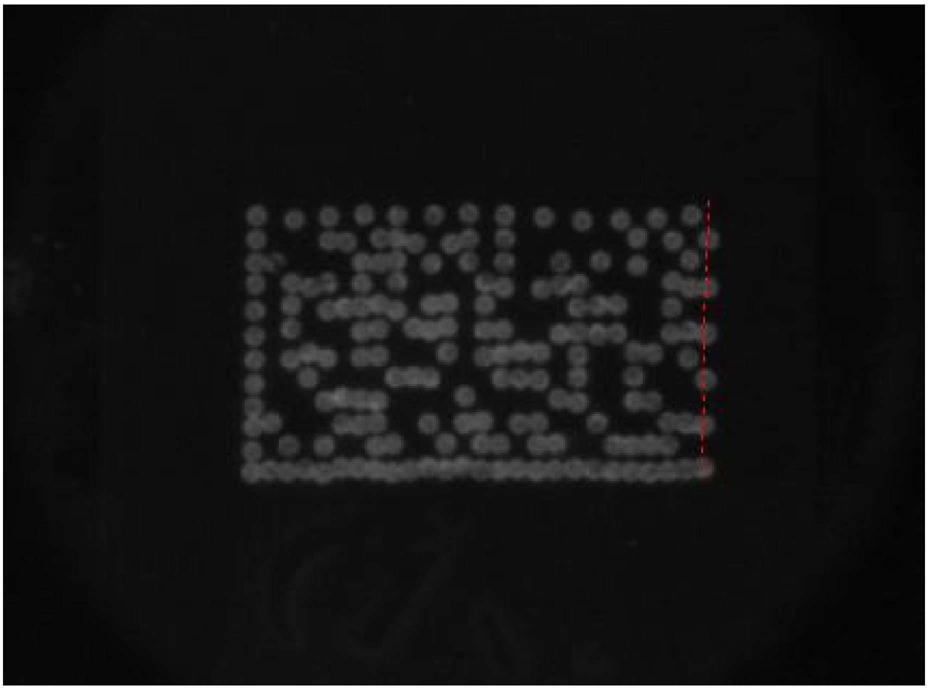


Figure 3.21 Short Frame of Timing Pattern

F- Finder Pattern Dot Centers and Determination of Four Corners

The “L” Shape Finder Pattern and the timing pattern of the invisible 2D data matrix are located and determined and also a line along their centers is drew. The intersections of these four lines brings the four center points of the four corner of the invisible 2D data matrix. By means of the labeled centers of the timing pattern of the 2D Data Matrix, the dot centers of the timing pattern are specified. That is the way to decoding stage of the algorithm is cleared.

3.2.2 ZIGZAG DECODING ALGORITHM AND ONLINE THRESHOLD LEARNING

Previously, the centers of the timing pattern are found and these centers lead to decode the data area of the invisible 2D data matrix. The data area of the invisible 2D data matrix is a 10x24 sized data matrix. The zig zag algorithm begins from the forth corner where long and short finder pattern intersects (upper right corner). The intersection points of the timing pattern centers set the data area dots’ centers. The algorithm’s traceroute is from the closest centers of the finder pattern to outmost centers intersection points as shown in Figure 3.22. Figure 3.23 illustrates an example of an intersection point of two timing pattern centers for zig zag decoding algorithm.

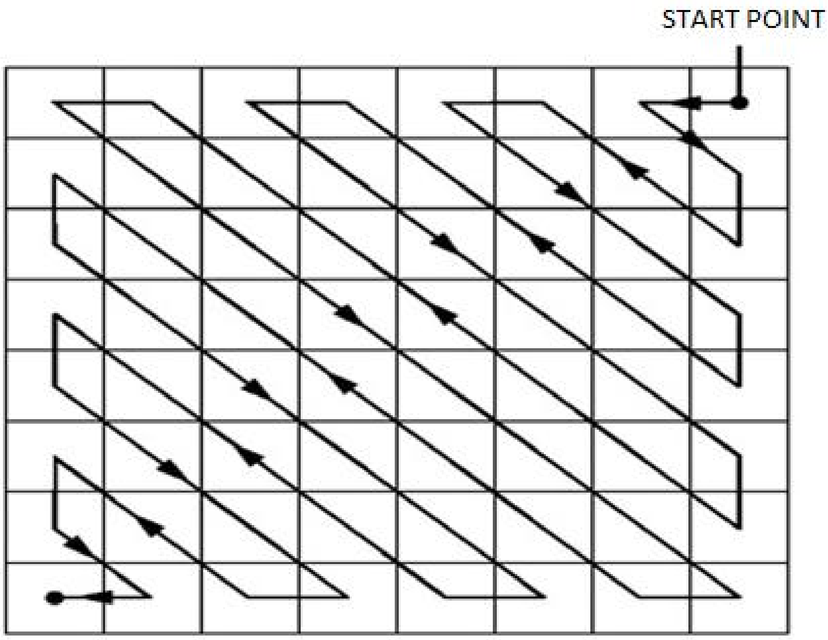


Figure 3.22 Zig Zag Route In the Data Matrix.

