The Graduate Institute of Sciences and Engineering

M.Sc. Thesis in Electrical and Computer Engineering

INVISIBLE 2D DATA MATRIX DETECTION WITH SMART PHONE BY USING GEOMETRIC CORRECTION FOR HOUGH TRANSFORM

by

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March 2015
Kayseri, Turkey

INVISIBLE 2D DATA MATRIX DETECTION WITH SMART PHONE USING GEOMETRIC CORRECTION BY HOUGH TRANSFORM

by

Halit SUN

A thesis submitted to

the Graduate Institute of Sciences and Engineering

of

Melikşah University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Electrical and Computer Engineering

March 2015
Kayseri, TURKEY

APPROVAL PAGE

This is to certify that I have read the thesis entitled "Invisible 2D Data Matrix Detection With Smart Phone Using Geometric Correction By Hough Transform" by Halit SUN 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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Halit SUN

M.S. Thesis – Electrical and Computer Engineering
March 2015

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ABSTRACT

In recent years, 2D Data Matrixes (such as QR codes) are used in many different areas that provide quick and automatic data entry to the computer system. This provides great convenience in daily life and business. Their most common usage is to automatically read labeled products (books, medicines, food, etc.), and recognize them. In Turkey, alcohol beverages and tobacco products are labeled and tracked with the invisible 2D Data Matrices for public safety and tax purposes. In this application, Data Matrixes are printed on a special paper with a pigmented ink. The code cannot be seen under daylight. Since invisible 2D Data Matrices reflects 630nm wavelengths light, 630nm wavelength LEDs are used for illumination by special barcode reader. Due to their physical dimensions, expensive price and requirement of special training for the usage, there is a need to development for smart phone application.

In this thesis, we developed an apparatus attached on the smart phone including a 630 nm wavelength LED light group and 630 nm wavelength band pass filter that allows passing only the light around 630nm wavelength. We developed the algorithm to processing images which are smart phone captured and decoded all information in the invisible 2D Data Matrix. The proposed method mainly involves four stages. Its first step is that a data matrix code is processed by Hough transform processing to find “L” shape pattern. In the second step, borders of the Data Matrix are founded by using the convex hull and corner detection method. After that, distortion of invisible 2D Data Matrix corrected by geometric correction technique and the size of every module is fixed in rectangular shape. Finally, invisible 2D Data Matrix is scanned line by line in the horizontal axis to decode it. Results obtained by testing the proposed algorithm with different images of invisible 2D Data Matrix shows high accuracy and low error rate.

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

GÖRÜNMEYEN KARE KODUN HOUGH TRANSFORM VE GEOMETRİK DÜZELTME YÖNTEMLERİ KULLANILARAK AKILLI TELEFON İLE OKUNMASI

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Yüksek Lisans Tezi – Elektrik ve Bilgisayar Mühendisliği
Mart 2015

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ÖZ

Günümüzde birçok farklı alanda kullanılan karekod sistemleri otomatik olarak hızlı bir şekilde bilgisayara veri girişini sağladığı için günlük hayatta ve iş hayatında büyük kolaylıklar sağlamaktadır. En yaygın kullanım alanı olarak ürünlerin (kitap, ilaç, gıda vb.) etiketlenmesi ve bu etiketlerin otomatik olarak okunarak ürünlerin tanınması söylenebilir. Ülkemizde ürün güvenliği ve takibi açısından tekel ürünlerinin takip ve denetiminde görünmeyen karekod uygulamasına geçilmiştir. Bu uygulamada karekod basımında özel pigment içeren mürekkep kullanılmakta ve ürün üzerine basılan karekodlar çıplak gözle gün ışığında görülemememektedir. Sadece belirli bir dalga boyunda ışık verildiği takdirde görünür hale gelen görünmez karekodlar özel okuyucular sayesinde okunabilmektedir. Mevcut olarak kullanılan görünmez kare kod okuyucularının fiziki yapısı, kullanım için eğitim gereksinimi ve pahalı olmasından dolayı akıllı telefon uygulamasının geliştirilmesi ihtiyacı doğmuştur.

Bu tezde, görünmez karekodların akıllı telefonla okunmasını sağlayan üzerinde 630nm dalga boyunda ışık verebilen LED'ler ve 630nm ışık dalga boyunu geçiren filtre bulunan bir aparat geliştirilmiştir. Alınan görüntüler, geliştirilen algoritmalar tarafından işlenerek karekod üzerindeki bilgiler okunabilmektedir. Geliştirilen algoritmalar dört temel adımdan oluşmaktadır. İlk adımda Hough Transform yardımıyla karekoda ait "L" şekil düzlemi bulunarak karekodun yer tespiti yapılmaktadır. İkinci adımda, "L" şekil düzlemi yardımıyla bulunan karekodun konveks alan ve köşe noktası tespiti yöntemleri kullanılarak sınırları belirlenmiştir. Sonrasında, çerçeve içerisine alınan karekoddaki bozulmalar geometrik düzeltme yöntemi kullanılarak giderilmiş ve her bir hücrenin aynı büyüklükte olması sağlanmıştır. Geometrik düzeltmeyle tam bir dikdörtgen çerçeveye alınan karekod yatay eksende satır satır taraması yapılarak karekod okunması gerçekleştirilmiştir. Geliştirilen algoritmalar farklı görünmez karekodlarla test edildiğinde yüksek doğruluk ve düşük hata oranı göstermiştir.

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

DEDICATION

Dedicated to my family for their endless support and patience during the forming phase of this thesis.

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor Ass. Prof. Dr. Mahmut KARAKAYA whose help, stimulating suggestions and encouragement helped me during the course of research and writing of this thesis.

I also want to thank my dearest friend Mahir Can UYSALTÜRK for his significant contributions to my research endeavors.

I express my thanks and appreciation to my family for their understanding, motivation and patience. Lastly, but in no sense the least, I am thankful to all of my colleagues and friends who believe in me about my researches.

I would like to thank to The Scientific and Technological Research Council of Turkey (TÜBITAK) that supported this thesis under the project number 114E563.

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INTRODUCTION

1.1 DEFINITION OF DATA BARCODES

It is very common to see black-and-white dots or lines obviously on your books, magazines, medicine, T-shirts, product packaging, and in all kinds of other places a bit like riddle without any words. There are different forms of these black-and-white dots or lines with different names and capabilities. Figure 1.1 shows a regular barcodes where it is formed black lines with different thickness and white spaces between black lines with different thickness. This regular barcodes stores only one-dimensional data with very small capabilities.

With the recent advances in imaging and laser science, barcodes technology is rapidly improved and different types of barcodes with large capabilities are developed. In order to develop the capability of the barcodes, data storage area of the barcodes is increased. As shown in Figure 1.2, Two-dimensional black-and-white dots, called two-dimensional (2D) barcodes or data matrix codes, are invented with more data capacity that are just like ordinary machine-readable barcodes. Therefore, barcodes can transfer on information about a product in until you close the blink of an eye. The one-dimensional barcode demonstrates a sequence of information as a one-dimensional line of black

Figure 1.1: An example of the one-dimensional barcode

Figure 1.2: 2D Data Barcode Implemented on Medicine Box

and white bars, two-dimensional barcodes store a lot more information than one-dimensional barcodes into their grids of black and white, where each grid is formed by square-shaped dots.

The first user organizations of 2D Data Matrix is The American space agency was one of the to make prevalent in use of data matrix. They need a new technology to store more information in a small piece.

1.2 TYPES OF DATA BARCODES

Different symbols of barcodes are used in different combinations of dots or square module to represent different characters. Barcode symbols, are developed different types such as, QR Code, Maxi Code, PDF417, Data Matrix as shown Table 1.1. There are different symbols improved to provide the expectations of the various applications. Each symbols include some of characteristics specification to these applications. Lately, some specific industries are using the barcode systems in products. Basically, two main subjects that should be notice when creating the barcodes. First is all the barcodes have to be part of in prevalent standard in organizational standard. If there is no standard becomes confused all the products .

Table 1.1: Type of 2D Data Barcode

	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

The second subject is the content of data that is needed to be encoded. ASCII code standard is used in all 2D Data Barcode. Additionally, coding region and its size is an important factor for coding the new barcode. Finally, the area code will be printed and will be published to be proper with scanner and printing equipment of 2D Data Barcode.

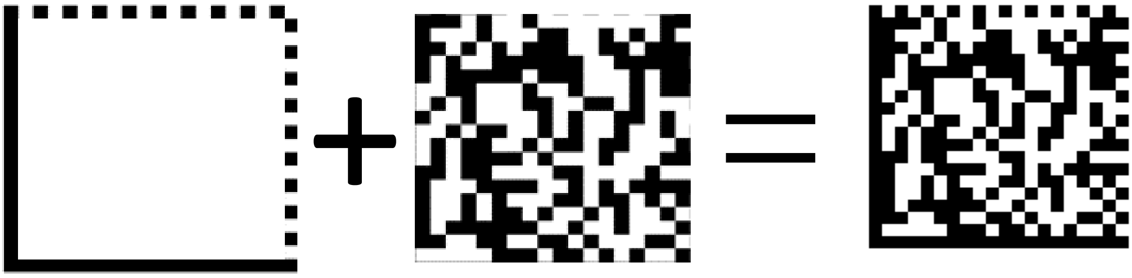

Figure 1.3: Generation of Data Matrix with Combining L-shape and Data Region

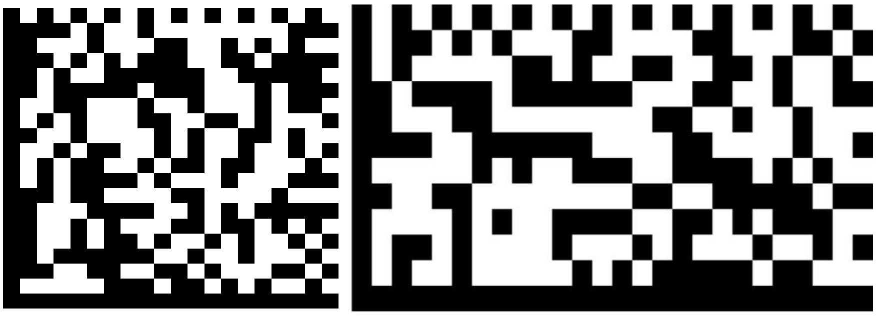

Figure 1.4: ISO/IEC Standardized of Data Matrix (ECC 200)

1.3 TWO DIMENSIONAL DATA MATRIX BARCODE

Data Matrix is a two-dimensional (2D) barcode it may be printed as a square or rectangular symbol made up with the individual dots or squares. This representation consists of ordered grids of dark dots that are bordered by a finder pattern. The “L” shape finder pattern is used to specify the orientation and structure of the barcode as shown in Figure 1.3. The data is encoded using a series of dark dot/square modules based on a pre-determined size. GS1 Data Matrix is the ISO/IEC recognized and standardized implementation of the Data Matrix shown Figure 1.4.

The user can be choose size of 2D Data Matrix. It depends on data capacity of the barcode, to chosen according to the area to be printed and the code size area. The symbol rectangle is build up by square dots its size is called "the module" that is also specified.

2D Data Matrix are printed as a square and rectangle form.

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

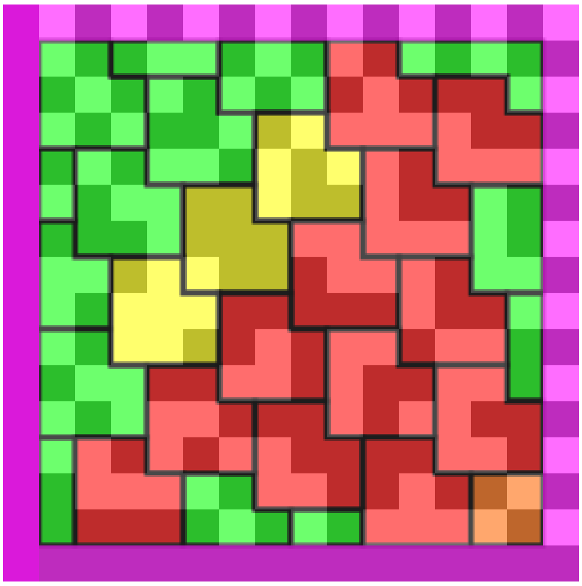

Figure 1.5: Data Matrix Code, Green Area to Show Data, Yellow Area is Padding, Red Area Error Correction, Magenta “L” Finder Pattern and Orange Not Used Area [1].

The mapping of 2D Data Matrix dependent on the used truth encoding list. Shortly, In short, this is used more efficiently to encode ASCII characters to fit more data into a fixed number of bytes. For example to encoding numeric information is using one byte for two digits. Figure 1.5 shows the modules in the data region of the Data Matrix. Each module is formed by different size of the dot groups and can be used of different purposes including the data, padding, error correction, timing, and unused modules. Following steps are used to encode 2D Data Matrix.

ASCII values (0-255) are using to encode using for encoding. The goal of the encoding is to print the data into a small size. If it is necessary to cover in information capacity of the barcode the data is padded to choose 2D Data Matrix size. If it possible input data has been included, error correcting parts are also added to recover the data if part of 2D Data Matrix has been removed. Finally the encoded data and the error correcting words are placed in the symbol according to an algorithm specified in the standard. This Data Matrix symbol of each data byte in a certain position is done by placing each bit. For those interested in a simplified and specific details of the above disclosure requirements in to refer ISO organization.

Table 1.2: Maximum Data Capacity for the Different Symbol Sizes in ECC-200 Data Matrix Subset

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 SYMBOLOGY DATA CAPACITY OF 2D DATA MATRIX

Symbol size determine by the data is encoded. Actual data capacity depends on the symbol size. According to the symbol size characters are selected from the available source of information the smallest possible symbol size. Table 1.2 gives the maximum capacity for the three most common encoding schemas. For each symbol size, the obustness in each symbol is specified as the number of errors (destroyed data) that can be recovered.

1.5 APPLICATION OF DATA MATRIX BARCODES

Today, barcodes are used in many different areas that provide quick and automatic data entry to the computer system. This provides great convenience in daily life and business. Their most common usage is to automatically read labeled products (books, medicines, food, etc.), and recognize them. Barcodes are in its simplest form printed as thin and thick black lines parallel on white rectangular background, where different thick spaces between these lines occur. It is also a symbol system which gives item reference number when read by an optical reader connected to the computer. In recent years, with the improvement in the camera, printer and integrated circuit technology, barcode systems can store more product relevant information into barcode and they can used in different applications such as product safety and monitoring. Product safety and monitoring systems that on the market, controls the product label whether indicates the manufacturer company or counterfeit production by a pirate company. In this system, manufacturers place a product identification number on each product box that contains a data matrix which is an improved barcode system, and these credentials are stored on a database. During the sale of products the data matrix is read by cashier or inspector using a reader to compare the product id within the database, so that the system can easily detect the non-registered products.

For example, 2D Data Matrices are used to chase the product from production line to the customer as shown Figure 1.6. 2D Data Matrix generated on label which attached on the box of alcohol beverages. The label includes information about alcohol beverages where and when it produced, volume of bottle, etc. The last user can see all information about that product with visible Data Matrix smart phone reader.

1.6 INVISIBLE 2D DATA MATRIX BARCODE

In Turkey, the illegal production and smuggling of medical drugs, liquor and tobacco products (called as Tekel products in Turkey) causes serious tax losses or public health problems. In order to prevent the sale of smuggled and counterfeit drugs and Tekel products, and to make the detection of these products easily, recently drugs sold in pharmacies and Tekel products sold in markets are required to put data matrix on them as shown in Figure 1.7. However, the visible data matrix can be easily copied by counterfeiters and smugglers, and fake data matrixes are printed on their products. To prevent this from happening, government has passed a new regulation for Tekel

Figure 1.6: 2D Data Matrix Implemented Alcohol Beverages Box

Figure 1.7: Invisible Data Matrix for a Tobacco Product

products that are tracked and inspected by imported invisible data matrix system. In this application special pigment ink is used for printing barcodes so that data matrix printed on materials such as paper, could not be seen in daylight. Only if under a specific wavelength of light, invisible data matrix can be read through a special reader. For this purpose, special handheld terminals, which makes the invisible codes visible under special wavelength light, are distributed to inspectors for controlling products. Due to reasons like this hand-held terminals distributed to the instructors to be imported from abroad, their physical dimensions, their expensive price and requirement of special training for the use, this data matrix reader terminals cannot be easily carried and given to each mobile law enforcement authority units (police and gendarmerie). So to easily

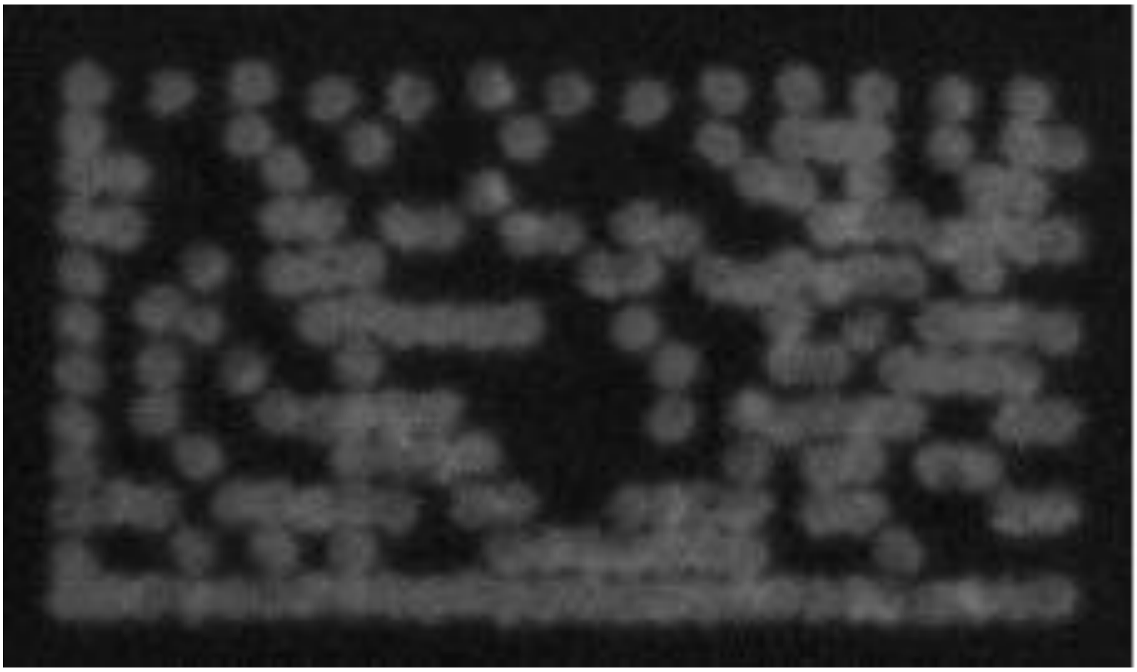

Figure 1.8: Invisible Data Matrix

detected and track contraband and counterfeit products that threaten public health and causes loss of tax; cheap, small sized and easily transported domestic mobile invisible data matrix reader systems are needed to deliver to any law enforcement authority.

Invisible 2D Data Matrix printed as a rectangular symbol with invisible pigmented ink. Invisible data matrix consist black background and white dot modules which can be visible under 630 nm light with a filter as shown in Figure 1.8. An invisible data matrix symbol is composed of two independent parts; the “L” shape finder pattern and the encoded data itself. The “L” shape finder pattern is used to locate the Data Matrix defines the rectangle and size of the symbol. Thus, it allows the scanner to identify the symbol as a data matrix.

“L” shape finder pattern consists of two lines which are vertical line on the left and horizontal lines at these two lines are perpendicular with each other bottom of the symbol. It is primarily used to determine the orientation of Data Matrix. Symmetrically opposite of the “L” shape pattern has dashed border lines for helping to find four edge points with “L” shape finder pattern. "L" shaped finder pattern spared Invisible Data Matrix code from another barcodes and background objects. The first procedure that work on to barcodes "L" shape finder pattern and timing pattern in Invisible Data Matrix. May this first step will be a perspective distortion in the image.

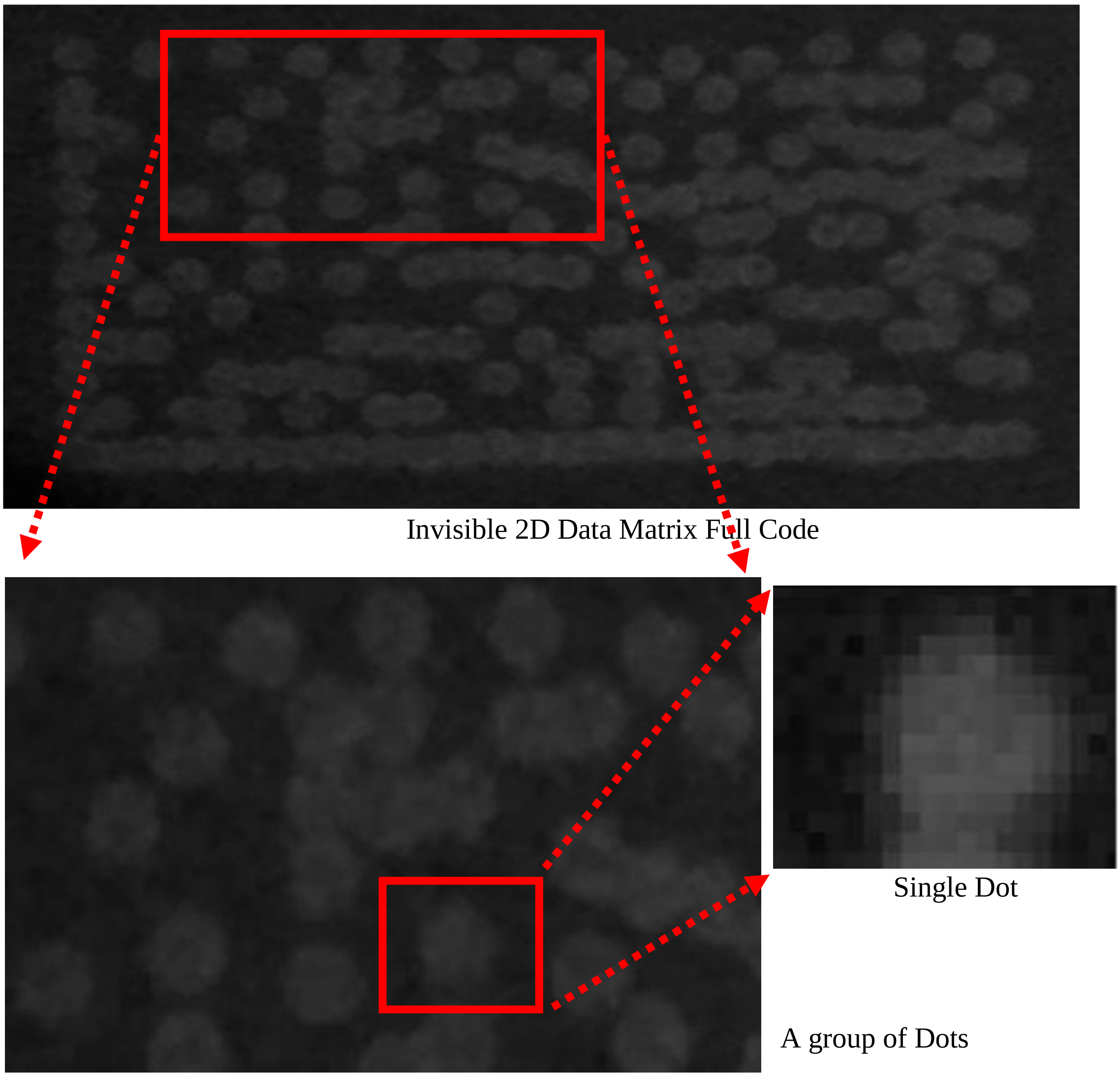

Figure 1.9: Quality of Invisible Data Matrix

Invisible Data Matrix printed with inkjet printer. The inkjet printer had low resolution affects ink when it spreads the ink on the paper. Therefore, the print quality of inkjet is poor as shown in Figure 1.9. The ink spreading problem in the cell area can be seen closer in Figure 1.9. The problems with the invisible data matrix can be listed as below:

- There are background noise due to the reflection and filters.
- Dots are touched each other.
- Ink spreads around during the printing.
- Dots are not at the same level with others in the same row.
- Print direction that it has an effect on code decoding.

CHAPTER 2

BACKGROUND AND RELATED WORKS

In literature, there are several works related with the Data Matrix reading systems. In these works, Data Matrix reading systems consists of two major steps including detection and decoding. In the first step, the location of the Data Matrix is determined. The second step decodes the encoded message in the Data Matrix from the data region. All the works related with the Data Matrix are focused on the visible Data Matrix and there is no work on invisible Data Matrix. Therefore, in this chapter, we present the works in literature related with the visible Data Matrix.

2.1 "L" SHAPE DETECTION IN 2D DATA MATRIX

The first step in the Data Matrix algorithms is to detect the location of the Data Matrix, "L" shape finder pattern. All 2D Data Matrix is printed of two solid borders in an "L" shape. It is also named finder pattern, and dashed line dark and light modules including the other two boundaries that "dashed border" is called as show in Figure 1.3. Rows and columns of modules to encode data inside of these borders. With the help of a the finder pattern is find to position of 2D Data Matrix, during dashed border pattern enable to obtain all number of rows and columns in the barcode.

Since "L" shape detection is the main step to find the location of the data matrix, there are several methods to detect "L" shape finder pattern in literature. Most of these algorithms are based on Hough Transform. Due to the high printing quality, visible Data Matrixes can be detected easily. However, we cannot use these methods directly to detect "L" shape finder pattern in an invisible data matrix because of the background noise, touching dots, spread out printing, and uneven contrast of the invisible data

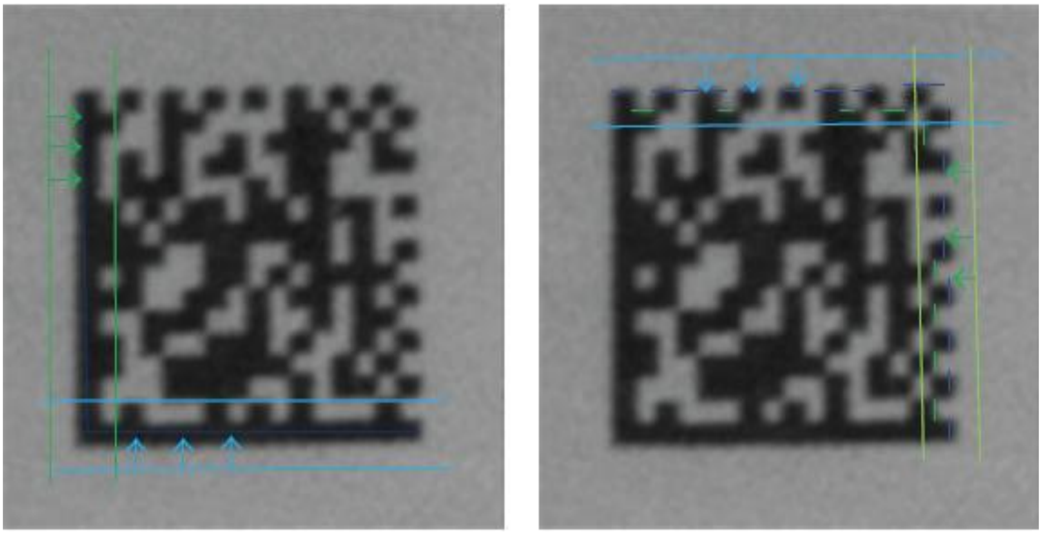

Figure 2.1: Scan Border Points

matrix. In this chapter, we focus on the related works on visible data matrix and figure out the advantages and shortcomings of these methods for invisible data matrix.

Donghong et al. [2] used Radon Transform to find the “L” shape finder pattern and dashed border of the data matrix. Donghong algorithm’s works well for high-sensitivity and high density 2D Data Matrix code, but is not so time consuming and more properly to be implemented to applications in real time. Chenguang et al. [3] worked the placement algorithm predicate on the Hough Transform. The algorithm reduce the consumption and memory starvation second Hough transform. The major problem is the low precision algorithm for complex background. Wenting and Zhi [4] worked on convex hull algorithm to find location of 2D Data Matrix. The algorithm obtained to set tree peak point from convex edge of "L" finder pattern. The algorithm is very simple to need clean background and gets to be exact.

The other Data Matrix locating algorithms [5, 6] and are only useful for specific cases, such as simple background requirement, good illumination options, and low density differences. Actually, generally barcode printed on complex background, and besides may get stained, missing, or printed in high density. With these cases, mostly algorithms are not effective or to need higher processing and more memory capacity for the work mentioned above. Also these algorithm cannot be satisfied for real-time application.

Huang et al [7] proposed line segment detector (LSD). In this paper, the authors introduce a new algorithm to find 2D Data Matrix that is based on the detection and fitting barcode “L” shape finder pattern border. This technique is roughly the size of a threshold gradient greater sharing the same gradient orientation angle and a connected set of points in a region called the support line defines the part of the line. Boundary points as shown in Figure 2.1 in the direction vertical to 2D Data Matrix boundary is defined as the first edge points outside and within. Barcode scanning range boundaries approximate such as 4-5 pixels.

Liu et al [8] recommended the pseudo algorithm. "L" is the edge feature is a very essential property for 2D Data Matrix barcodes, the first three steps of the algorithm will erase "L" shape border by pseudo region. Initially, dual barcode image will be identified on the edge of the image. Used to estimate the pixel size difference between adjacent pixels in the diagonal direction of the gradient to determine where the edges, Roberts' operator is used. It is performed high accuracy and strong robustness for the distortion "L" shape border. After, the grammar convex hull algorithm is detected all four corner points hence to has regional convex polygon. The length of the convex peak and the adjacent edge angle is used to facilitate body of the peak. In the last step, determine whether or not convex polygonal region "L" shape. There will determine the final barcode of compact.

2.2 DECODING 2D DATA MATRIX

After locating the L-shape of the Data Matrix, second step is finding and the determining each module, which can be square or dot shape in data region. For this purpose, it has been carried out many different studies in literature.

Rathod and Ladhake [9] proposed Two-way medial working length method to scan the data of mixed models ordinarily applied to perform bit decoding bit with special sufficient of the background information in 2D Data Matrix. Then classified and dimension detection code, the code length is computed and as the coordinates of the four corners. They only hold code and scaling rectangle rectangular limited to normal size. The cells which are embedded close to the code side seems relatively easy to determine where the central peers. The data region is segmented into four sections. Each quarter screening of columns and rows is done from the outside and inside during the previous scan are used to estimate the parameters of consecutive ones.

Liu, et al [10] presented that after detects the four edges of the connecting box, offered that their method of image and decode binarize start. If not passed on to the next step, it moves to the next frame. Perspective distortion first step calculates the correction mapping function between real non-ideal perspective the captured image. It can be define as a plane-to-plane homography matrix.

Pârvu and Bălan, [11] in this paper, 2D Data Matrix detection and decoding the trouble solving devices with limited resources. They recommend a fast and strong method especially build for 2D Data Matrix barcode scanning. Their approach is based on one or two key corners and fabrication steps follow a contour tracing technique for determining the segmentation. This technique where the real-time solution is required, the mobile instrument application or applied to other systems. This technique comprising binarization and object classification approaches, such as conventional image processing techniques. Because all images have straight line. Therefore, the algorithm is scanning row by row and the classic image segmentation and object processing steps with a doubling candidates. Individual components are defined by contour tracking algorithm. Out of ignoring the noise and other errors, (straight or all shapes) is determined by the longer of the two segments of the contour corner analysis. If this exceeds exact criteria, may provide support for the two parts of “L” shape marker. The corners of the code segment has already been obtained starting from the fourth corner deflection relative maximum allowed two consecutive compiler and re- compiler steps.

In detection process, the algorithm detects each binary image row for without tag significant pixels. If a limit to the raw pixel scan-line monitoring methods and new-found out a sequential approach is ticking stroke. If properly algorithm finds raw border of pixel in line scanned and sign a new contour. The number of traced contour is effected processing speed and time. Their main method of detecting active thus gaining significant acceleration does not use domestic. The corner is obtained on the basis of successive pixel tracking. When the first contour pixel is detected, following pixel is scan to test the neighboring pixels in the direction of clockwise. Freeman chain-code elements are marked the neighboring pixels. Direction of scanning is appointed starting number that adapt to the last pixel tracking.

The related works that are briefly described above are proposed for visible data matrix. The printing procedure of the visible Data Matrix is simpler and easier than invisible Data Matrix. In most application, visible Data Matrixes are printed on a white and clean background with a high quality laser printer where each module of the visible Data Matrix has a square shape. However, the printing technique of the invisible Data Matrix is different where inkjet printers print the special pigmented ink on a special paper. Since inkjet printers spray the ink on the paper, shape of each module become round and the distribution of the ink is not stable. In addition, the printing paper has different patterns to make the invisible ink not to be seen on the day light. This pattern on the printing paper also reflects a bit of light during the image acquisition procedure and causes a background noise even if a band pass filter is used. Due to these problems, the image quality of the visible and invisible Data Matrix is very different. This makes detection and decoding the invisible Data Matrix is harder than visible Data Matrix. Therefore, the methods related with visible Data Matrix cannot be used directly for invisible Data Matrix.