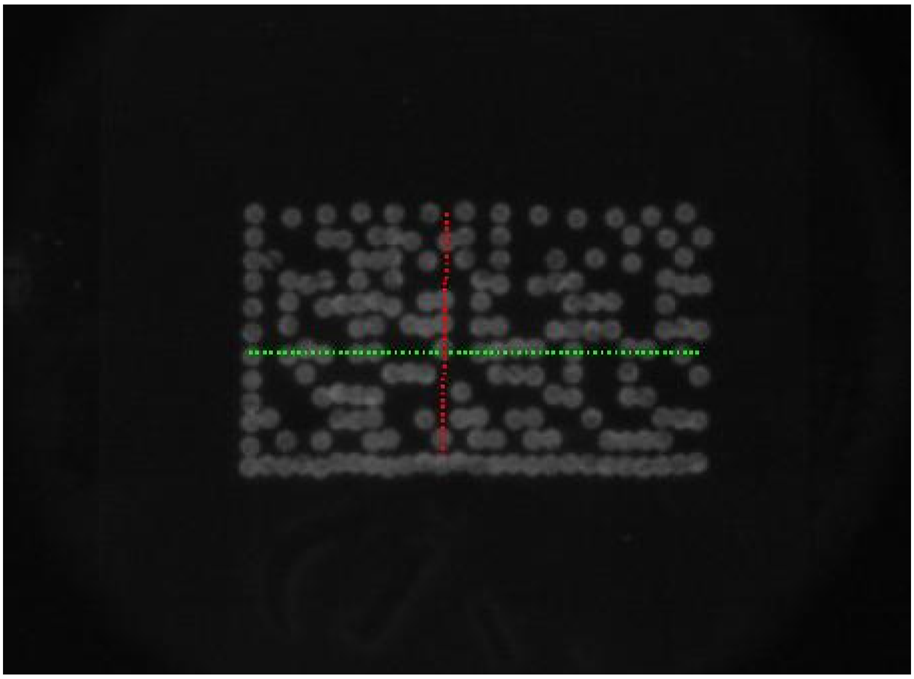


Figure 3.23 Zigzag Tracing of the Data Area

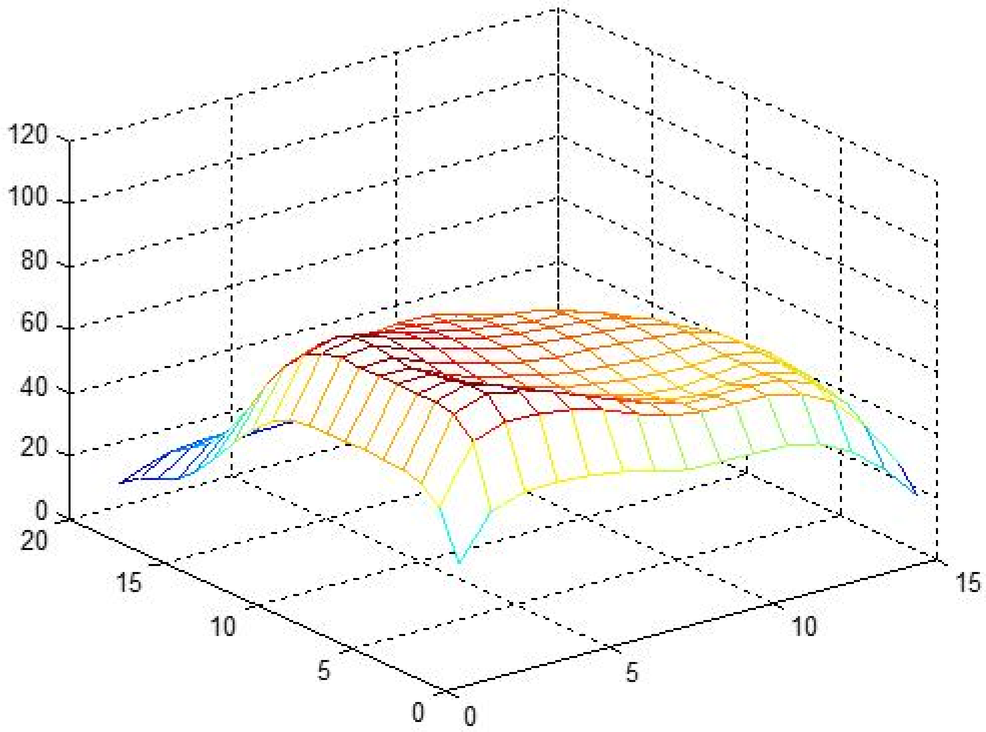


Figure 3.24 Mesh Plot of Intersection Region

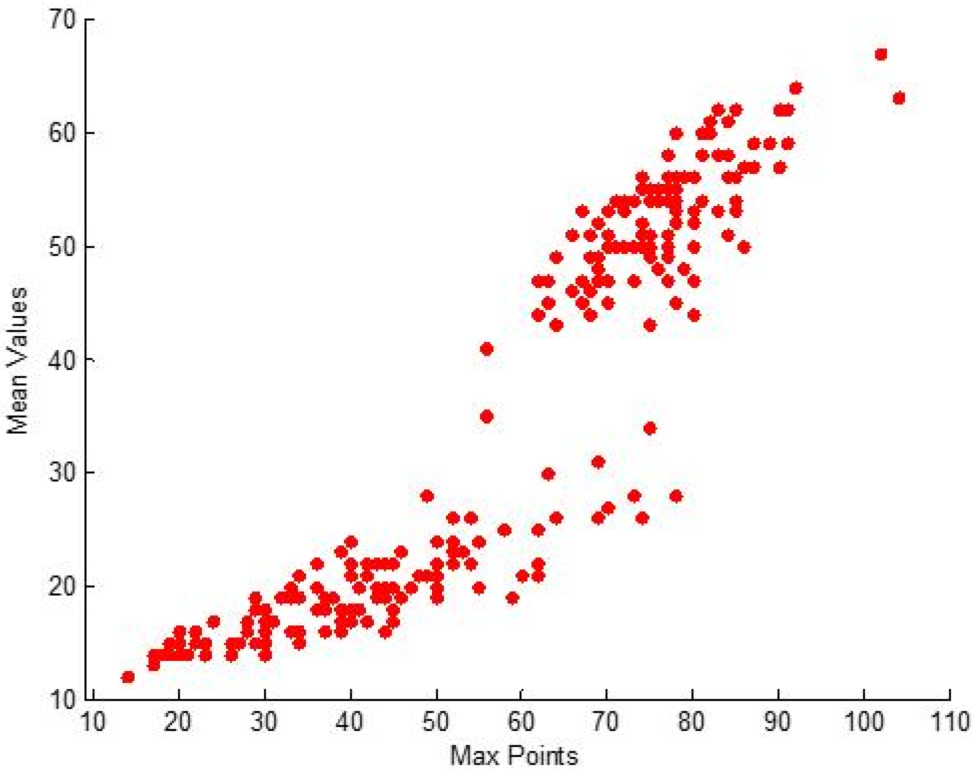


Figure 3.25 Clusters

During the zig zag tracing the intersection points of long and short timing pattern brings a dot center of the data area. This dot is named as target module. By using the center point and the estimated dot dimension a region is determined for detected module. The mesh plot of the region of the target module is shown in Figure 3.24. From the mesh plot of the detected region, the maximum pixel value and the mean value of the region is stored for obtain clusters. The output for zig zag algorithm is; clusters are shown above in Figure 3.25. These modules which are waiting for classification, in the invisible 2D data matrix. For classification of these modules, during zig zag algorithm is running, local threshold algorithm is running simultaneously for classification of the new detected module.

The local threshold algorithm working principle is; after the determination of the target module, already found neighbor modules are checked. These neighbors are also controlled if they are 1 or 0 modules. The closest three neighbors from ones and the closest neighbors from zeros are determined. There six neighbors are chosen for specifying the threshold value for the target module. The pixel values of zero and one neighbor modules' standard deviations are not influential on the threshold value so the standard deviations are assumed equal. The mean values of zeros and ones' mean value composes the local threshold value for the target module. In Figure 3.26 a zoomed region of invisible 2D data matrix is shown. The first target module of the data area is analyzed, the chosen neighbors are demonstrated. The target module is red circled, the ones neighbors are green circled and the zeros neighbors are yellow circled. For the first target module the mean value for the ones neighbors is 43,59 and the standard deviation is 0,7145, the mean value for the zeros neighbors is 16,99 and the standard deviation is 2,22. As a result of that, the local threshold value for the first target module becomes 30,29. The target module has 21,14 pixel value, so the target module is determined as 0 module.

In Figure 3.27 the second target module is analyzed and the first target module's pixel value affects the second target module's threshold value. The mean values for the ones neighbors is 43,59 and the standard deviation is 0,7145, the mean value for the zeros neighbors is 19,98 and the standard deviation is 1,00. As a result of that, the local threshold value for the first target module becomes 31,78. The second target module has 49,69 pixel value, so the target module is determined as 1 module.

20	21	22	23	24	25	26
15,42439	43,02623	19,28305	44,35111	19,53603	42,9333	15,60345
NaN	NaN	NaN	NaN	NaN	21,14175	43,48756
NaN	NaN	NaN	NaN	NaN	NaN	15,80317
NaN	NaN	NaN	NaN	NaN	NaN	45,19296
NaN	NaN	NaN	NaN	NaN	NaN	14,2396
NaN	NaN	NaN	NaN	NaN	NaN	47,15691
NaN	NaN	NaN	NaN	NaN	NaN	15,93447
NaN	NaN	NaN	NaN	NaN	NaN	43,89926
NaN	NaN	NaN	NaN	NaN	NaN	14,13157
NaN	NaN	NaN	NaN	NaN	NaN	45,05301
NaN	NaN	NaN	NaN	NaN	NaN	16,59999
48,1395	52,69692	50,69499	47,40687	49,33486	45,71815	46,89175

Figure 3.26 The First Target Module.

21	22	23	24	25	26
43,02623	19,28305	44,35111	19,53603	42,9333	15,60345
NaN	NaN	NaN	49,69654	21,14175	43,48756
NaN	NaN	NaN	NaN	NaN	15,80317
NaN	NaN	NaN	NaN	NaN	45,19296
NaN	NaN	NaN	NaN	NaN	14,2396
NaN	NaN	NaN	NaN	NaN	47,15691
NaN	NaN	NaN	NaN	NaN	15,93447
NaN	NaN	NaN	NaN	NaN	43,89926
NaN	NaN	NaN	NaN	NaN	14,13157
NaN	NaN	NaN	NaN	NaN	45,05301
NaN	NaN	NaN	NaN	NaN	16,59999
52,69692	50,69499	47,40687	49,33486	45,71815	46,89175

Figure 3.27 The Second Target Module.

10	11	12	13	14	15	16	17
17,36207	40,38113	19,533	42,54977	18,33911	46,03913	15,66786	44,30909
45,64573	18,83248	50,10951	49,66474	17,02665	46,56675	13,97631	13,64464
NaN	52,77116	20,54168	49,03241	20,32785	45,22062	14,51946	14,50097
NaN	NaN	28,4013	19,61109	57,73031	55,81048	17,13417	50,08536
NaN	NaN	NaN	20,30108	50,25374	23,59836	14,41095	15,09614
NaN	NaN	NaN	NaN	NaN	54,01087	27,79668	25,25946
NaN	NaN	NaN	NaN	NaN	NaN	54,28743	51,97728
NaN	NaN	NaN	NaN	NaN	NaN	NaN	54,91611
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
52,29647	57,19765	57,96015	55,64411	48,90974	56,23895	54,94959	54,98451

Figure 3.28 110th Target Module.

The very first modules are analyzed, the 110th target module's analysis is in Figure 3.28. The mean values for the ones neighbors is 52,33 and the standard deviation is 4,7089, the mean value for the zeros neighbors is 23,87 and the standard deviation is 4,40. As a result of that, the local threshold value for the first target module becomes 38,10. The second target module has 20,30 pixel value, so the target module is determined as 0 module. After the whole detection of the modules the overall threshold values matrix is generated and can be seen on Figure 3.29. The visualization of the local threshold matrix can be seen on Figure 3.30. The local threshold matrix expresses that, the illumination is not uniformly distributed on the invisible data matrix. The regional illumination of the invisible data matrix can be different. As seen on Figure 3.30 the threshold values are increased left bottom part of the invisible data matrix. If a global threshold is used for solve this cluster problem, the modules which are closest to the global threshold boundary the classification of the modules can be wrong. For avoid risks of the global threshold the local threshold learning is designed.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	31	32	32	32	33	34	35	33	33	33	31	31	31	30	29	29	30	30	31	33	32	33	32	30	0
3	0	31	30	31	32	38	35	38	36	34	32	35	33	33	31	30	29	31	29	30	32	31	34	34	32	0
4	0	30	32	33	37	37	40	36	39	38	37	35	36	34	31	31	31	30	32	33	31	32	33	34	32	0
5	0	33	34	33	35	38	40	40	40	41	40	37	38	33	34	34	33	33	34	32	32	31	30	34	33	0
6	0	33	37	35	38	41	40	43	40	43	39	40	38	39	39	38	37	34	34	34	31	31	32	32	32	0
7	0	36	37	38	38	39	38	38	38	42	39	38	37	40	38	39	40	36	37	35	35	33	33	32	33	0
8	0	36	39	41	41	40	41	39	38	40	37	39	37	38	40	41	37	36	36	34	33	32	31	33	31	0
9	0	36	36	41	42	43	42	39	39	38	39	38	37	38	38	38	36	37	36	34	32	32	30	31	29	0
10	0	35	34	36	41	41	42	43	37	36	39	37	40	35	36	36	36	36	35	35	36	34	30	31	31	0
11	0	34	34	35	36	39	41	39	39	37	39	42	41	38	38	36	37	36	35	34	35	36	34	32	32	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure3.29 The Local Threshold Values Matrix

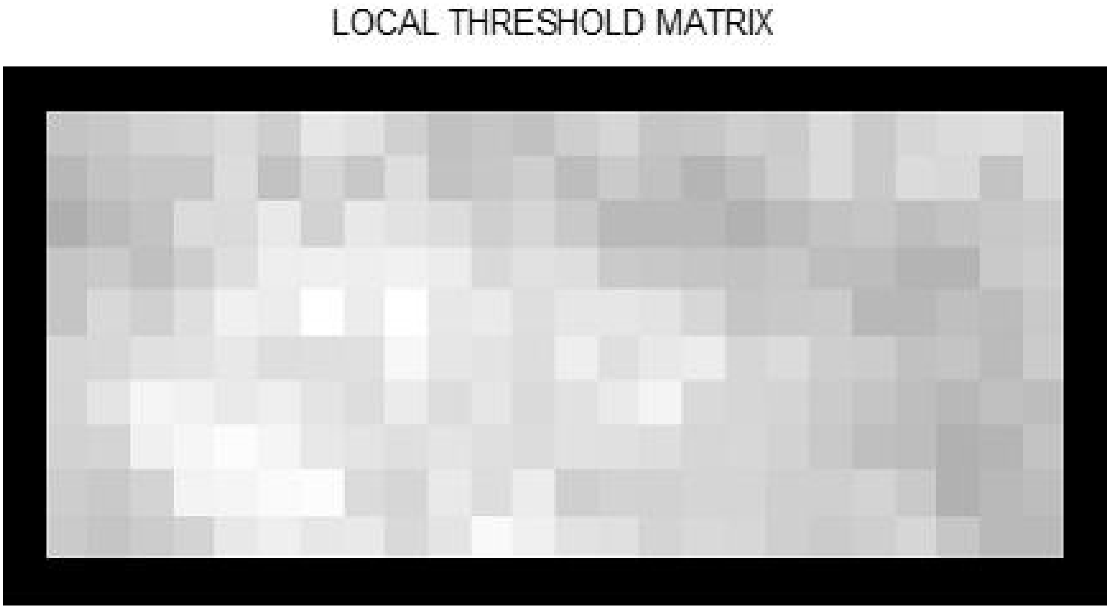


Figure 3.30 The Local Threshold Matrix

The black window frame is the finder patterns. The “L” shape finder pattern and the timing pattern are the reference threshold values so local threshold algorithm runs for the data area. The obtained pixel values matrix which is shown in Figure 3.31 and the local threshold matrix the module vise comparison is done by the algorithm. Finally, the output of the invisible 2D data matrix is achieved in Figure 3.32.