CHAPTER 3

INVISIBLE 2D DATA MATRIX DETECTION WITH SMART PHONE USING GEOMETRIC CORRECTION BY HOUGH TRANSFORM

3.1 TECHNOLOGY BEHIND THE INVISIBLE 2D DATA MATRIX

Due to the special printing technology, the invisible 2D Data Matrix cannot be seen in day light with the naked eyes. It requires special components to recognize 630 nm wavelength led light is needed for illumination. Under this illumination on Data Matrix there is a filter, which behaves like a band pass filter, should be used to catch the Data Matrix. If the filter is not appropriate for the wavelength the back ground is going to be noisy. Unlike the standard Data Matrices the invisible 2D Data Matrix consists of dot cells instead of square cells, which brings us complexity for finding sharp cell frame.

The other difficulty of the 2D Data Matrix is printing. The printer, which is used to create 2D Data Matrix, is not sustainable on printing. The pigmented ink disturbs the modulation of inkjet printer. Therefore, the orientation of the lines in the invisible 2D Data Matrix can be deviated. While coding the invisible 2D Data Matrix, Inkjet's printing head spread the dots it brings undefined cell boarders which we have discussed above.

When considered smart phones technical efficiency, camera infrastructure and cameras elements in that to detect invisible Data Matrix; because of all these challenges we need a different algorithm development. The algorithm should be performing under bad light illumination and printing. It can be detect all dots are moved different position.

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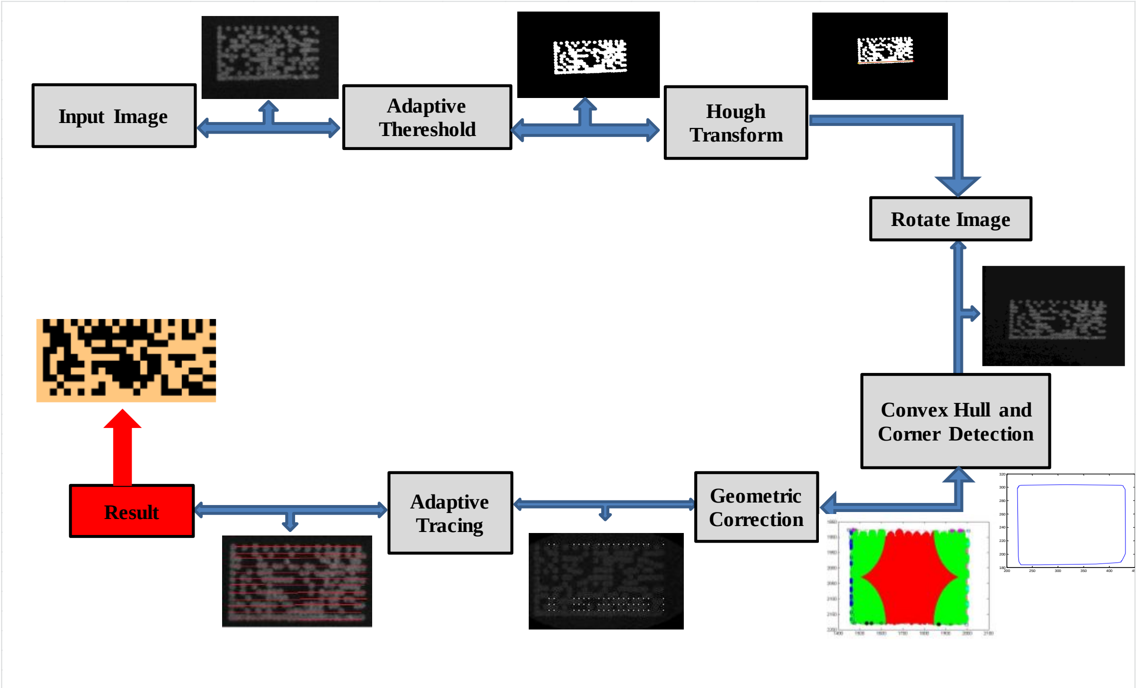


Figure 3.1: Flow Chart of the Algorithm

3.2 PROPOSED ALGORITHM

In the proposed algorithm for invisible 2D Data Matrix detection, we used the similar approach as in visible data matrix by dividing the proposed algorithm into two parts. We first detect the “L” shape finder pattern to locate the invisible data matrix. Then, in the second decoding step, each individual cell detected as dotted or empty.

In the second chapter, we examined for “L” shape finder studies to figure out the pros and cons of these methods. Due to the difficulties in invisible data matrix compared to visible data matrix, methods used for visible Data Matrixes cannot be used for the invisible data matrix, directly. We modified these algorithms and combined the good approaches of them. The proposed algorithm is illustrated in the flow chart as shown in Figure 3.1.

Flow chart includes the basic steps of the proposed algorithm with an input image and the output data matrix with detected cells. First step of the algorithm is the image acquisition. Then, we implement an adaptive threshold method to eliminate the noise and to detect the rough location of the invisible 2D Data Matrix. After the adaptive threshold, Hough transform is used to find the longest edge of the “L” shape finder pattern. In most cases, data matrix are rotated certain degrees. To align the data matrix with the image plane, we rotate the input image by using the angle between longest edge of the “L” shape finder pattern and the image plane. Then, the simplified convex hull points are used to determine the boundary of the invisible 2D Data Matrix. Although, convex hull method gives a rough corner, it cannot provide the accurate position of the corner points of the “L” shape finder pattern. In the next step, we used the line intersection method to find the accurate location of corner points. After determining the accurate locations of corner points, it’s ready to apply to geometric correction. Geometry correction is the process of digitally manipulating image to compensate the changes in the shape of the modules because of the perspective distortion. As a final step, adaptive tracing method used for detect to the dots in modules by scanning all modules row by row. Details about each step of the proposed algorithm is presented in the subsections below.

3.2.1 “L” SHAPE FINDER PATTERN ALGORITHM

A- Adaptive Threshold

In order to detect the 2D Data Matrix, we first need to find its location. To locate the Data Matrix, we first focus on the finding “L” shape finder pattern as other related works done in literature. Since “L” shape finder pattern consists of two longest lines in the 2D Data Matrix, Hough Transform is one of the best option to orient the “L” shape finder pattern. Before applying the Hough Transform, we subtract the background from the input image and find the foreground 2D Data Matrix area by using an adaptive threshold method at the input image. Due to the lack of obvious density difference between the background and region of interest, we have to use a special threshold technique. The adaptive threshold is an effective method to remove the effect of light reflection from the background banderole paper in input image. The most difficult process to obtain the proper number of automatic threshold. The common problem of these algorithm cannot compute automatic threshold value of the image. Our threshold technique includes two threshold method, following each other. First, we used adaptive threshold method to extract 2D Matrix from background and then Otsu’s threshold classify each cell if it is empty or dotted at the decoding stage.

In the first step of the adaptive threshold, let us consider an image, I, where I(x, y) ∈ [0, 255] in that pixel density at oriented (x, y) direction. The threshold is computed using the mean, M(I) and variance of the pixel intensities, V(I) in the input image, I as shown equation (1). The pixel value is bigger than the threshold value, I(x, y) are classified as object pixels otherwise I (x, y) are defined as background pixels.

$$V = \begin{cases} 1, & \text{if } I(x,y) > M(I) + 1.5 * V(I) \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

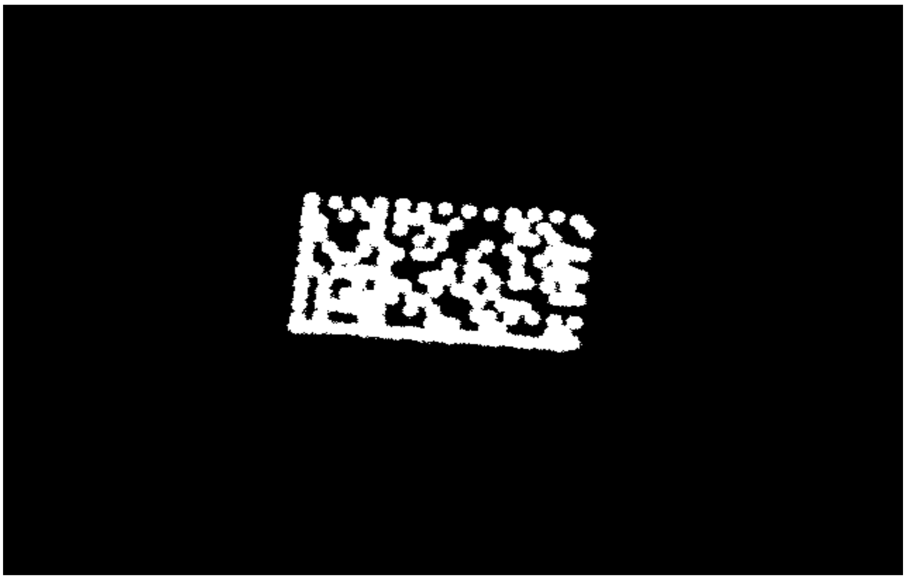


Figure 3.2: The image after applying the adaptive threshold

In the second step of the proposed algorithm, we utilize the Otsu's Threshold method and additional morphological opening filter to classify each cell if it is empty or dotted and to remove the noisy small pixel groups. It works well to separate automatically the region of interest from the background as shown in Figure 3.2. Because of the variation in the illumination in the invisible 2D Data Matrix, each invisible 2D Data Matrix image has different threshold values.

B- Hough Transform and Line Detection

After finding the foreground image, we implement the Hough transform to find out location of the invisible Data Matrix. Hough transform is used to detect the lines in the image because the longest two lines in the 2D Data Matrix forms the "L" shape finder pattern. The Hough transform is a commonly used algorithm to detect lines and other features in the images. Linear transformation that Hough transform to detect straight lines The Hough transform is a technique used for detecting a particular shape within an image as straight lines, circles, ellipses. [12]. The transform is applied by characterize the Hough parameter place into finite intervals. In an image analysis context, the straight line can be defined as $y = mx + b$ and can be graphically sketched for each pair of image points (x, y). The Hough transform is not considered a main argument in a straight line features, image points (x1, y1), (x2, y2). However, the slope parameter m and crossing parameters in point of b. In respect to this, the straight line $y = mx + b$ can be demonstrate as a point (b, m) in the parameter place. However, it has a problem that vertical lines take rise

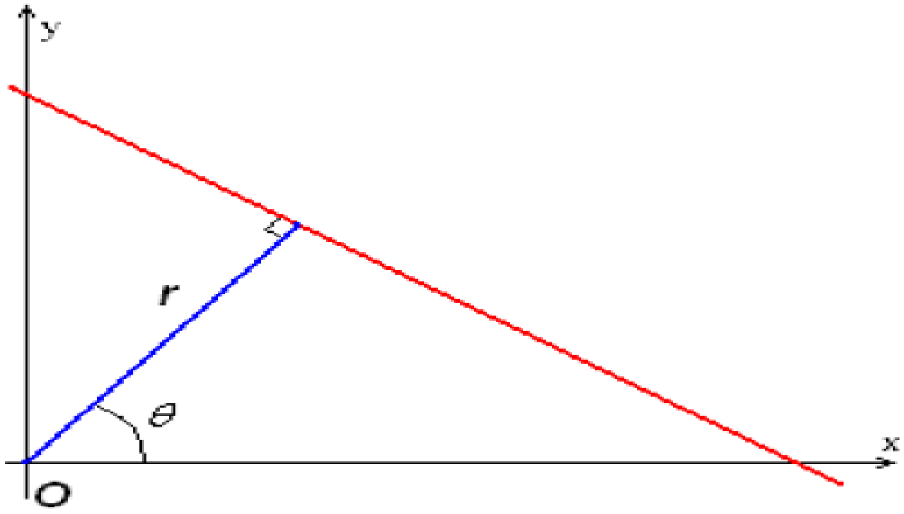


Figure 3.3: R, Theta line parameters

to unmeasured values of the parameters m and b. Due to the calculation result, the Hough lines as shown in Figure 3.3, this pair of polar coordinates transformation of different parameter and (theta) is better to use. Hough line detection first finds out peaks in the Hough space. Matlab has a function named Houghpeaks that gives Hough peaks density as shown in Figure 3.4. In Figure 3.4, high lighting areas demonstrates line groups which are positioned in angle and distance from origin manner. The high number of crossing lines in the image marked as red dot which gives the longest line in the image. It is expected that the longest line of the image is the longest line of the "L" shape of the invisible 2D Data Matrix. The Hough Transform function returns rho and theta values where "rho" is the distance from the origin and "theta" is the angle of the line to the origin. In Figure 3.4, y-axis shows line distance from center (origin) and x-axis shows lines angle to origin.

By using the Hough Peak Point, the longest line in the image is determined the longest line of the L shape finder pattern. In Figure 3.5, the longest line is shown as a red line. The obtained longest line provides us the coordinates of the invisible 2D Data Matrix in the image. There are clues lie in the longest line for the orientation of the invisible 2D Data Matrix in the image. As a result the recommended rotations can be applied after finding longest line of the "L" shape finder pattern. The slope of the longest line of the "L" shape finder pattern gives us the orientation of the invisible 2D Data Matrix in the image. By using the slope of the invisible 2D Data Matrix, the rotating angle, which makes the longest line of the "L" shape finder pattern parallel to the x-axis, can be found.

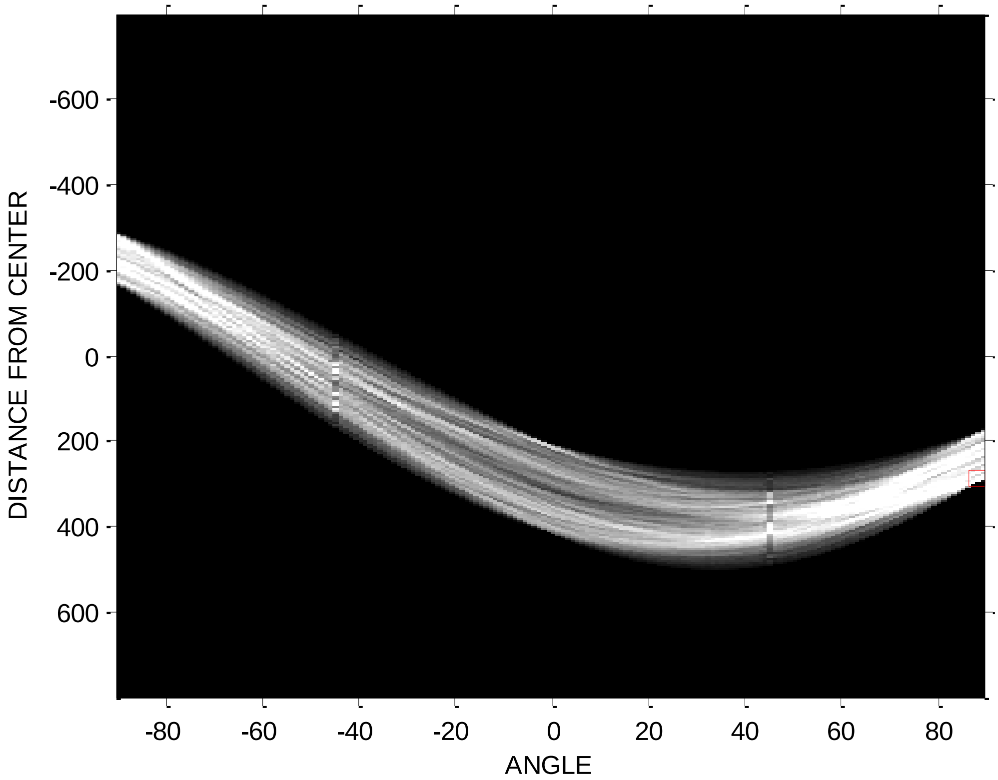


Figure 3.4: Hough Peaks in Hough Transform

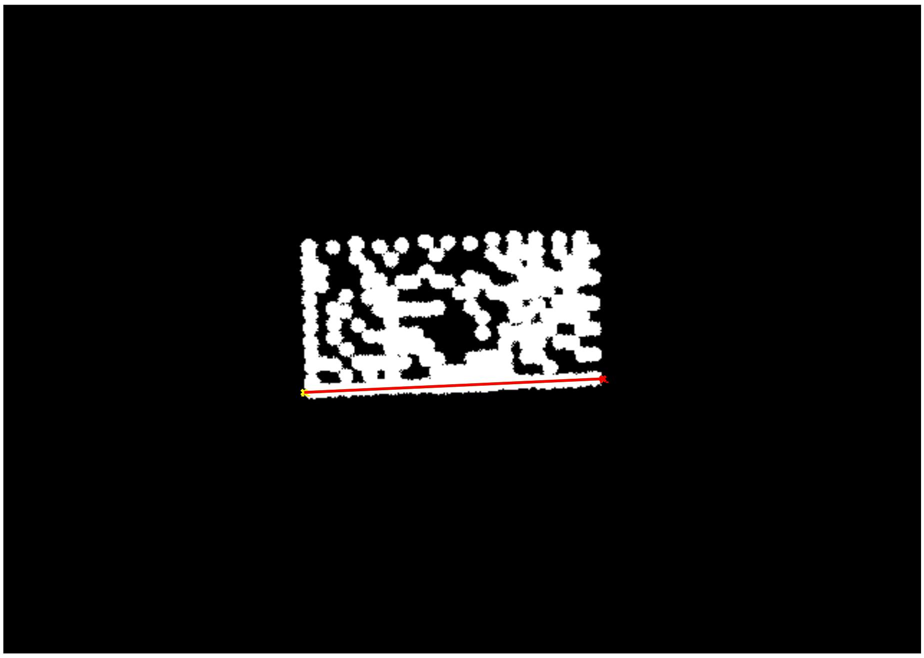


Figure 3.5: The Longest Line in the Image as “L” Shape Finder Pattern

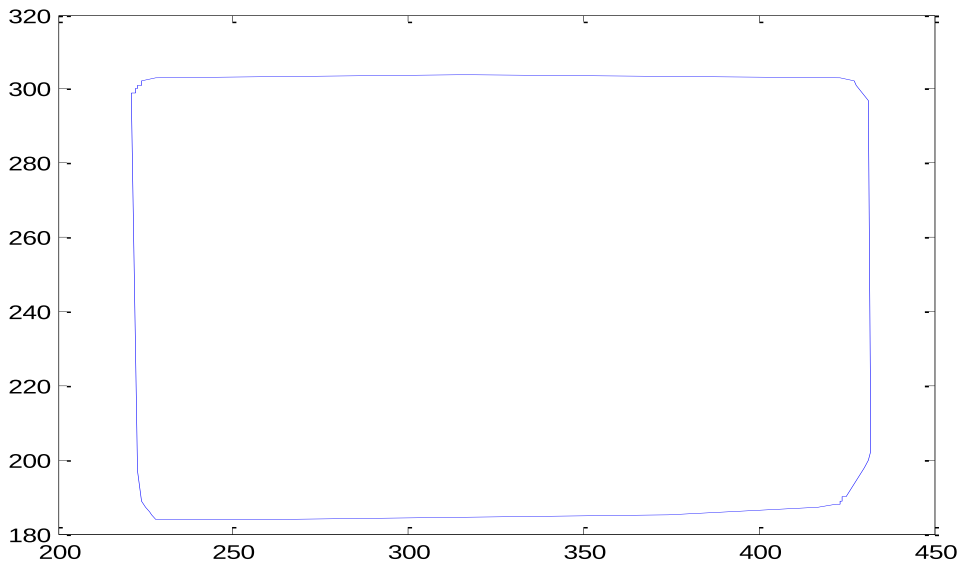


Figure 3.6: Region Props Convex Hull

C- Corner Detection with Convex Hull and Line Intersection

The rectangular-shaped 2D Data Matrix was placed in the four corners of the "L" shape finder pattern. Figure 3.6 illustrates rectangular shape of invisible 2D Data Matrix. The rough coordinates of four corners of the invisible 2D Data Matrix can be found by using the Region Props function. After rearranging the orientation of the Invisible 2D Data Matrix we apply the Region Props' Convex Hull function to get the rough coordinates of the invisible 2D Data Matrix as shown in Figure 3.6. These coordinates are going to be the reference points for detecting the accurate locations of four corners.

For correcting the geometric distortion at the invisible 2D Data Matrix image, the accurate corner points are required. The rough location of corner points and the neighboring edge points are used to estimate a best line for 2D Data Matrix edges. By finding the intersection points of the best lines, accurate location of corner points for geometric correction is found. To set the new location of the invisible 2D Data Matrix we create a transformation function for a 2-dimensional projective transformation. After generation of the function, inverse spatial transformation is applied to the input image. The corner points, their neighboring edge points and the best lines of the invisible 2D Data Matrix are shown in Figure 3.7.

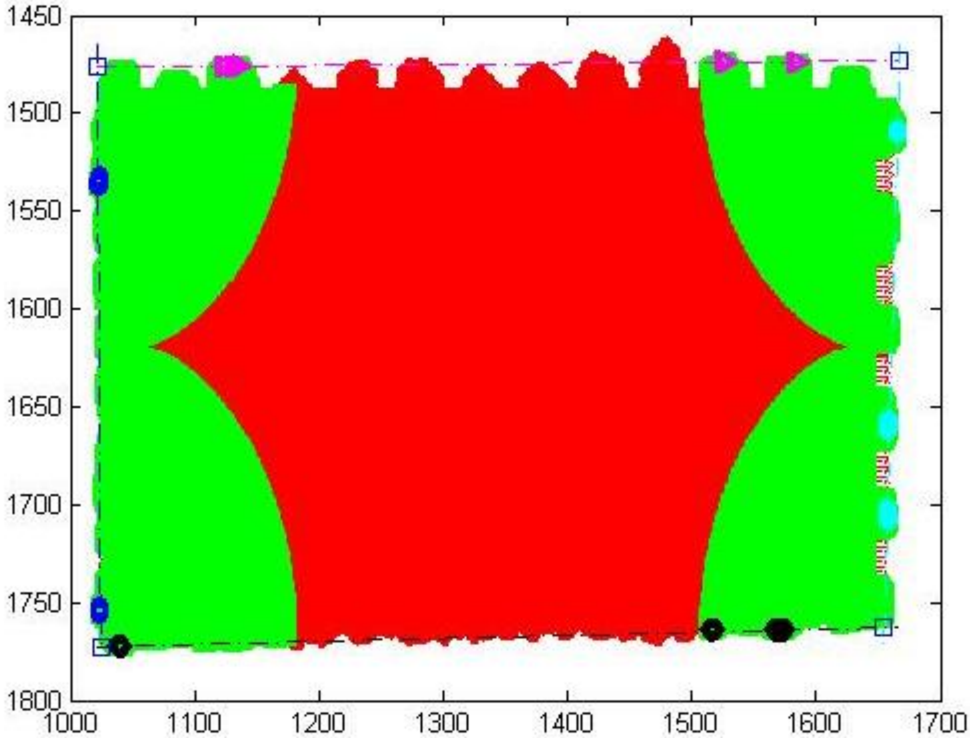


Figure 3.7: Corner Detection with Line Intersection

3.2.2 DECODING DATA REGION ALGORITHM

After detecting the “L” shape finder pattern, we obtain the location of the data matrix and coordinates of the four corner of the invisible 2D Data Matrix in the input image. At the second step of the proposed algorithm, we decode the data region of the invisible 2D Data Matrix by detecting if each cell in data region is dotted or empty. Four corner coordinates of the invisible 2D Data Matrix is used to determine the cell distribution in the image, as shown Figure 3.8. Due to the disorder of the dot sequences in a row of the Invisible 2D Data Matrix, we develop two different approaches for decoding the data region.

In the first approach, since the number of cell is fixed as 10x24 cells in the data region, we set the fixed dot location in the invisible 2D Data Matrix and scan cells row by row and cell by cell to determine if they are dotted or empty. While detecting a cell, we use a global threshold method based on the Otsu's method. Otsu's method is used to automatically get a clustering-based image threshold or the converting the gray-scale input image to a binary image. The algorithm suppose that the image ingredient two classes of pixels follow-up bi-modal histogram (all foreground and background pixels), then (class variance) less spread their mixed will calculate the optimum threshold division the two classes [13]

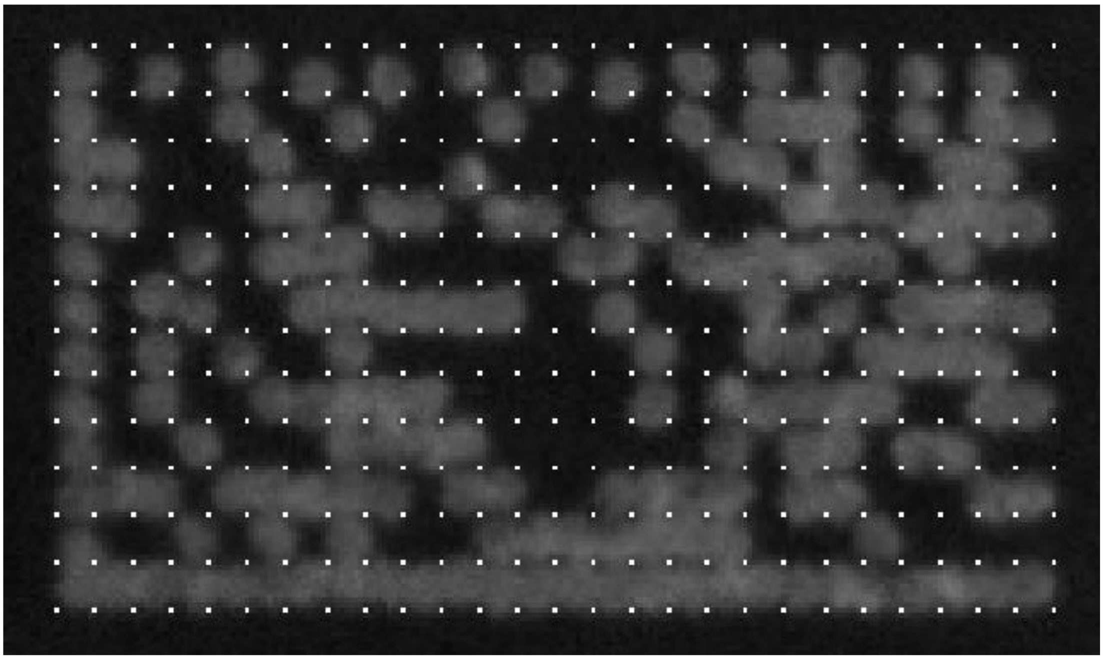


Figure 3.8: Estimated Cell Coordinates

In the second approach, the proposed algorithm follows two steps. In the first step, after specifying a dot's coordinates, we set a cell center to try to estimate whether if specified cell is dotted ("1") or empty ("0"). The disruption of the dot sequence in row by row manner is not considered in this method. For the second approach, the specified cell is detected by the disturbance of the dot sequence in row. In this approach, after determining the coordinates and the center of the cell, the window frame which is set on the dot region is moving only through the y axis to trace centers of dots and blanks.

CHAPTER 4

DATA COLLECTION AND EXPERIMENT RESULT

4.1 INVISIBLE DATA MATRIX CODE COLLECTON

Since invisible data matrix detection is a new research area, there is no open source data provided in the literature. In addition, this thesis presents the first study about the reading the invisible data matrixes by using a smart phone based on our knowledge. Therefore, there is no data available to test our proposed algorithm. To test our proposed algorithm, we designed an invisible data matrix code collection setup, collected several cigarettes boxes and alcoholic beverage caps, and captured images of these boxes and caps with an industrial camera and smart phone camera.

In order to capture the image of the invisible 2D Data Matrix, there are several types of components needed. Invisible 2D invisible Data Matrix visualization system will be embedded to Smart Phones. For the first step of the proposed thesis; the research and development studies should be studied to design a device which is going to be embedded to smartphones and the enhancement of this device is aimed. First, the invisible 2D Data Matrix region is illuminated by a special wavelength light to detect the invisible 2D Data Matrix by smart phones through the developed system.

The most important difficult part is to make the invisible 2D Data Matrix, visible for the camera. To achieve this goal, we first illuminate the invisible data matrix area with a certain wavelength LED light. Since invisible 2D Data Matrices are printed by special pigmented ink which reflects 630 nm wavelength light, 630 nm wavelength LEDs are used for illumination. With the LED illumination, the special pigments on the invisible data matrix area reflects the incoming light and becomes visible at the

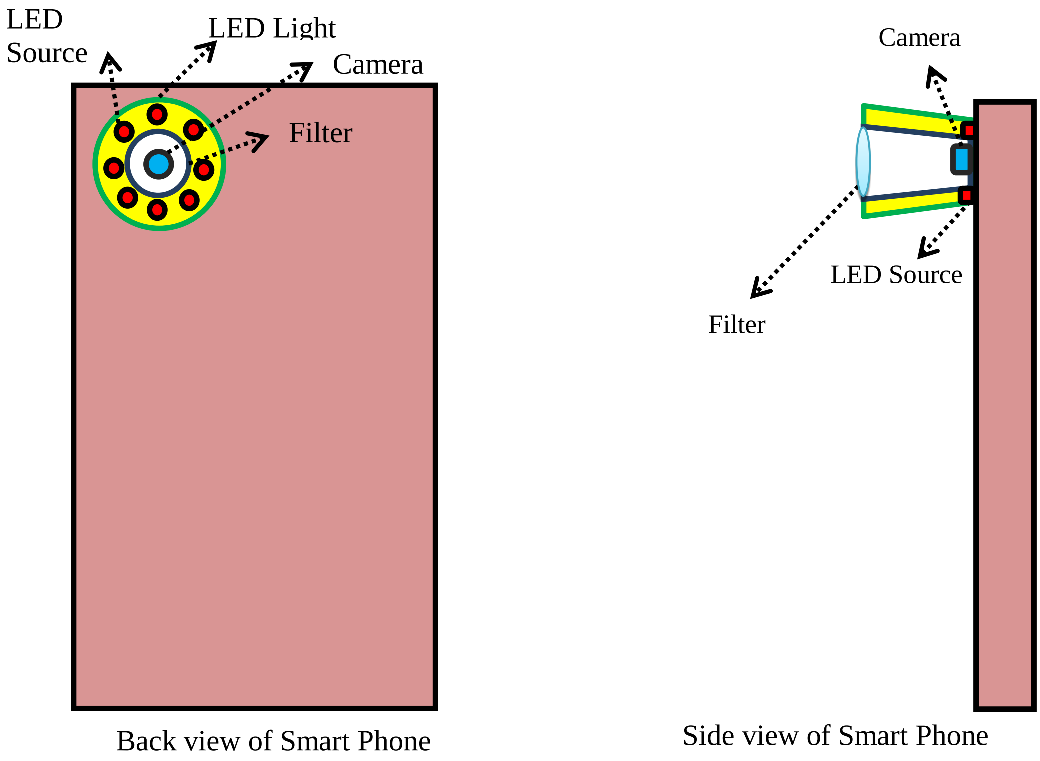


Figure 4.1: Mounting LED and Filter Back of Smart Phone

corresponding wavelength. However, it is not seen by the camera without a band pass filter due to the contrast issues. Then, there should be a filter which is permeable for 630 nm wavelength light and prevents the rest wavelength light, is going to be planted to the device for smart phones for filter the background of the Invisible2D Data Matrix. Therefore, we placed a band pass filter in front of the camera. In order to capture images with smart phone, we used Samsung GT-N7100 (Galaxy Note2). As an industrial camera, we used IDS UI-3240ML-NIR-GL camera is used.

Thus, the invisible 2D Data Matrix image which is reflection of the special pigmented ink provides high gloss. After the recommended brightness and clearness of the image is obtained, the image is taken by smart phone. Due to the distance between invisible 2D Data Matrix and smart phone is close, while taking the image the camera option should be at macro for the ease for focus. If the clearness does not reach to the recommended level, a macro lens that helps to focus can be planted on to the device which will be embedded to smart phone. For this purpose within the project different types of lenses are needed. The initial setup of the invisible 2D Data Matrix visualization system which is going to be embedded to smart phones can be seen in Figure 4.1.

Figure 4.2: Invisible Data Matrix is Shown Naked Eyes

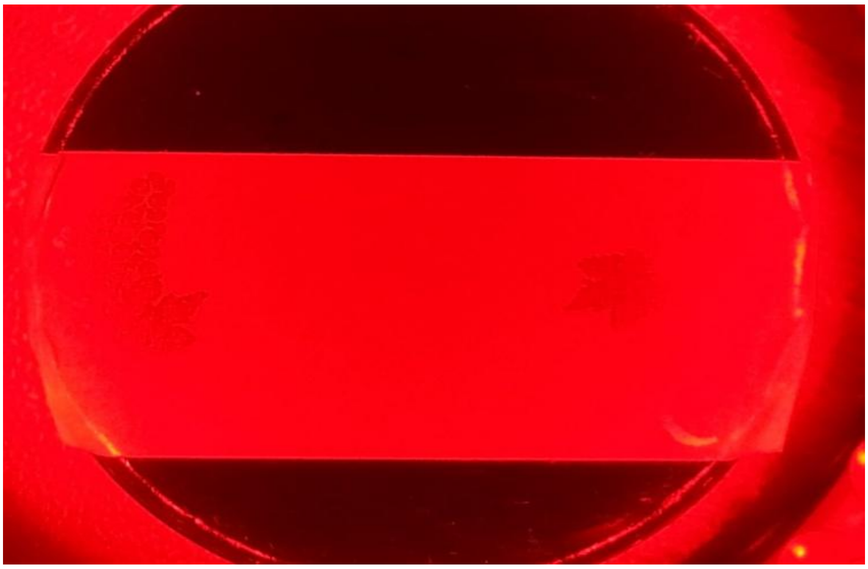


Figure 4.3: Invisible Data Matrix is Shown 630 nm Wave Length Led Illumination.