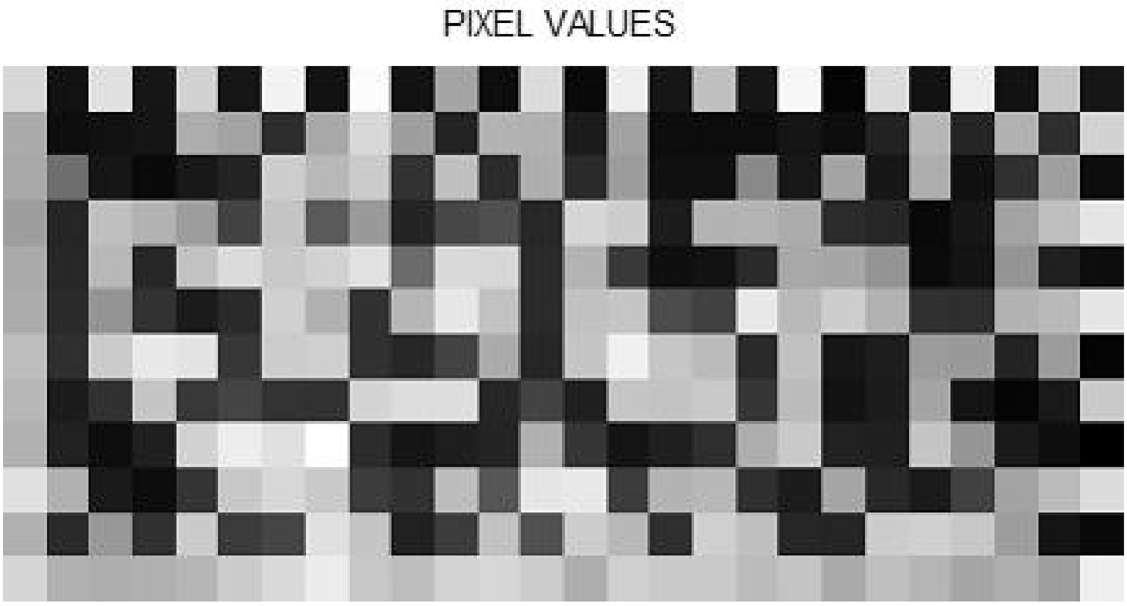


Figure 3.31 The Pixel Values Matrix

DATA MATRIX

Figure 3.32 The Data Matrix

CHAPTER 4

DATA ACQUISITION AND TEST RESULTS

4.1 INVISIBLE 2D DATA MATRIX ACQUISITION

Invisible 2D Data Matrices are the very new aspect of the Data Matrix literature. Because of this, very limited source is found. For building a data base for The invisible 2D data matrix, a setup is designed for acquisition of the data by industrial camera and also and an apparatus is designed for a smart phone which is Samsung Galaxy G900 S5 smart phone. Images of the alcohol beverage covers are obtained via these setup and the apparatus.

For the image acquisition via the smart phone the apparatus which is shown in Figure 4.1 and 4.2 is designed. This apparatus is portable and it has own battery and also contains LED and its focuser lens. Between smart phone camera and apparatus there is a space for the filter. The illumination is obtained by the LED light and the invisible 2D data matrix image acquisition is done by the filter. As we discussed before the smart phones have their own low pass filter in their hardware. That is, the illumination and the capture process should be done sensitively. The prototypes of the apparatus is designed by 3D printer.

Figure 4.1: Designed apparatus

Figure 4.2 Designed Apparatus-2

Figure 4.3 Image Acquisition via Apparatus

The distinguishing issue is making the invisible 2D data matrix as visible. This part also seems as a hardware concern but the ease of the process this hardware part should be done perfectly. Perfect illumination is obtained by red LED light which has wavelength around 630 nm. While conducting the experiments, the other Green and Blue LED light are tested. Since their wavelength are below 630 nm, the light could not be reflected as desired by the pigmented ink. Figure 4.4 demonstrates the wavelength spectrum of the Red, Green and Blue light.

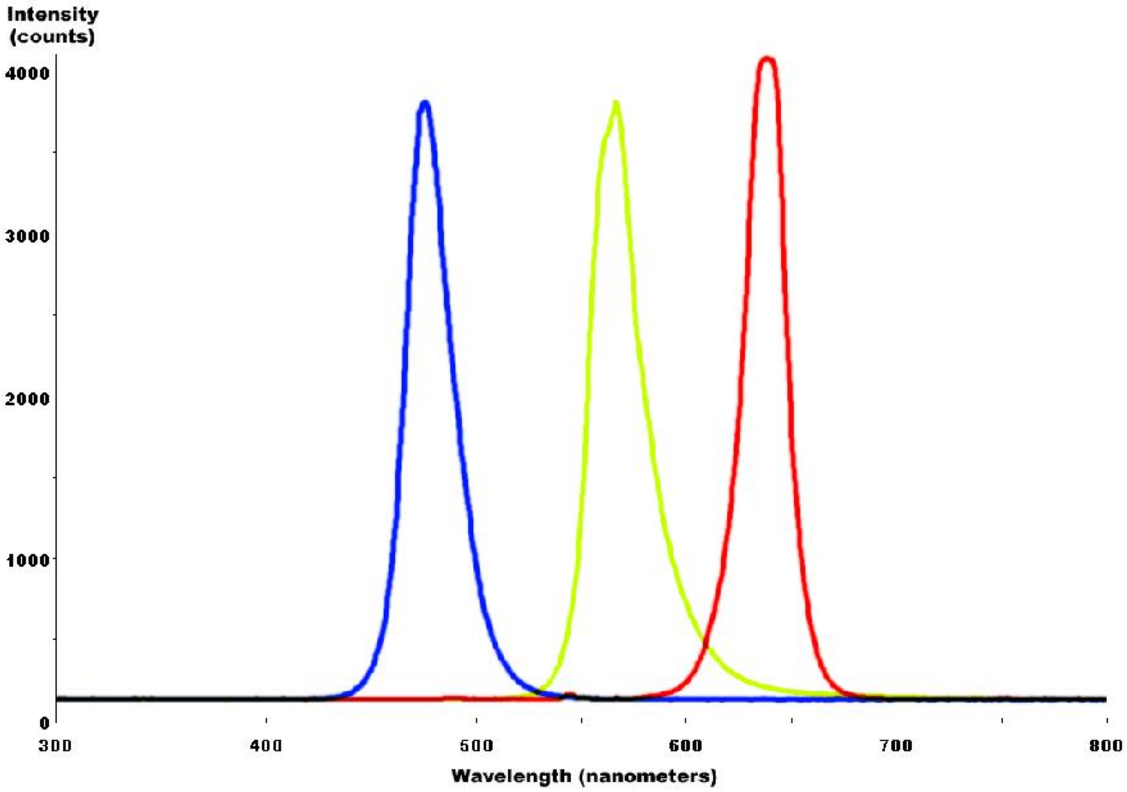


Figure 4.4 The Wavelength Spectrum of Red, Green and Blue Light

As discussed in the Introduction Chapter, pixel size, sensor size and quantum efficiency concerns distinguish the industrial camera from smart phone camera. The loss of light data makes the image which is taken by smart phone camera, noisy and distorted. Due to these reasons, the difficulty between capturing invisible 2D data matrix via smart phone camera can be proved.

The setup for the industrial camera is shown in Figure 4.5. By the help of the setup the distance between camera and the invisible data matrix can be arranged and stabilize for image acquisition. Additionally, the light source is handled by the setup and the stability of the light source is established.

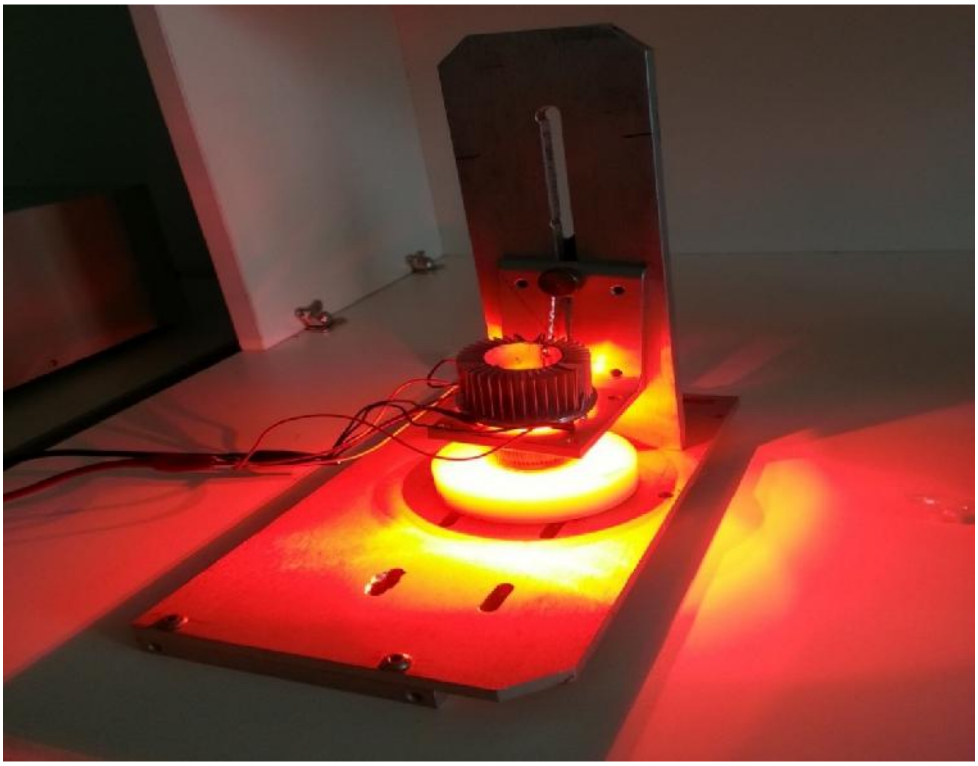


Figure 4.5 The Camera Setup for Acquisition of The Invisible 2D Data Matrix

In the Figure 4.6 the light source is shown. There are four Red LEDs are utilized for illumination. These four Red LEDs are mounted on a circuit board and a cooler. The LEDs are energized with voltage level of 2.5 Volts and current level of 800 mAmperes.