Figure 4.4: Invisible Data Matrix under 630 nm Wavelength LED Illumination and Filter in front of the camera.

Figure 4.5: LED Source

Figure 4.2 shows the banderol on an alcoholic beverage caps where invisible 2D Data Matrix is embedded on the banderol attached on the cap. As seen, the invisible data matrix is cannot be seen by naked eyes in day light. In Figure 4.3 the banderol is shown under illumination which has 630 nm wavelengths LED light. In this figure, there is nothing significant to see with naked eye because of the contrast. Therefore, it shows that there should be any other components to catch the invisible 2D Data Matrix.

Figure 4.4 shows the filtered vision of banderol under 630 nm wavelength led light. By the help of a 630 nm wavelength band pass filter that allows to pass only the light around 630nm wavelength, the invisible 2D Data Matrix becomes visible and camera can capture the image of the invisible data matrix. The reason for black and gray tone colors of the image is the smart phone camera options were adjusted to mono color mode for color effect, night mode for light mode, fluorescent for white balance and macro focus mode.

In Figure 4.5, a group of four LED is shown that is mounted on a circle circuit with heat sink. The holder is used to hold the LED light and smart phone without vibration above the banderole that has an invisible Data Matrix on it. The holder allows to adjust the distance between the smart phone and the banderole by moving up and down direction as shown in Figure 4.6. Figure 4.7 shows the procedure of capturing an invisible 2D Data Matrix where all explained components above is used. We supply 800 mA current and 2.5 V voltage to the LED group.

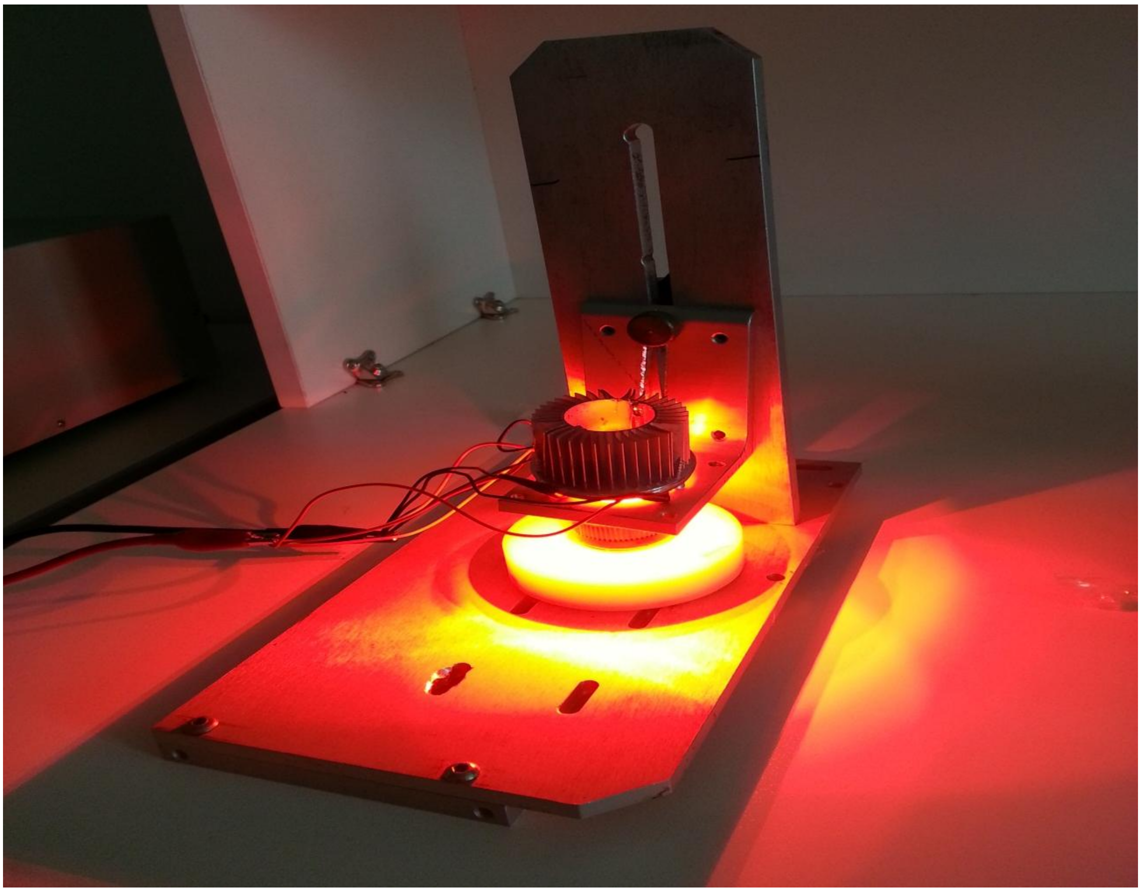


Figure 4.6: The Holder

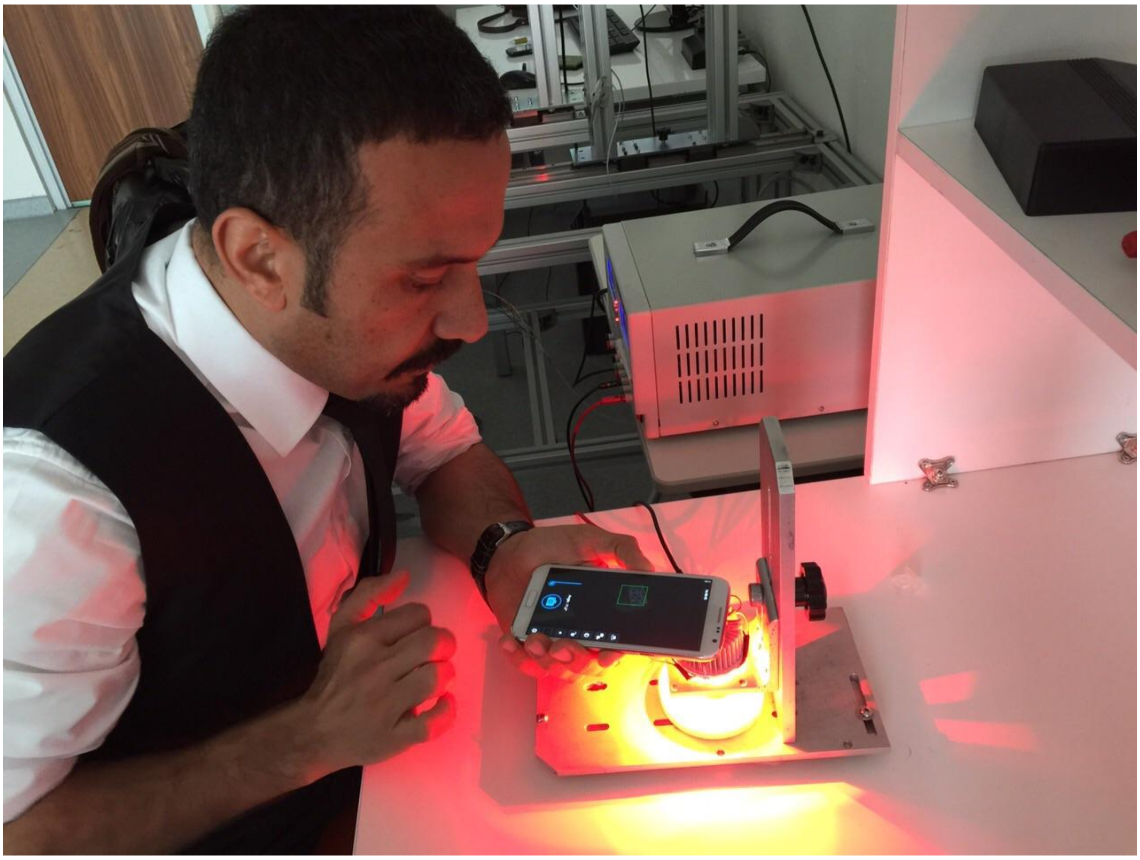


Figure 4.7: Working in Progress

4.2 EXPERIMENTAL RESULT

In this part, we study on two different types of images which are captured by two different cameras, including industrial camera and smart phone camera. Industrial camera and smart phone camera images are tested with the proposed algorithm. IDS UI-3240ML-NIR-GL model used for as an industrial camera. IDS camera has CMOS mono sensor 1.31 Mpix and 1280x1024 resolutions. IDS camera is capturing images with 8.69 mm (1/1.84") diagonal optical sensor 60 frame per second. IDS camera has specific properties for industrial vision applications. On the other hand, results of IDS camera are better than smart phone. We used Samsung GT-N7100 (Note II) for the data capture with smart phone camera. The main purpose of using industrial camera is to generate a ground truth results to compare with images captured with the smart phone camera by testing our proposed algorithm. Since the industrial camera has better quality of imaging sensors, lens and variable iris, the captured images with industrial camera is better quality than the smart phone camera with less noisy and better contrast. Therefore, the results of the proposed algorithm are better in industrial camera than smart phone camera.

We captured images from 10 alcoholic beverages caps and 15 cigarettes boxes and created our datasets with these images. Location and orientation of the invisible data matrix printed on the banderoles can be changes. We did not force their location and orientation for a specific value to make it a real scenario.

4.2.1 Performance Metrics for Proposed Algorithms

To show the performance of the proposed algorithm, we generate the confusion matrix for each result coming from the proposed algorithm tested with each images in our dataset. Confusion matrix is a table that is used to describe the performance of a classification algorithm on a set of test data for which the true values are known. General represent of confusion matrix as shown in Figure 4.8. Standard operand have been determined for the confusion matrix [14]: *Accuracy* (AC) which is the ratio of the total number of correct predictions. R*ecall or true positive rate* (TP) is the percentage of positive cases were detected correctly identified. *True negative rate* (TN) is the percentage of negatives cases were detected correctly identified. *False negative rate* (FN) is the proportion of positives cases that were incorrectly classified as negative. Finally, *precision* (P) is the proportion of the predicted positive cases that were correct.

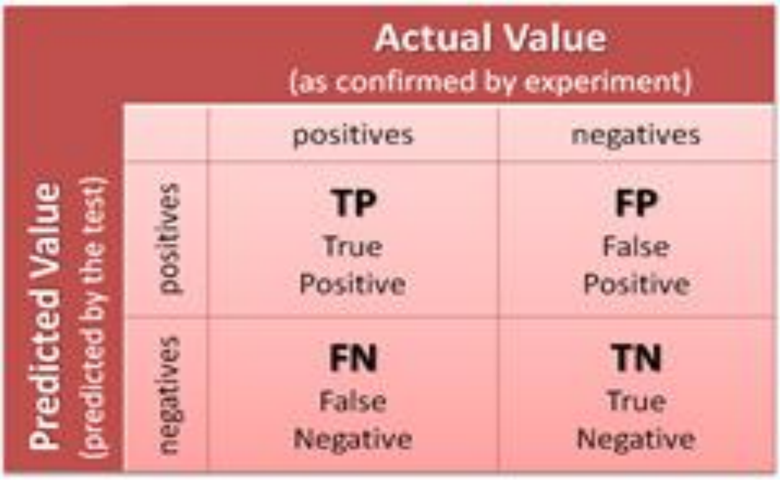


Figure 4.8: Confusion Matrix

Table 4.2.1: Confusion Matrix of Smart Phone Camera's 3rd Sample

		ACTUAL	
PREDICTED		Ones Positive	Zeros Negative
	Ones Positive	171 TP	0 FP
	Zeros Negative	2 FN	139 TN

In Table 4.2.1, the confusion matrix of smart phone camera's 3rd sample is shown. Positive elements are used for ones where a cell is dotted; negative elements denotes to zeros where a cell is empty. Accuracy is calculated as in Eq. 2,

$$Accuracy = \frac{\text{TP+TN}}{\text{TP+FP+FN+TN}} \tag{2}$$

$$Recall = \frac{\text{TP}}{\text{FN+TN}} \tag{3}$$

$$True\ Negative\ Rate\ = \frac{TN}{TN+FN} \tag{4}$$

$$False\ negative\ rate\ = \frac{\text{FN}}{\text{FN+TN}} \tag{5}$$

$$Precision\ = \frac{\text{TP}}{\text{TP+FP}} \tag{6}$$

$$Accuracy = \frac{179 + 139}{179 + 0 + 2 + 139} = \ 0.99375$$

$$Recall = \frac{171}{2+171} = 0.98843$$

$$True\ Negative\ Rate = \frac{139}{139+2} = 0.98581$$

$$False\ Negative\ Rate = \frac{2}{2+139} = 0.01418$$

$$Precision = \frac{171}{171+0} = 1$$

Result of the accuracy show that the proposed algorithm has a high correct rate when it is tested with our dataset. The recall is called true positive rate that means to capture 139 dots out of the 141 dots. The true negative rate is too small value that means all predicted negatives (zeros) are too close to actual negative (zeros). The false negative rate is too small value that means all predicted negatives (zeros) errors number is adoptable. The precision is one that means all predicted positives (ones) numbers are same ground truth.

4.2.2 Results of Industrial Camera Data

The proposed algorithm is tested with four images that are captured with the IDS UI-3240ML series industrial camera where two images comes from the banderol of the alcohol beverages cap and the other two are from the tobacco banderol.

We provide the results of each test images in Figure 4.9-4.12. In each figure, input images are shown on upper left corner, resultant confusion matrix is shown in upper right corner, each ground truth result is show in lower left corner, and each result of the proposed algorithm is shown in lower right corner of the figure. Ground truth result shows correct result of all empty and dotted cells. In order to cross check the ground truth and result sample, we showed them next to each other.

Confusion matrix provides the number of empty cells detected as empty and the number of dotted cells detected as dotted cell. In addition, the error can be obtained from the confusion matrix. Due to the quality of the image which is taken by the industrial camera, the total error in the confusion matrix is zero.

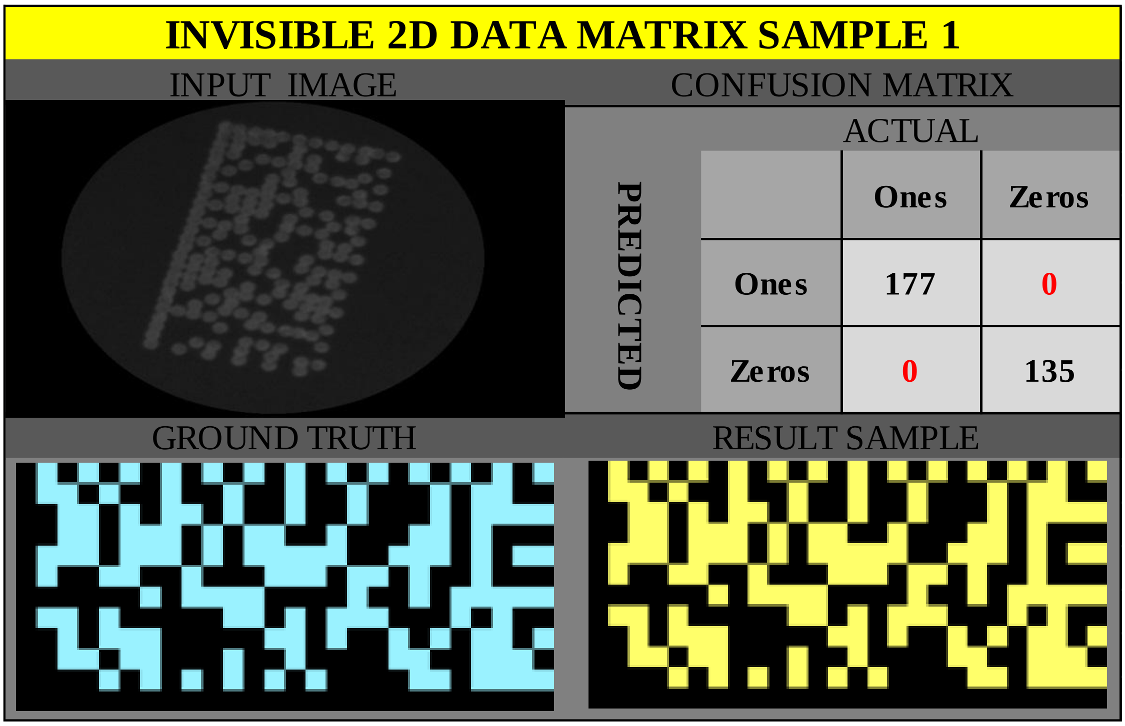


Figure 4.9: 1th Test Image Captured with the Industrial Camera

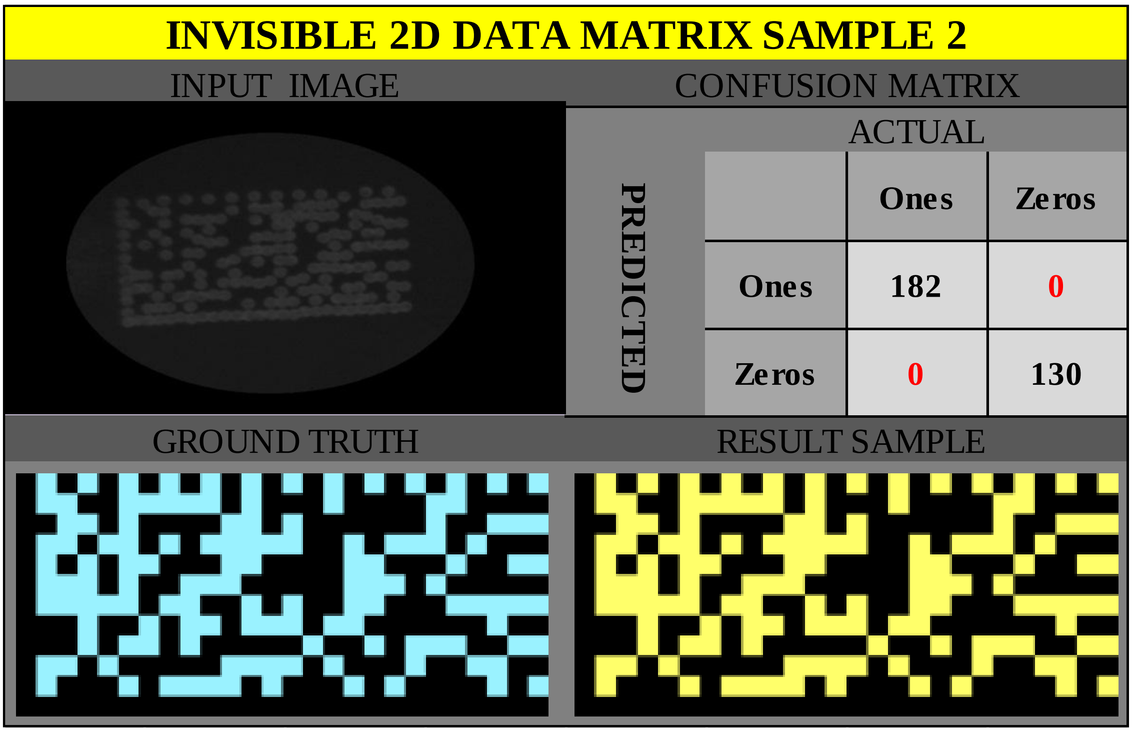


Figure 4.10: 2nd Test Image Captured with the Industrial Camera

As shown in Figure 4.9 and 4.10, the proposed algorithm finds all 312 dots in the 12x26 rectangular matrix. 76 dots used for “L” shape finder pattern and dashed border. In the data region, 1st test image has 177 ones and 135 zeros. 2nd test image has 182 ones and 130 zeros. The algorithm finds all dots and shows 100% accuracy rate.

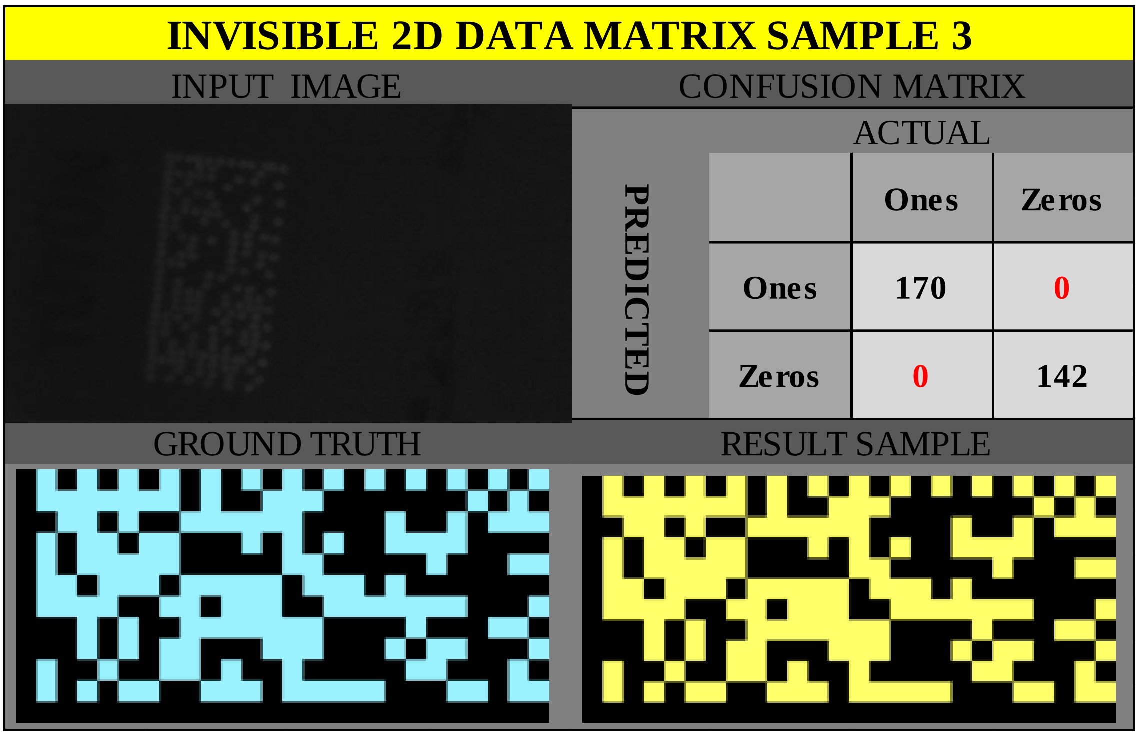


Figure 4.11: 3rd Test Image Captured with the Industrial Camera

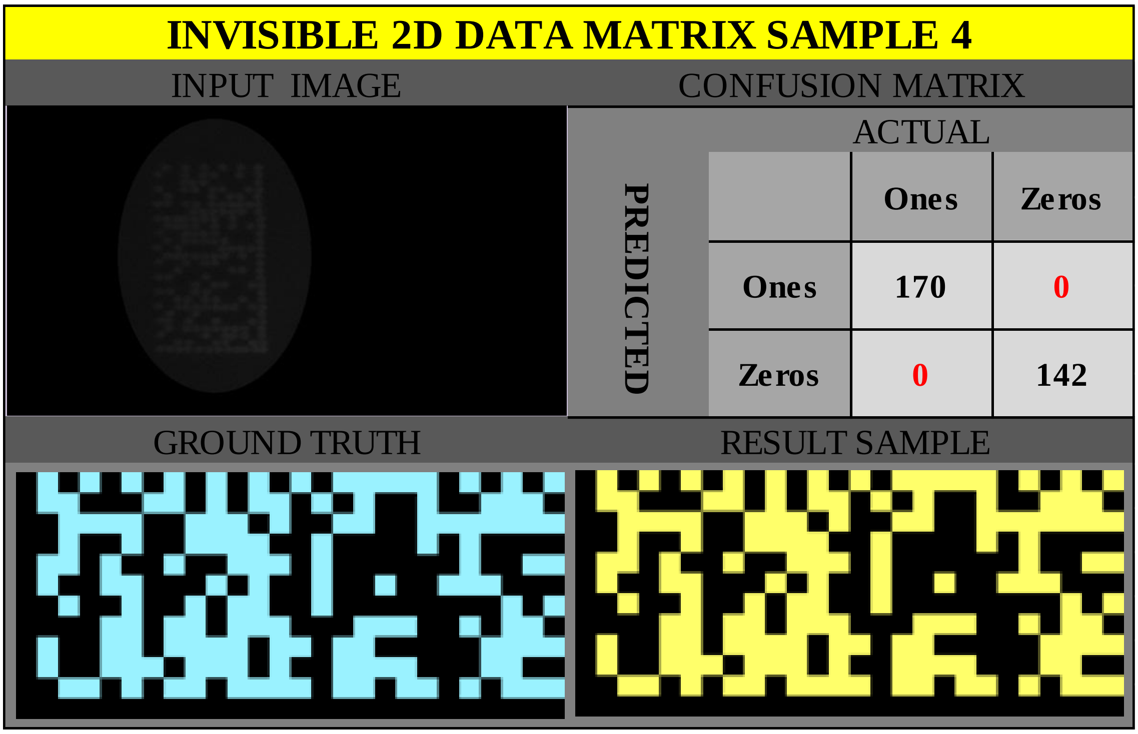


Figure 4.12: 4th Test Image Captured with the Industrial Camera

As shown in Figure 4.9 and 4.10, 3rd test image has 170 ones (dotted) and 142 zeros (not dotted). 2nd test image has 170 ones and 142 zeros. The algorithm finds all modules and shows 100% accuracy rate.

OVERALL CONFUSION MATRIX			
		ACTUAL	
PREDICTED		Ones	Zeros
	Ones	699	0
	Zeros	0	549

Figure 4.13: Overall Confusion Matrix for IDS Camera's Result

We observed that the proposed algorithm gives 100% accuracy for these four sample images as shown in overall confusion matrix in Figure 4.13. Each empty cell in data region of the invisible matrix is detected as empty and each dotted cell in data region of the invisible matrix is detected as dotted.

4.2.3 Results of Smart Phone Camera Dataset

In this subsection, the proposed algorithm is tested with 25 test images that are captured with the camera of a Samsung GT-N7100 (Note II) smart phone where 10 images comes from the banderol of the alcohol beverages cap and the 15 images are from the tobacco banderol.

We provide the results of each test images in Figure 4.15-4.39. Ground Truth image shows the correct results generated by the user manually. Cross check of the ground truth and result sample is used to generate the confusion matrix. As shown in overall confusion matrix in Figure 4.14, we observed that the proposed algorithm shows a high accuracy for the images captured by the camera of the smart phone.

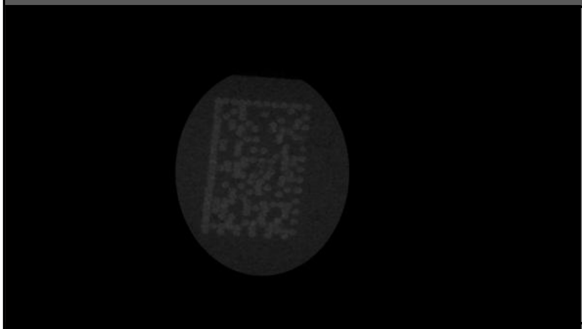
We also observed that there exist some errors where zeros are detected as ones and ones are detected as zeros. We checked the errors and observed that center of the dotted cell is shifted too much as half of the dot moved to other cell. This is caused by the low printing quality of the invisible data matrix. During the print procedure of the invisible 2D Data Matrix, inkjet's printing head spread the dots around or spray the ink out of the cell boarders. Therefore, it is the difficulty to detect these types of problematic cells in the invisible 2D Data Matrix.

OVERALL CONFUSION MATRIX		
PREDICTED \ ACTUAL	**Ones**	**Zeros**
Ones	**4304**	**18**
Zeros	**6**	**3472**

Figure 4.14: Overall Confusion Matrix for Smart Phone's Results

INVISIBLE 2D DATA MATRIX SAMPLE 1

INPUT IMAGE



CONFUSION MATRIX

PREDICTED \ ACTUAL	**Ones**	**Zeros**
Ones	**163**	**1**
Zeros	**0**	**148**

GROUND TRUTH

RESULT SAMPLE

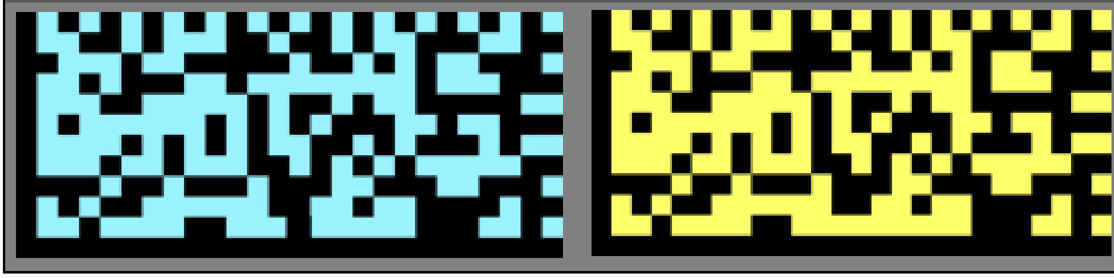


Figure 4.15: 1th Test Image Captured with the Smart Phone Camera

Since the lack of adjustable lens in the smart phone, the quality of the images captured by the smart phone camera is less than industrial camera image. The noise at the background and neighbor cells of empty cells and the inkjet's printing errors are become significant problem for detecting and decoding the invisible 2D Data Matrix. The threshold method which we are using provides us the best utilizable vision of the invisible 2D Data Matrix.