Figure 4.6 LED Light Source.

The invisible 2D data matrix is shown in Figure 4.7 under day light. Only the banderole can be seen under day light. In Figure 4.8 the illuminated banderole can be seen by naked eyes. The invisible 2D data matrix cannot be seen unless a filter is attached in front of the lens of the camera. In Figure 4.9 the invisible 2D data matrix is taken by industrial camera image can be seen.

Figure 4.7: Invisible 2D Data Matrix Under Day Light

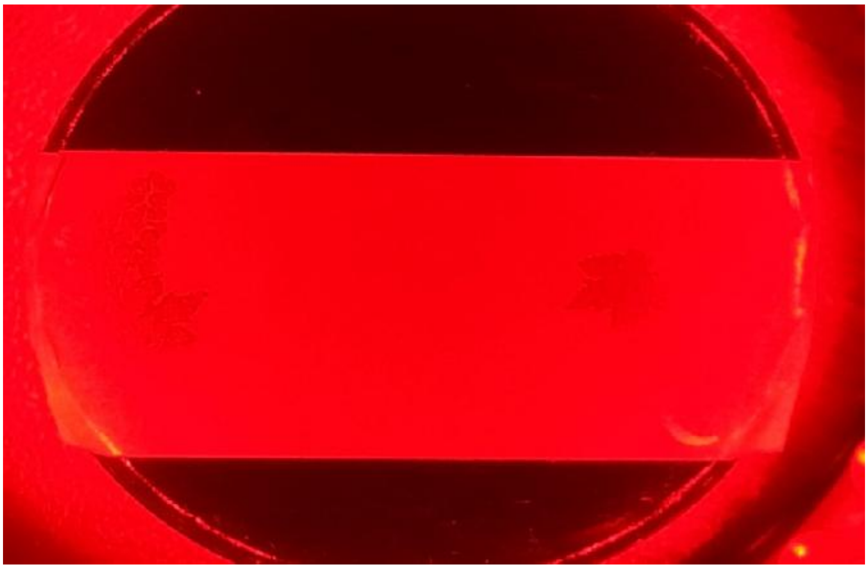


Figure 4.8: Invisible 2D Data Matrix Under 630 nm Wave Length Red Led Light

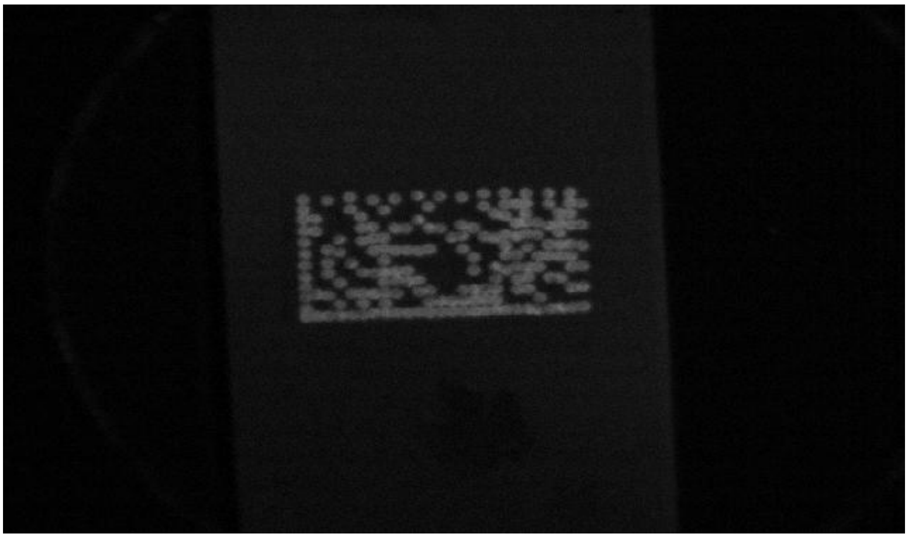


Figure 4.9: Captured Invisible 2D Data Matrix via high pass filter

4.2 TEST RESULTS

In this section, there are two images are taken for each invisible 2D data matrix samples. One of the samples is from industrial camera and the other is from smart phone camera. The recommended algorithm is tested on these samples. The IDS UI-3240ML-NIR-GL camera is used for industrial camera and Samsung GT-N7100 (Note II) is used for smart phone tests. . IDS camera has CMOS mono sensor 1.31 Mpix and 1280x1024 resolution and 8.69 mm (1/1.84") diagonal optical sensor, captures 60 frame per second. Samsung Note II has 8 megapixels camera and 3264x2248 resolution, auto focus and capture 30 frame per seconds. As we discussed before the most important differences between these cameras are quantum efficiency and pixel size. The tests are performed on 50 Invisible 2D Data Matrices. The comparison between IDS camera and the smart phone camera is going to be analyzed in the results stage.

4.2.1 Performance Diagnostics

For evaluation of the outputs of the recommended algorithm, the confusion matrix is generated. The confusion matrix is shown in Figure 4.8

		ACTUAL VALUE	
		Positives	Negatives
PREDICTED VALUE	Positives	**TP** True Positive	**FP** False Positive
	Negatives	**FN** False Negative	**TN** True Negative

Figure 4.10 Confusion Matrix

Standard operand have been determined from the confusion matrix [14]: *Accuracy* (AC) is the correct predictions ratio. R*ecall or true positive* (TP) is the percentage of true predicted and actually true found cases. *True negative* (TN) is the percentage of false predicted and actually false found cases. *False negative rate* (FN) is the proportion of false predicted but true found cases. *False positive* (FP) is the proportion of true predicted and false found cases. Lastly, *precision* (P) is the proportion of the true predicted with respect to all positive predicted cases [15]. The formulation is shown below;

$$A = \frac{T + T}{T + F + F + T} \tag{1}$$

$$R = \frac{T}{F + T} \tag{2}$$

$$T \quad N \quad R = \frac{T}{T + F} \tag{3}$$

$$F \quad n \quad r = \frac{F}{F + T} \tag{4}$$

$$P = \frac{T}{T + F} \tag{5}$$

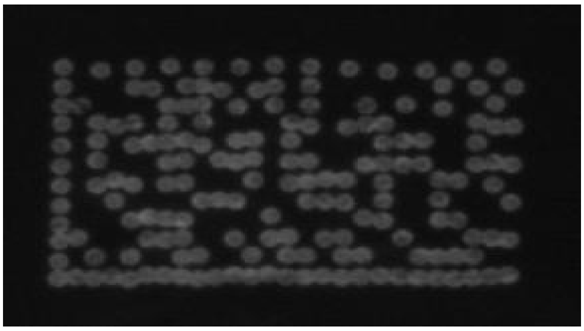
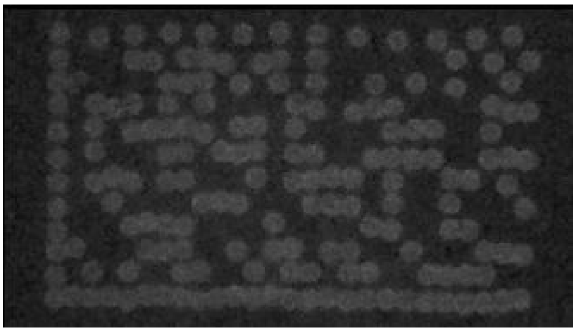
4.2.2 Test Results

The tests are conducted on 50 samples and two cameras. The IDS-1240ML-NIR-GL is used for industrial camera and Samsung GT-N7100 (Note II) is used for smart phone. There are 20 samples are evaluated in the following sections.

In figures below there are 3 rows and 2 columns. Each column belong to a device which one of them is IDS camera image and the other one is the smart phone image. The first raw is for input pictures from camera devices for same invisible 2D data matrix. The second raw is for the output images which are processed by the algorithm. The third raw consists the confusion matrix of the outputs. This confusion matrix will introduce the efficiency of the algorithm for the images.

The invisible 2D data matrix has 12x26 size. That is, it contains 312 modules which are 1 or 0 modules. The “L” shape finder pattern and the timing pattern composed of 76 modules. The remaining 236 modules belong to the data area. In the first stage algorithm detects the finder patterns and next step detects the data area. The 20 alcohol beverages invisible 2D data matrices’ are investigated and decoded by the algorithm. The comparison tables between IDS camera and smart phone camera images are shown below.