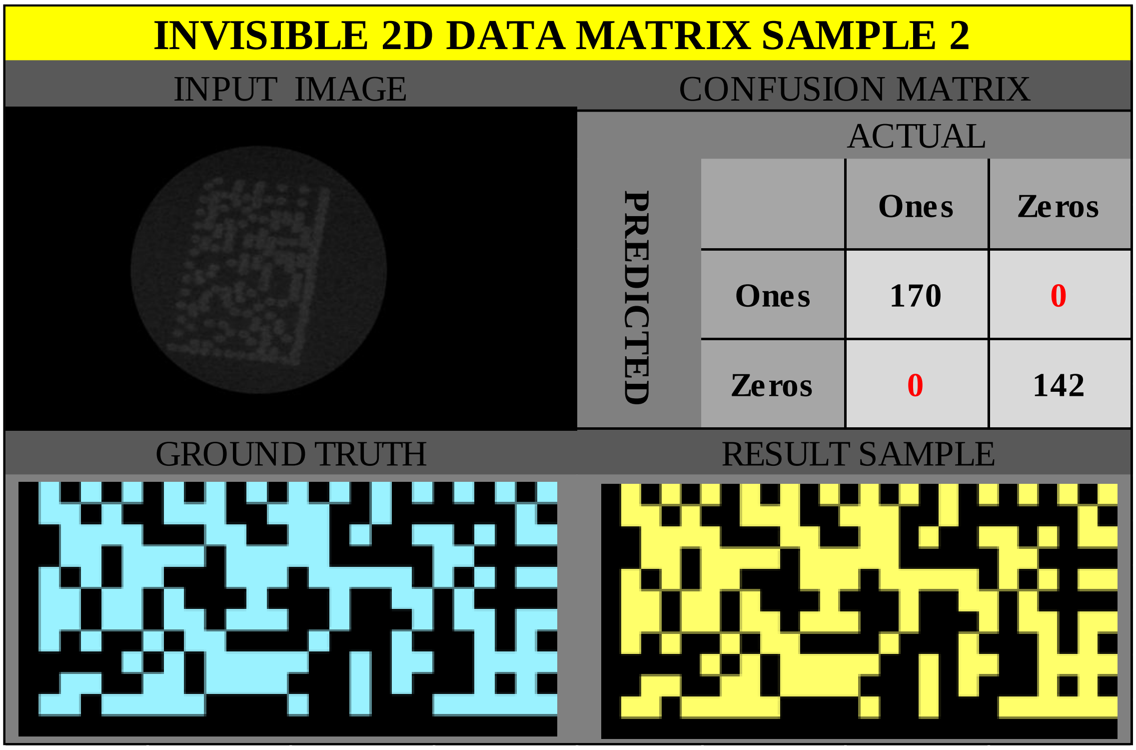


Figure 4.16: 2nd Test Image Captured with the Smart Phone Camera

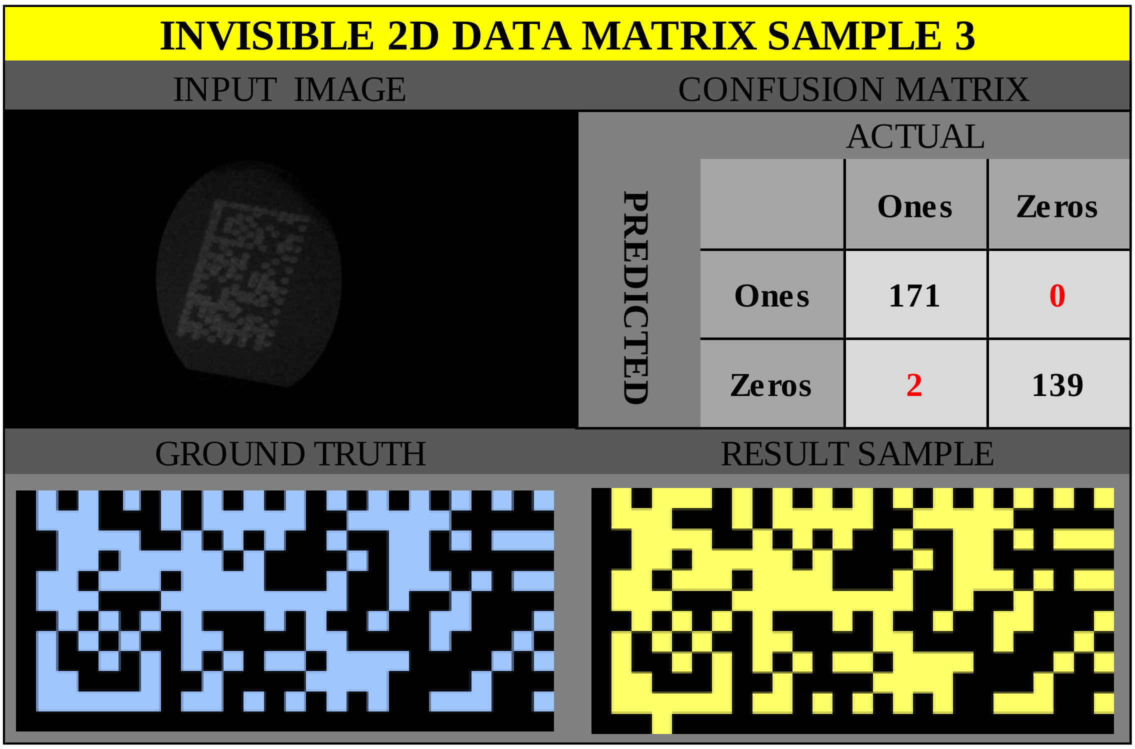


Figure 4.17: 3rd Test Image Captured with the Smart Phone Camera

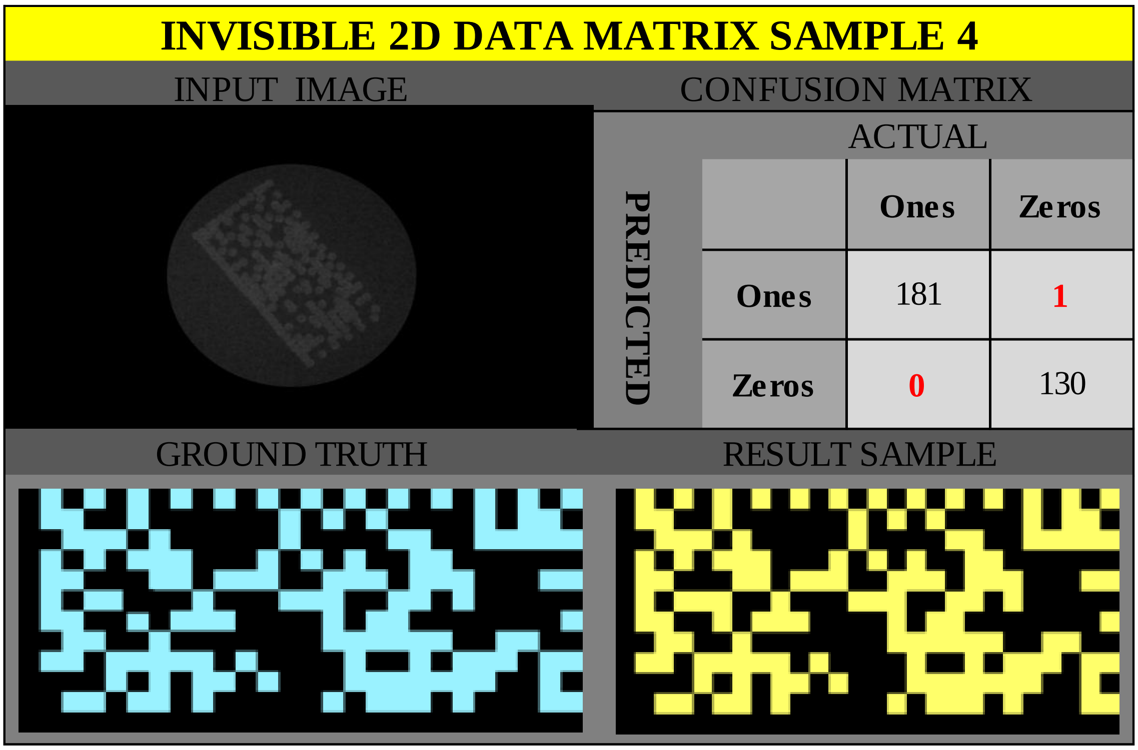


Figure 4.18: 4th Test Image Captured with the Smart Phone Camera

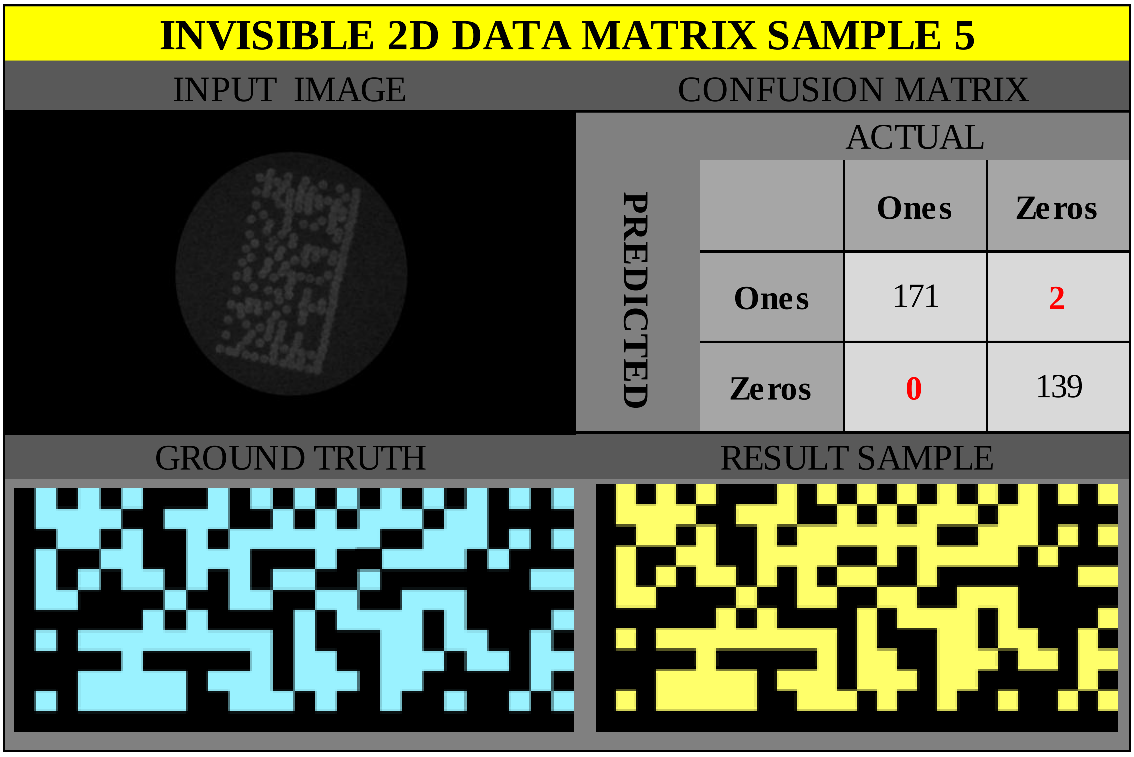


Figure 4.19: 5th Test Image Captured with the Smart Phone Camera

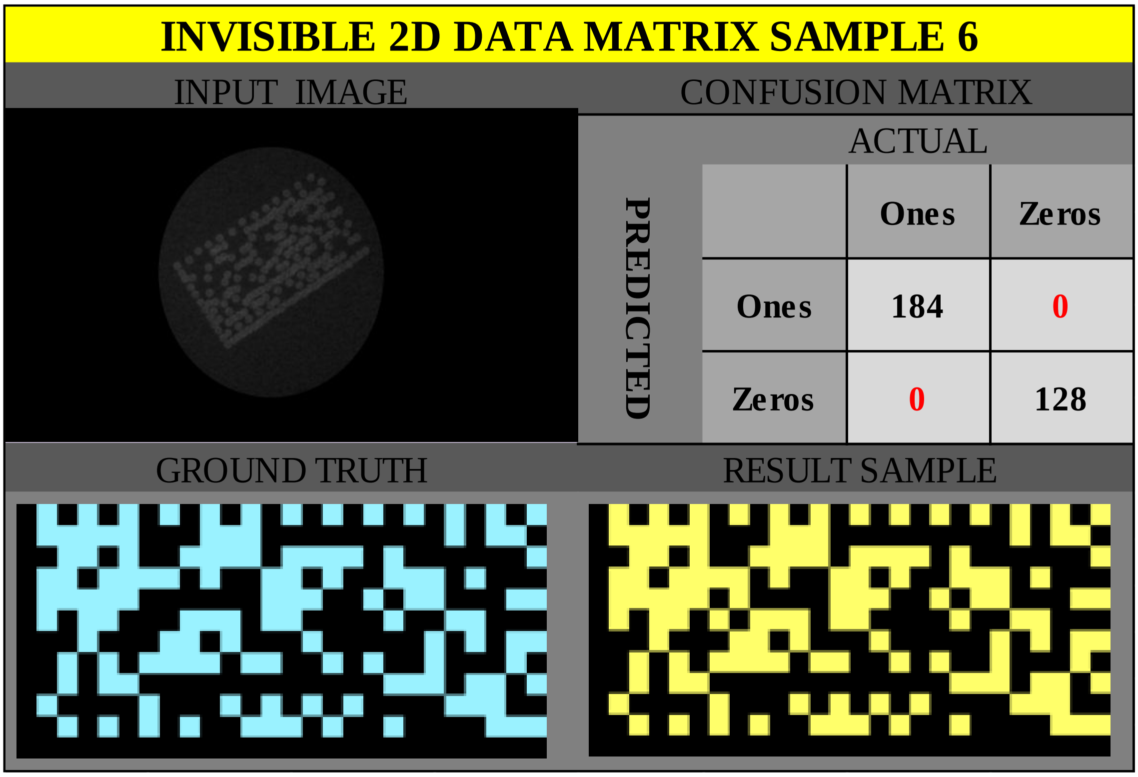


Figure 4.20: 6th Test Image Captured with the Smart Phone Camera

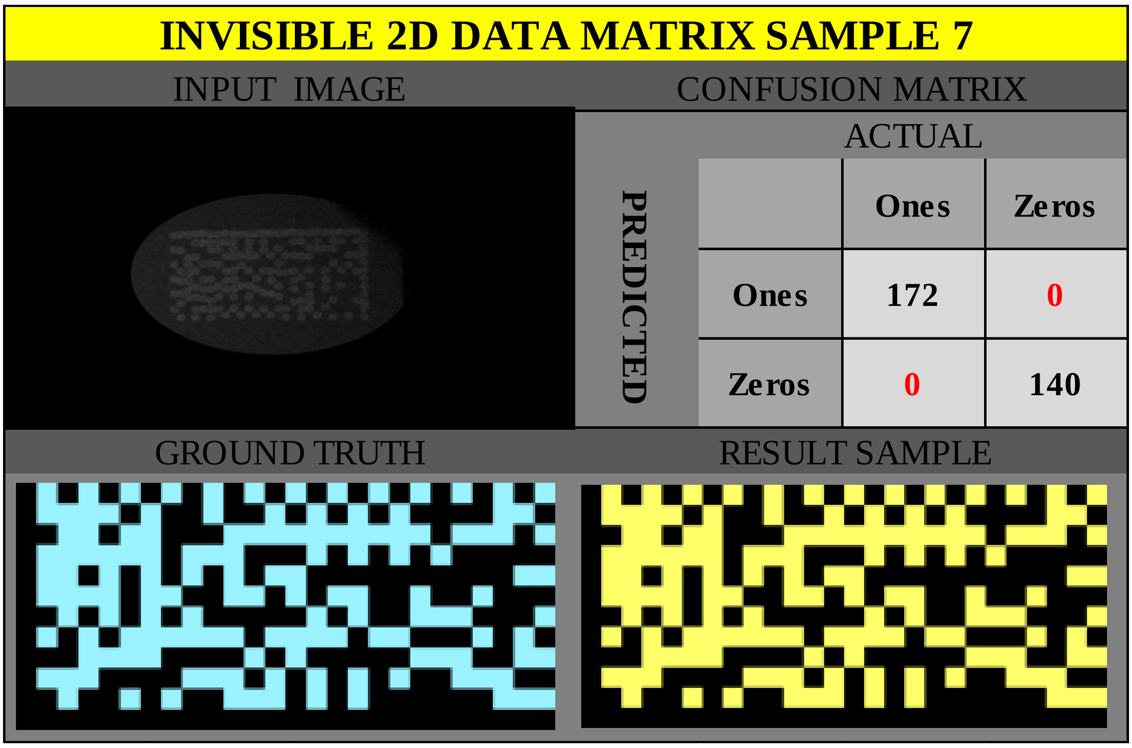


Figure 4.21: 7th Test Image Captured with the Smart Phone Camera

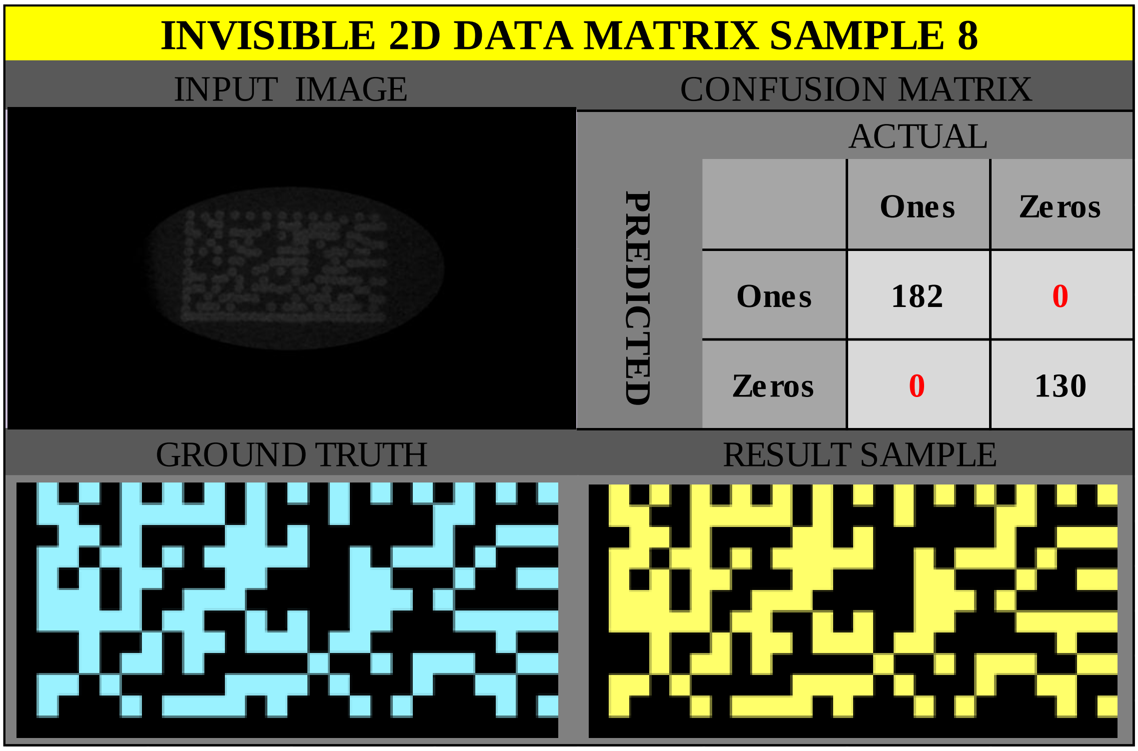


Figure 4.22: 8th Test Image Captured with the Smart Phone Camera

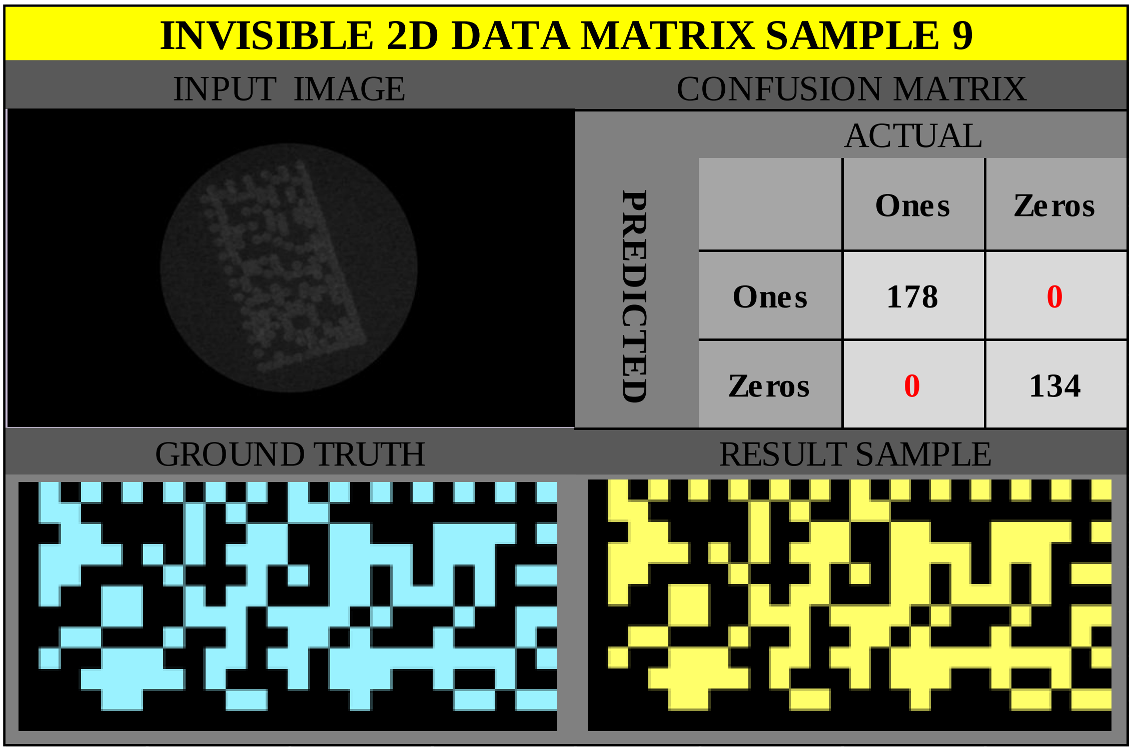


Figure 4.23: 9th Test Image Captured with the Smart Phone Camera

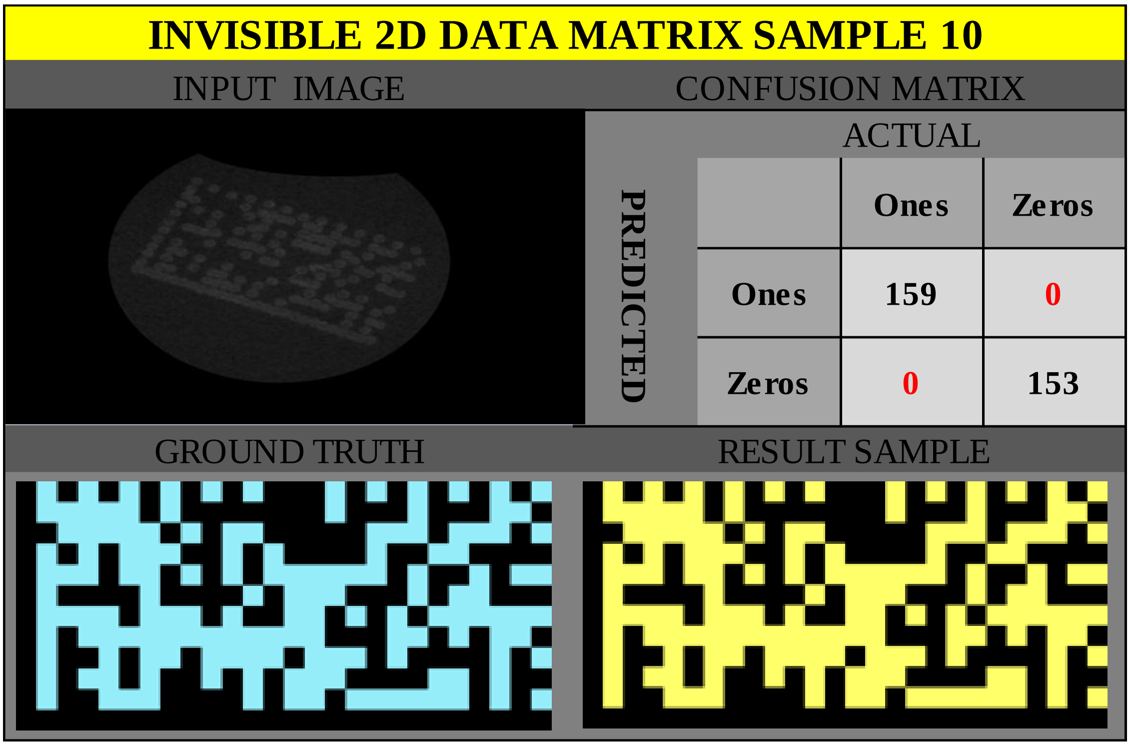


Figure 4.24: 10th Test Image Captured with the Smart Phone Camera