SAMPLE 1:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	141	0
	Zeros Negative	0	171

SMART PHONE CAMERA

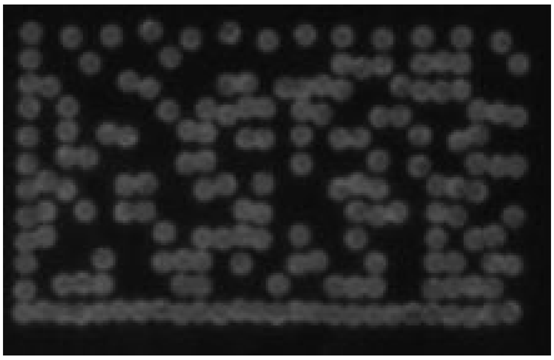
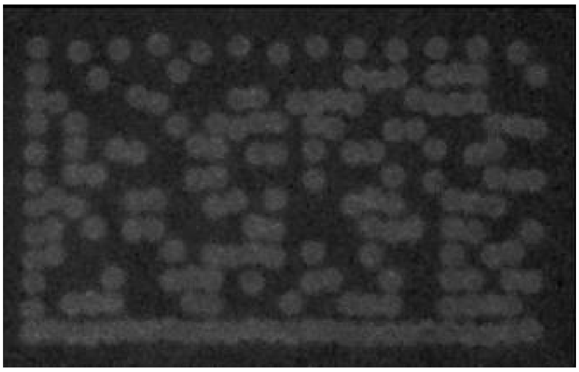
PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	140	0
	Zeros Negative	1	171

Table 4.1 Comparison Table for Sample 1

Accuracy of the algorithm for the IDS camera result is : 1.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

SAMPLE 2:

IDS CAMERA	**SMART PHONE CAMERA**
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	142	2
	Zeros Negative	0	168

SMART PHONE CAMERA:

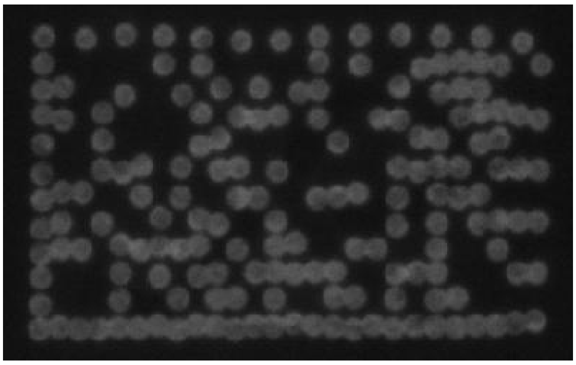
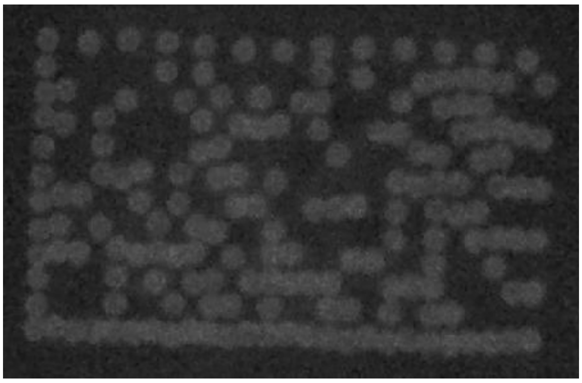
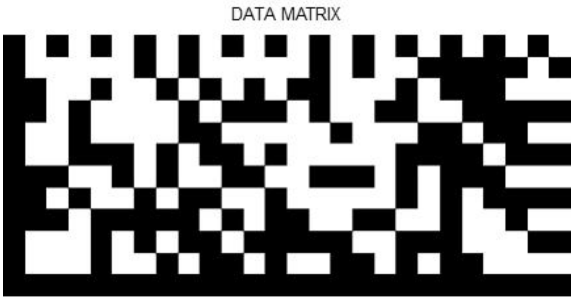
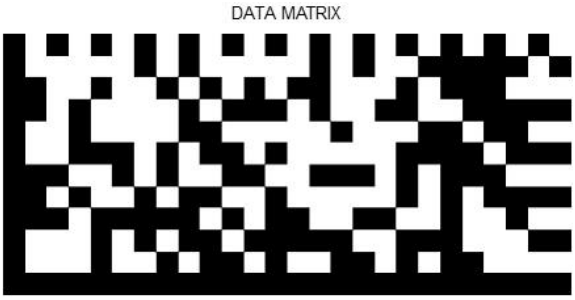
PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	142	0
	Zeros Negative	1	169

Table 4.2 Comparison Table for Sample 2

Accuracy of the algorithm for the IDS camera result is : 0,993.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

SAMPLE 3:

IDS CAMERA	SMART PHONE CAMERA
	
	

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	143	0
	Zeros Negative	0	169

SMART PHONE CAMERA:

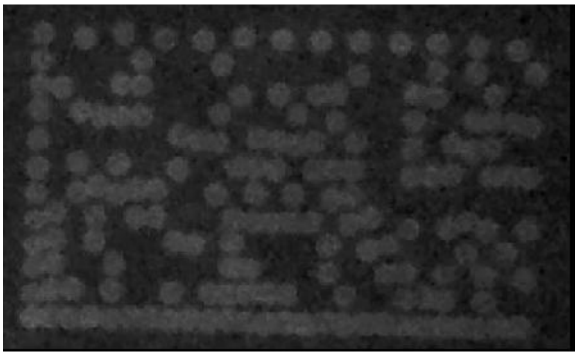
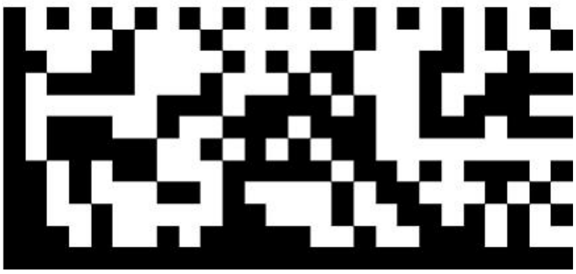
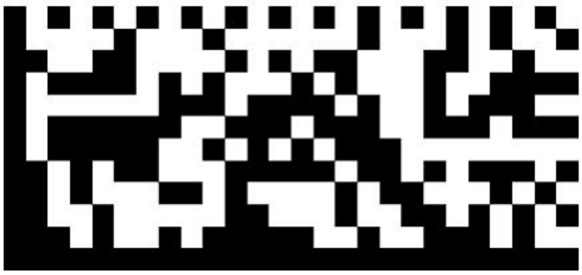
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	143	0
	Zeros Negative	0	169

Table 4.3 Comparison Table for Sample 3

Accuracy of the algorithm for the IDS camera result is : 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 4:

IDS CAMERA	SMART PHONE CAMERA
	
	

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	146	0
	Zeros Negative	1	165

SMART PHONE CAMERA:

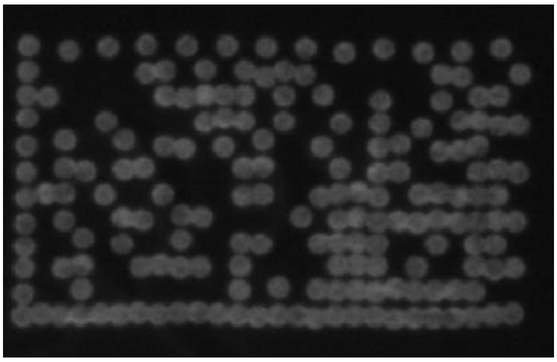
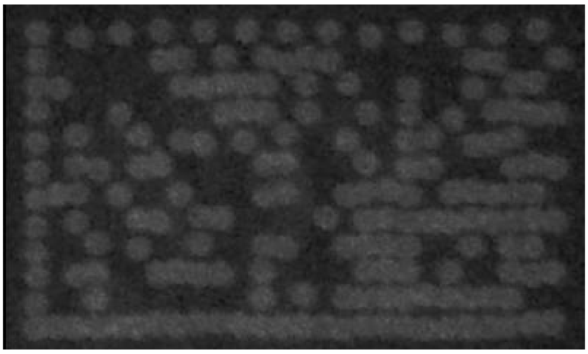
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	144	2
	Zeros Negative	3	163

Table 4.4 Comparison Table for Sample 4

Accuracy of the algorithm for the IDS camera result is: 0,996.

Accuracy of the algorithm for the smart phone camera result is: 0,984.

SAMPLE 5:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

		ACTUAL	
PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	136	0
	Zeros Negative	0	176

SMART PHONE CAMERA:

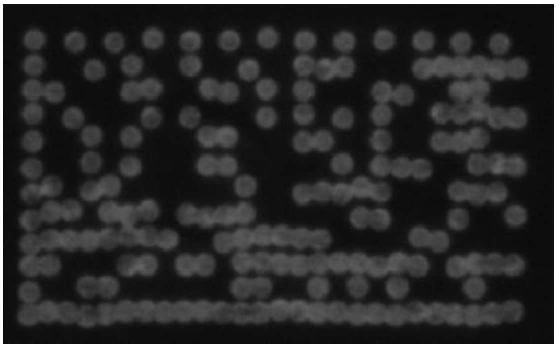
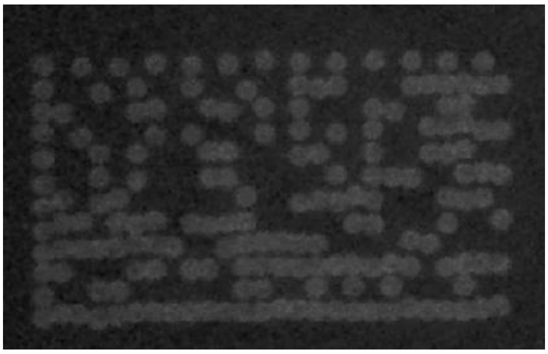
		ACTUAL	
PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	136	0
	Zeros Negative	0	176

Table 4.5 Comparison Table for Sample 5

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 6:

IDS CAMERA	**SMART PHONE CAMERA**
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	139	0
Zeros Negative	0	173

SMART PHONE CAMERA:

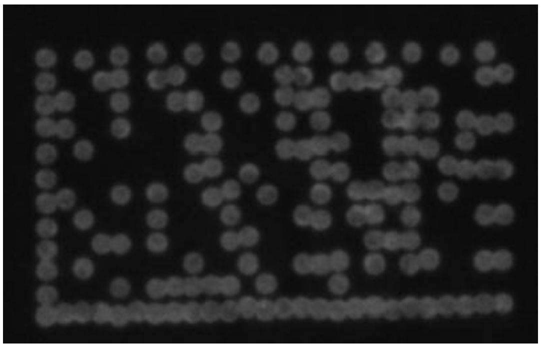
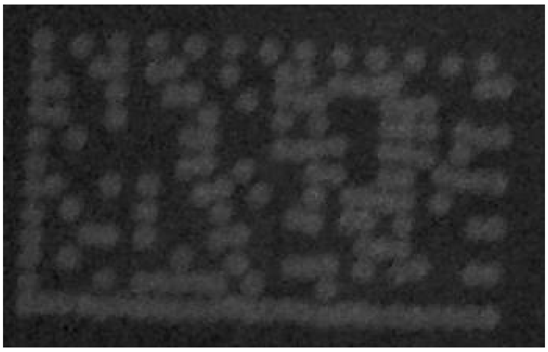
PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	139	0
Zeros Negative	0	173

Table 4.6 Comparison Table for Sample 6

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 7:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	157	0
Zeros Negative	0	155

SMART PHONE CAMERA:

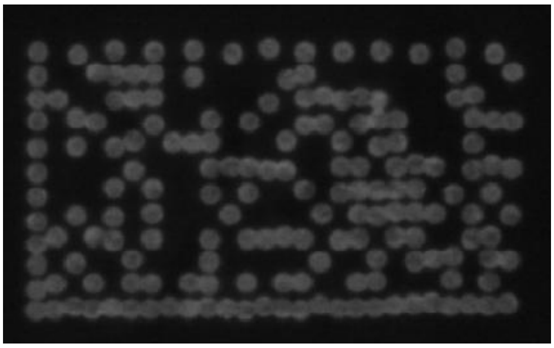
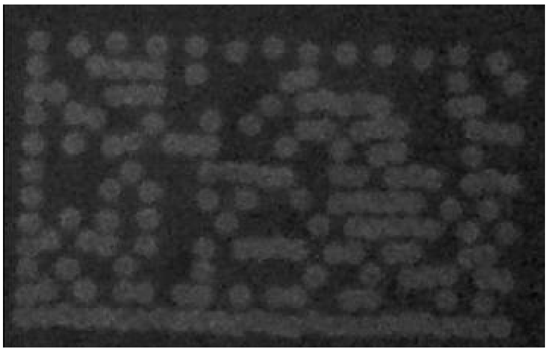
PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	157	0
Zeros Negative	0	155

Table 4.7 Comparison Table for Sample 7

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 8:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	140	0
	Zeros Negative	1	171

SMART PHONE CAMERA

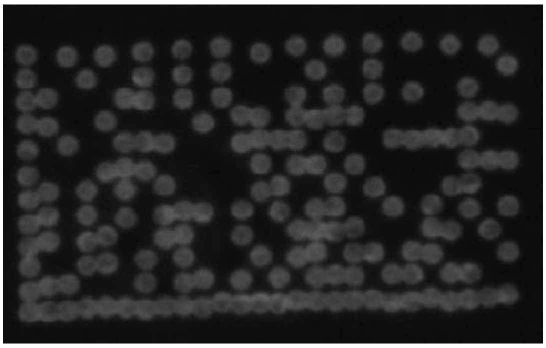
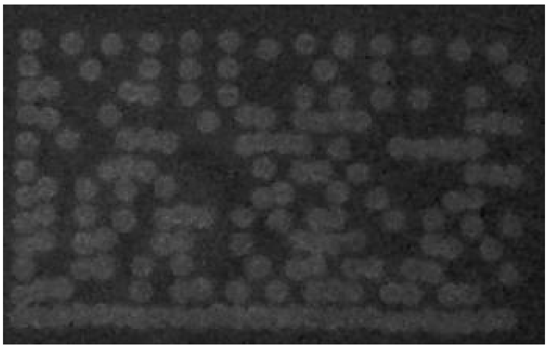
PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	138	2
	Zeros Negative	0	171

Table 4.8 Comparison Table for Sample 8

Accuracy of the algorithm for the IDS camera result is: 0,996.

Accuracy of the algorithm for the smart phone camera result is: 0,990.

SAMPLE 9:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	145	0
	Zeros Negative	2	165

SMART PHONE CAMERA

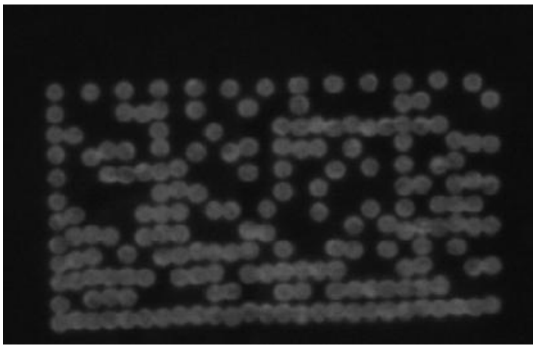
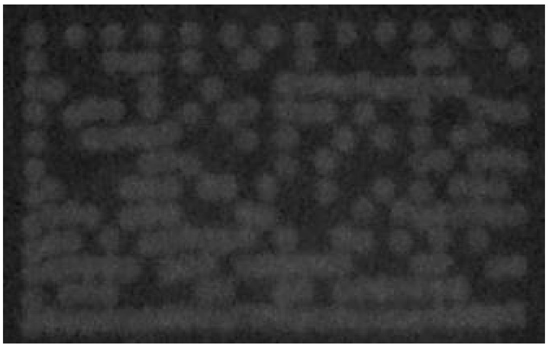
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	147	0
	Zeros Negative	0	165

Table 4.9 Comparison Table for Sample 9

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 10:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	128	0
Zeros Negative	0	184

SMART PHONE CAMERA:

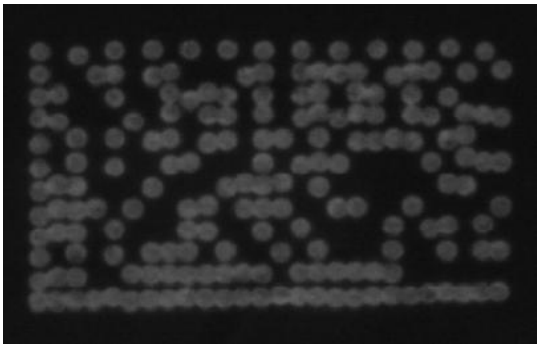
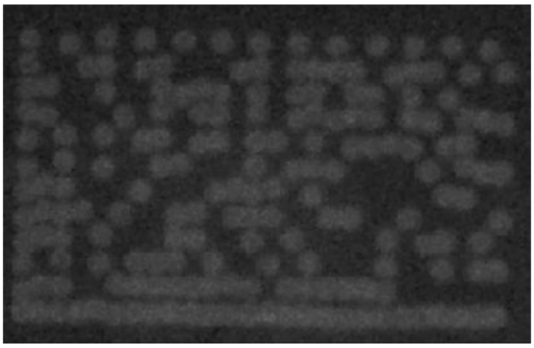
PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	128	0
Zeros Negative	0	184

Table 4.10 Comparison Table for Sample 10

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 11:

IDS CAMERA	SMART PHONE CAMERA
	
	

IDS CAMERA:

PREDICTED		ACTUAL Ones Positive	ACTUAL Zeros Negative
	Ones Positive	130	0
	Zeros Negative	0	182

SMART PHONE CAMERA:

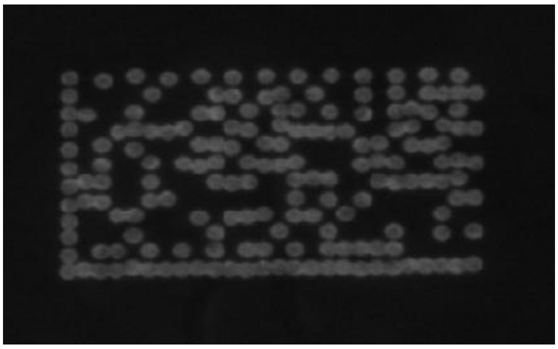
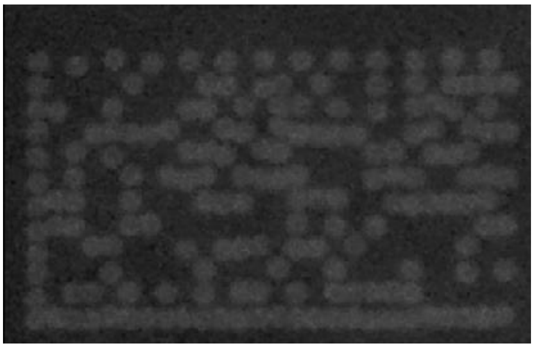
PREDICTED		ACTUAL Ones Positive	ACTUAL Zeros Negative
	Ones Positive	130	0
	Zeros Negative	0	182

Table 4.11 Comparison Table for Sample 11

Accuracy of the algorithm for the IDS camera result is:1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 12:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	140	0
	Zeros Negative	0	172

SMART PHONE CAMERA:

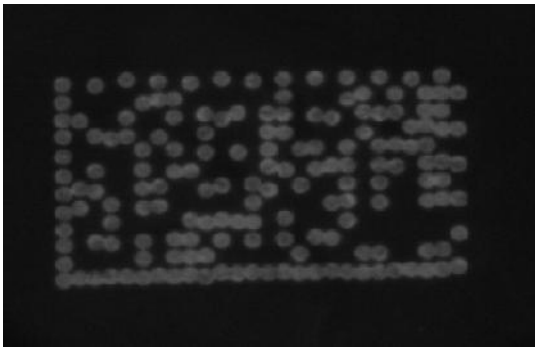
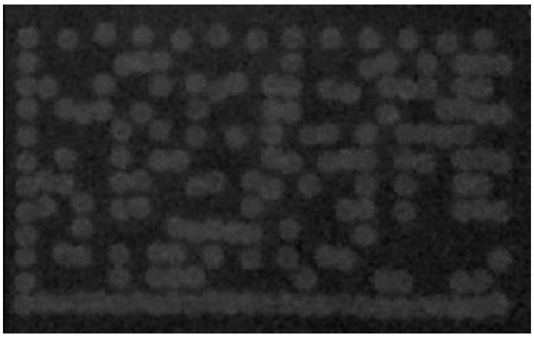
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	140	0
	Zeros Negative	0	172

Table 4.12 Comparison Table for Sample 12

Accuracy of the algorithm for the IDS camera result is:1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 13:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS camera:

PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	148	0
Zeros Negative	0	164

Smart phone camera:

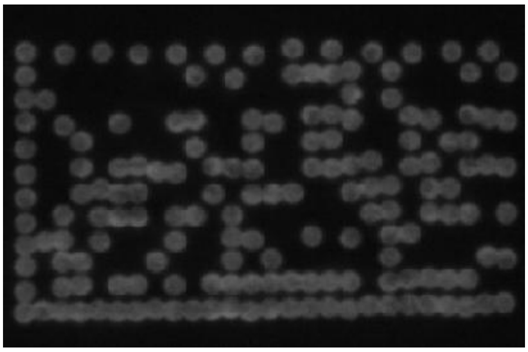
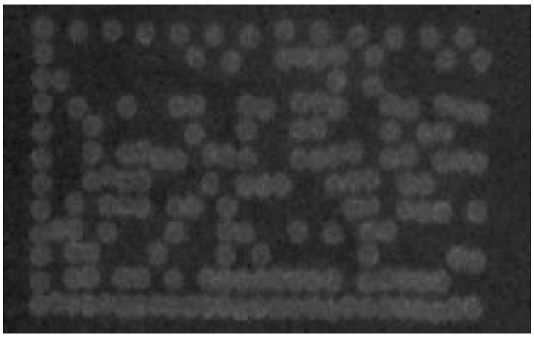
PREDICTED \ ACTUAL	Ones Positive	Zeros Negative
Ones Positive	148	0
Zeros Negative	0	164

Table 4.13 Comparison Table for Sample 13

Accuracy of the algorithm for the IDS camera result is:1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 14:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	149	1
	Zeros Negative	0	162

SMART PHONE CAMERA:

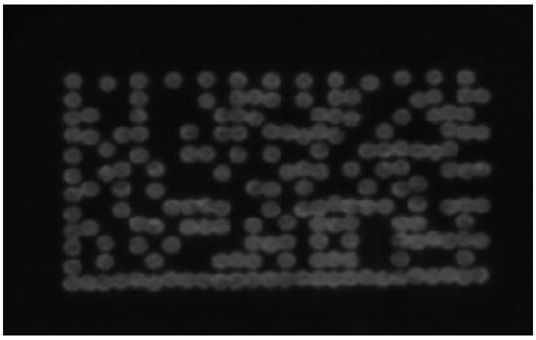
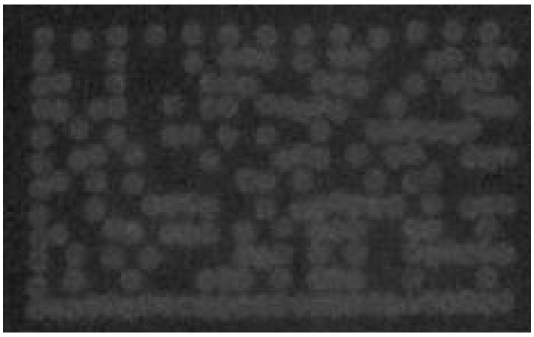
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	148	0
	Zeros Negative	0	164

Table 4.14 Comparison Table for Sample 14

Accuracy of the algorithm for the IDS camera result is:0,996.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 15:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED	ACTUAL	Ones Positive	Zeros Negative
	Ones Positive	134	0
	Zeros Negative	0	178

SMART PHONE CAMERA:

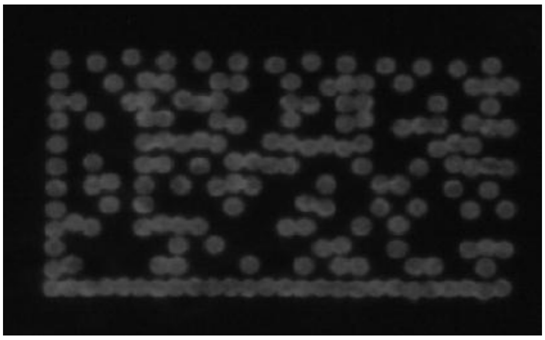
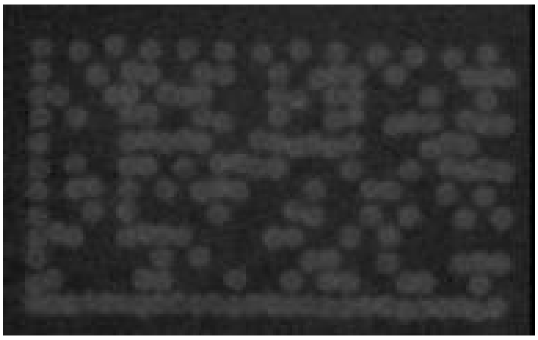
PREDICTED	ACTUAL	Ones Positive	Zeros Negative
	Ones Positive	132	2
	Zeros Negative	1	177

Table 4.15 Comparison Table for Sample 15

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,990.

SAMPLE 16:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	142	1
	Zeros Negative	2	167

SMART PHONE CAMERA:

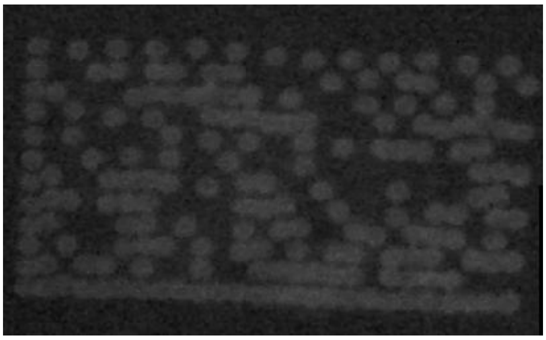
PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	147	0
	Zeros Negative	0	165

Table 4.16 Comparison Table for Sample 16

Accuracy of the algorithm for the IDS camera result is: 0,990.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 17:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	133	0
	Zeros Negative	0	179

SMART PHONE CAMERA:

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	126	7
	Zeros Negative	2	177

Table 4.17 Comparison Table for Sample 17

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,971.

SAMPLE 18:

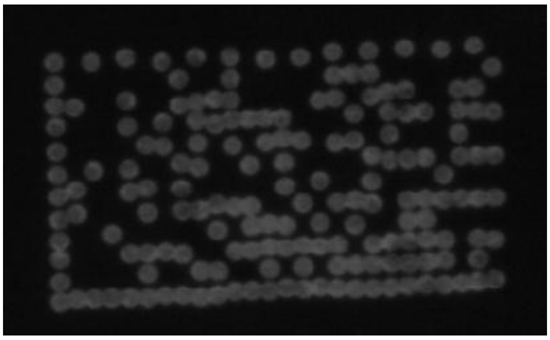
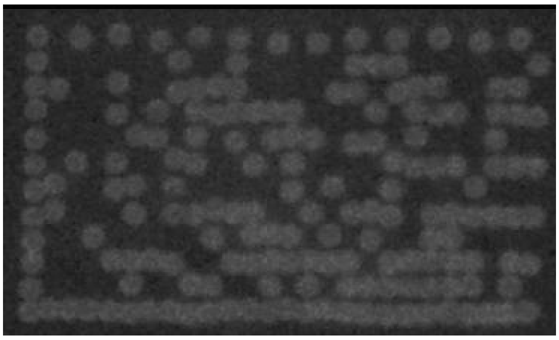
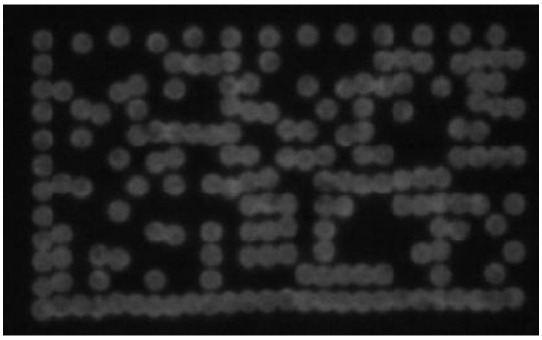
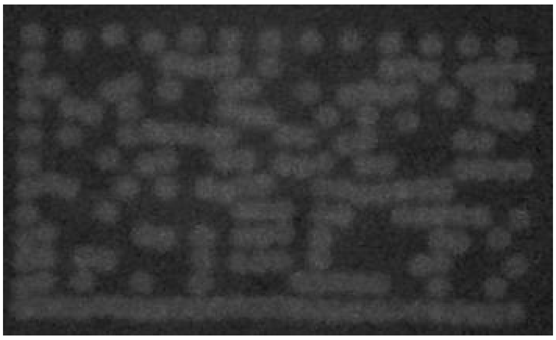
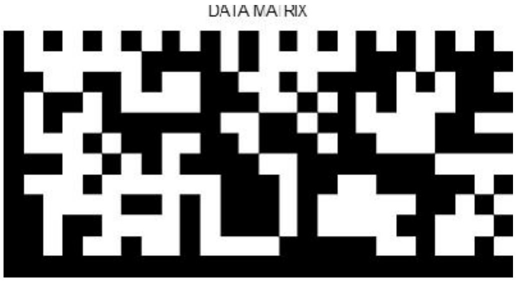
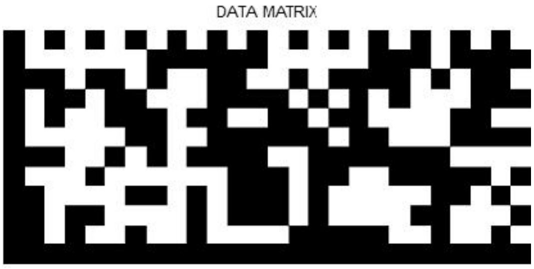
<table>
<tr><th>IDS CAMERA</th><th>SMART PHONE CAMERA</th></tr>
<tr><td></td><td></td></tr>
<tr><td>DATA MATRIX</td><td>DATA MATRIX</td></tr>
<tr><td>
<table>
<tr><th rowspan="4">PREDICTED</th><th colspan="3">ACTUAL</th></tr>
<tr><th></th><th>Ones Positive</th><th>Zeros Negative</th></tr>
<tr><th>Ones Positive</th><td>140</td><td>0</td></tr>
<tr><th>Zeros Negative</th><td>0</td><td>172</td></tr>
</table>
</td><td>
<table>
<tr><th rowspan="4">PREDICTED</th><th colspan="3">ACTUAL</th></tr>
<tr><th></th><th>Ones Positive</th><th>Zeros Negative</th></tr>
<tr><th>Ones Positive</th><td>140</td><td>0</td></tr>
<tr><th>Zeros Negative</th><td>0</td><td>172</td></tr>
</table>
</td></tr>
</table>

Table 4.18 Comparison Table for Sample 18

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

SAMPLE 19:

IDS CAMERA	SMART PHONE CAMERA
	
	

IDS CAMERA:

PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	138	0
	Zeros Negative	0	174

SMART PHONE CAMERA:

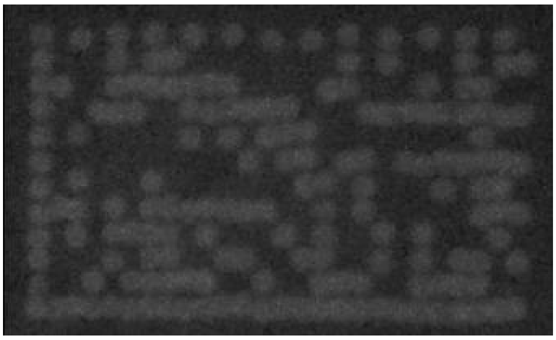
PREDICTED	ACTUAL		
		Ones Positive	Zeros Negative
	Ones Positive	133	5
	Zeros Negative	2	172

Table 4.19 Comparison Table for Sample 19

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,997.

SAMPLE 20:

IDS CAMERA	SMART PHONE CAMERA
	
DATA MATRIX	DATA MATRIX

IDS CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	145	0
	Zeros Negative	0	167

SMART PHONE CAMERA:

PREDICTED		ACTUAL	
		Ones Positive	Zeros Negative
	Ones Positive	145	0
	Zeros Negative	0	167

Table 4.20 Comparison Table for Sample 20

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 21:

IDS CAMERA				SMART PHONE CAMERA			
	ACTUAL				ACTUAL		
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	154	0		Ones Positive	154	0
	Zeros Negative	0	158		Zeros Negative	0	158

Table 4.21 Comparison Table for Sample 21

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 22:

IDS CAMERA				SMART PHONE CAMERA			
	ACTUAL				ACTUAL		
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	137	5		Ones Positive	131	12
	Zeros Negative	0	170		Zeros Negative	2	167

Table 4.22 Comparison Table for Sample 22

Accuracy of the algorithm for the IDS camera result is: 0,984.

Accuracy of the algorithm for the smart phone camera result is: 0,955.

Sample 23:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	139	1		Ones Positive	137	3
	Zeros Negative	1	171		Zeros Negative	0	172

Table 4.23 Comparison Table for Sample 23

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 0,990.

Sample 24:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	139	0		Ones Positive	133	6
	Zeros Negative	0	173		Zeros Negative	0	173

Table 4.24 Comparison Table for Sample 24

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,980.

Sample 25:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	136	2		Ones Positive	138	0
	Zeros Negative	0	174		Zeros Negative	0	174

Table 4.25 Comparison Table for Sample 25

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 26:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	142	0		Ones Positive	142	0
	Zeros Negative	0	170		Zeros Negative	0	170

Table 4.26 Comparison Table for Sample 26

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,955.

Sample 27:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	134	0		Ones Positive	134	0
	Zeros Negative	0	178		Zeros Negative	0	178

Table 4.27 Comparison Table for Sample 27

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 28:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	141	3		Ones Positive	144	0
	Zeros Negative	0	168		Zeros Negative	0	168

Table 4.28 Comparison Table for Sample 28

Accuracy of the algorithm for the IDS camera result is: 0,990.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 29:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	149	0		Ones Positive	148	1
	Zeros Negative	0	163		Zeros Negative	0	163

Table 4.29 Comparison Table for Sample 29

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

Sample 30:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	142	0		Ones Positive	142	0
	Zeros Negative	0	170		Zeros Negative	0	170

Table 4.30 Comparison Table for Sample 30

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 31:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	140	0		Ones Positive	139	0
	Zeros Negative	0	172		Zeros Negative	1	172

Table 4.31 Comparison Table for Sample 31

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

Sample 32:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	136	6		Ones Positive	134	7
	Zeros Negative	0	170		Zeros Negative	0	171

Table 4.32 Comparison Table for Sample 32

Accuracy of the algorithm for the IDS camera result is: 0,980.

Accuracy of the algorithm for the smart phone camera result is: 0,977.

Sample 33:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	142	0		Ones Positive	142	0
	Zeros Negative	0	170		Zeros Negative	1	170

Table 4.33 Comparison Table for Sample 33

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 34:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	143	2		Ones Positive	141	2
	Zeros Negative	0	167		Zeros Negative	0	169

Table 4.34 Comparison Table for Sample 34

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 0,993.

Sample 35:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	141	0		Ones Positive	141	0
	Zeros Negative	0	171		Zeros Negative	1	170

Table 4.35 Comparison Table for Sample 35

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

Sample 36:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	141	4		Ones Positive	145	0
	Zeros Negative	0	167		Zeros Negative	0	167

Table 4.36 Comparison Table for Sample 36

Accuracy of the algorithm for the IDS camera result is: 0,987.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 37:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	136	0		Ones Positive	136	0
	Zeros Negative	0	176		Zeros Negative	2	174

Table 4.37 Comparison Table for Sample 37

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,993 .

Sample 38:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	144	0		Ones Positive	141	2
	Zeros Negative	0	168		Zeros Negative	0	169

Table 4.38 Comparison Table for Sample 38

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,993.

Sample 39:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	132	0		Ones Positive	129	3
	Zeros Negative	0	180		Zeros Negative	0	180

Table 4.39 Comparison Table for Sample 39

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,990 .

Sample 40:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	147	0		Ones Positive	146	1
	Zeros Negative	0	165		Zeros Negative	0	165

Table 4.40 Comparison Table for Sample 40

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,996.

Sample 41:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	149	0		Ones Positive	149	2
	Zeros Negative	0	163		Zeros Negative	0	161

Table 4.41 Comparison Table for Sample 41

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,993 .

Sample 42:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	145	0		Ones Positive	142	3
	Zeros Negative	0	167		Zeros Negative	0	167

Table 4.42 Comparison Table for Sample 42

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,990.

Sample 43:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	145	0		Ones Positive	139	6
	Zeros Negative	0	167		Zeros Negative	1	166

Table 4.43 Comparison Table for Sample 43

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,977.

Sample 44:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	135	1		Ones Positive	136	0
	Zeros Negative	0	176		Zeros Negative	0	176

Table 4.44 Comparison Table for Sample 44

Accuracy of the algorithm for the IDS camera result is: 0,996.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 45:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	161	0		Ones Positive	161	0
	Zeros Negative	0	151		Zeros Negative	0	151

Table 4.45 Comparison Table for Sample 45

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 46:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	133	0		Ones Positive	133	0
	Zeros Negative	0	179		Zeros Negative	0	179

Table 4.46 Comparison Table for Sample 46

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 47:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	142	0		Ones Positive	142	0
	Zeros Negative	0	170		Zeros Negative	0	170

Table 4.47 Comparison Table for Sample 47

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 48:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	147	1		Ones Positive	148	0
	Zeros Negative	0	164		Zeros Negative	0	164

Table 4.48 Comparison Table for Sample 48

Accuracy of the algorithm for the IDS camera result is: 0,996.

Accuracy of the algorithm for the smart phone camera result is: 1.

Sample 49:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	134	0		Ones Positive	132	2
	Zeros Negative	0	178		Zeros Negative	0	178

Table 4.49 Comparison Table for Sample 49

Accuracy of the algorithm for the IDS camera result is: 1.

Accuracy of the algorithm for the smart phone camera result is: 0,993.

Sample 50:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	137	1		Ones Positive	138	0
	Zeros Negative	1	173		Zeros Negative	0	174

Table 4.50 Comparison Table for Sample 50

Accuracy of the algorithm for the IDS camera result is: 0,993.

Accuracy of the algorithm for the smart phone camera result is: 1.

In order to show the overall accuracy of the proposed algorithm with industrial camera and smart phone, the confusion matrices of 50 samples of invisible data matrix are created. The overall results are shown in Table 4.51.

OVERALL:

IDS CAMERA				SMART PHONE CAMERA			
		ACTUAL				ACTUAL	
PREDICTED		Ones Positive	Zeros Negative	PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	7059	30		Ones Positive	7021	68
	Zeros Negative	8	8503		Zeros Negative	17	8494

Table 4.51 Comparison Table for Overall

Accuracy of the algorithm for the IDS camera result is: 0,997.

Accuracy of the algorithm for the smart phone camera result is: 0,994.

CHAPTER 5

CONCLUSION

To conclude, in this thesis invisible 2D data matrix detection and decoding issues are considered. Unlike traditional 2D data matrices, invisible 2D data matrix has several distinguishing properties, printing, capturing and also decoding of the invisible 2D data matrix. The invisible 2D data matrix cannot be seen under daylight with naked eye. The reflected light from special pigmented ink is used. By using a high pass filter, the image of the invisible data matrix can be seen. For mobility of the invisible 2D data matrix systems and other traditional data matrix applications for smart phones are gathered and composed the thesis.

The most difficult issue for this purpose is the camera properties. The industrial cameras which are used in the invisible 2D matrix systems have better properties than smart phone cameras. The distinguishing properties are quantum efficiency and the pixel size. The obtaining of the light data the quantum efficiency is very crucial especially while red LED light is utilizing. Higher rate of the pixel size gives an advantage of capturing more light data. Smart phones are generally have low quantum efficiency of red light, since taking perfect images under daylight. Additionally, the pixel size of smart phones are so small compared to industrial cameras. Under these conditions, the algorithm is developed, setup is established and an apparatus is designed for smart phone. Samples are taken from industrial camera and smart phone camera for comparison the efficiency of the algorithm.

The proposed algorithm composed of two parts. First part, detection and locating the invisible 2D data matrix. The second part, decoding the invisible 2D data matrix. In the first step, global thresholding, edge detection and Hough Transform are applied. In second step zigzag tracing and during tracing online threshold learning is processed.

For avoidance from the global threshold, online threshold learning applied to each module. The image quality difference between IDS camera and smart phone camera can be exceed by local thresholding method. The experiments demonstrate that, the image quality affects the algorithm directly. Nevertheless, the algorithm works fine for all images which are taken IDS camera and smart phone camera.

Consequently, the invisible 2D data matrix detection with smart phone algorithm indicates high accuracy for different quality images. By the help of the prototypes and the developing algorithms mobility of the invisible 2D data matrix systems is coming soon.

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