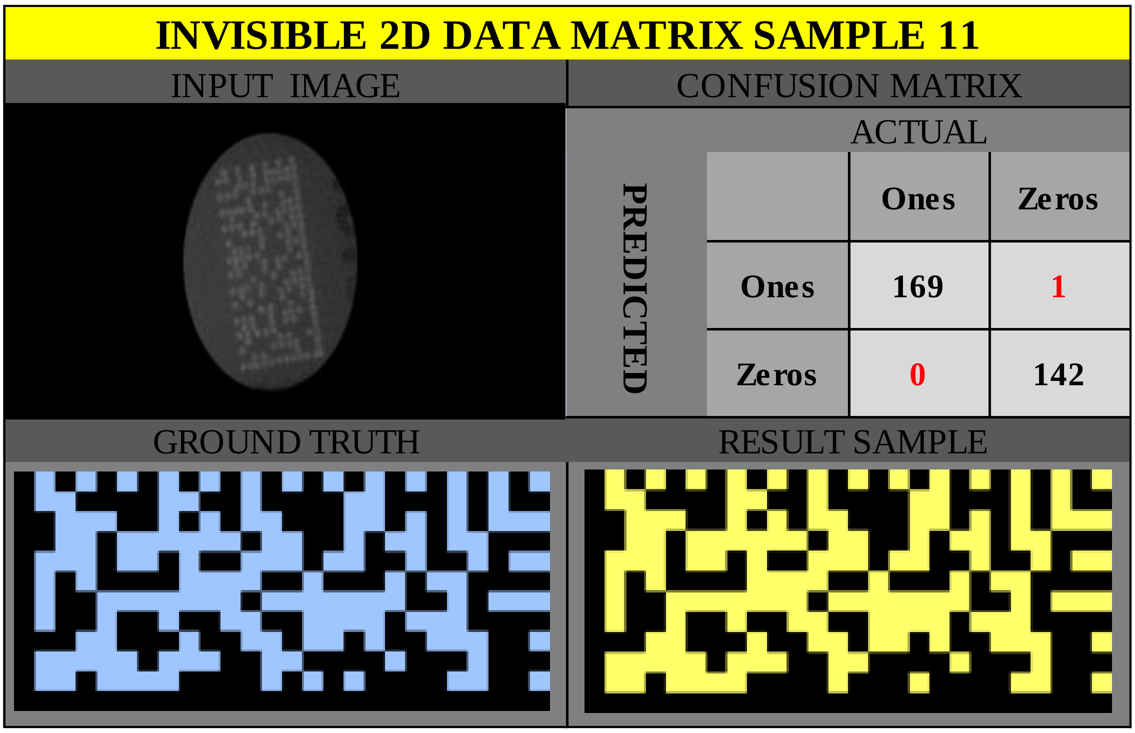
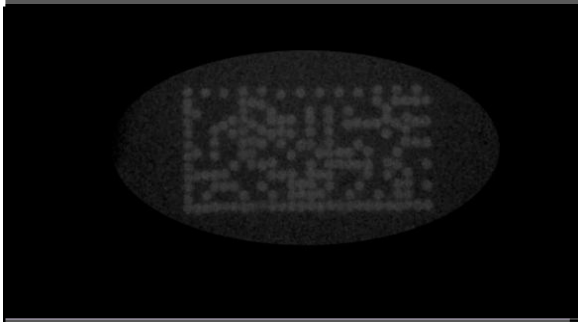


Figure 4.25: 11th Test Image Captured with the Smart Phone Camera

INVISIBLE 2D DATA MATRIX SAMPLE 12

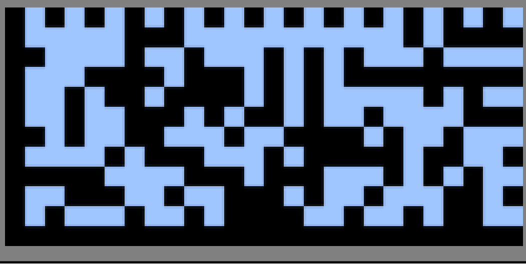
INPUT IMAGE



CONFUSION MATRIX

PREDICTED \ ACTUAL	Ones	Zeros
Ones	165	0
Zeros	0	147

GROUND TRUTH



RESULT SAMPLE

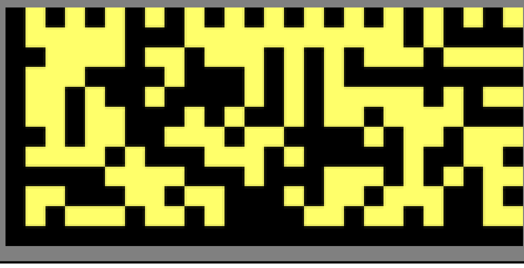
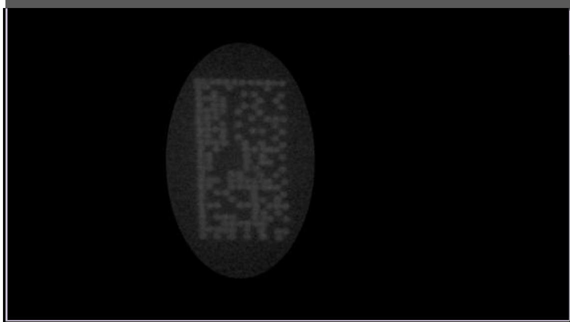


Figure 4.26: 12th Test Image Captured with the Smart Phone Camera

INVISIBLE 2D DATA MATRIX SAMPLE 13

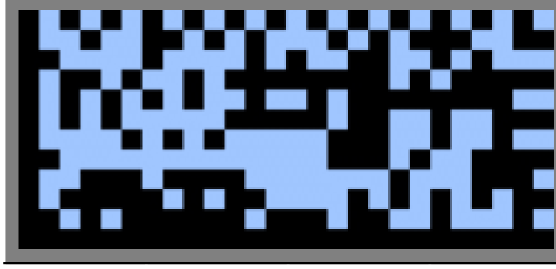
INPUT IMAGE



CONFUSION MATRIX

PREDICTED \ ACTUAL	Ones	Zeros
Ones	171	0
Zeros	0	141

GROUND TRUTH



RESULT SAMPLE

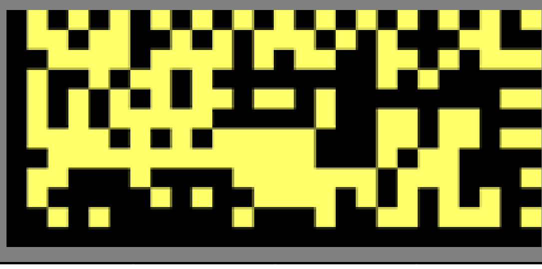


Figure 4.27: 13th Test Image Captured with the Smart Phone Camera

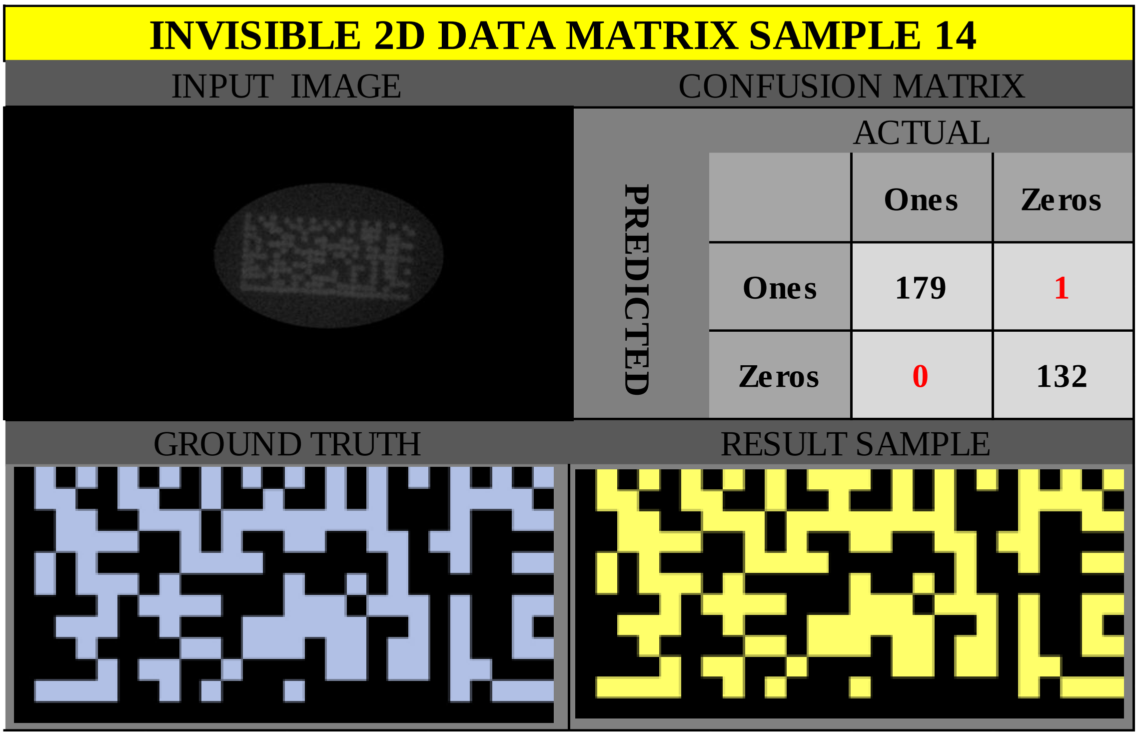


Figure 4.28: 14th Test Image Captured with the Smart Phone Camera

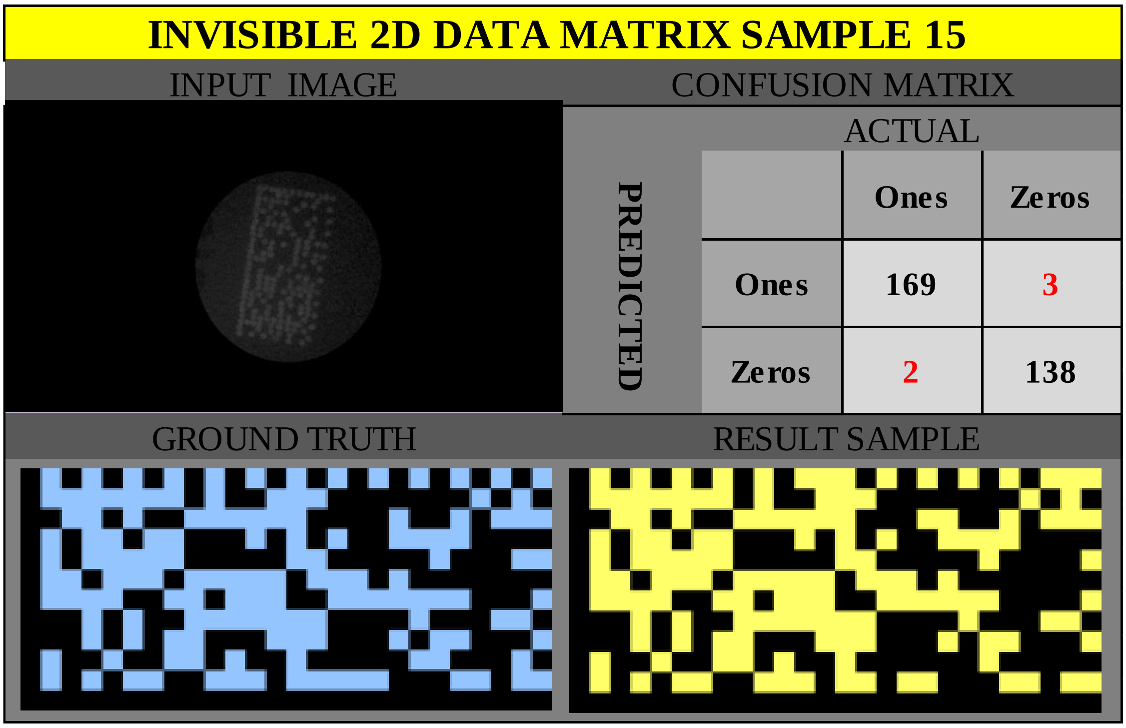


Figure 4.29: 15th Test Image Captured with the Smart Phone Camera

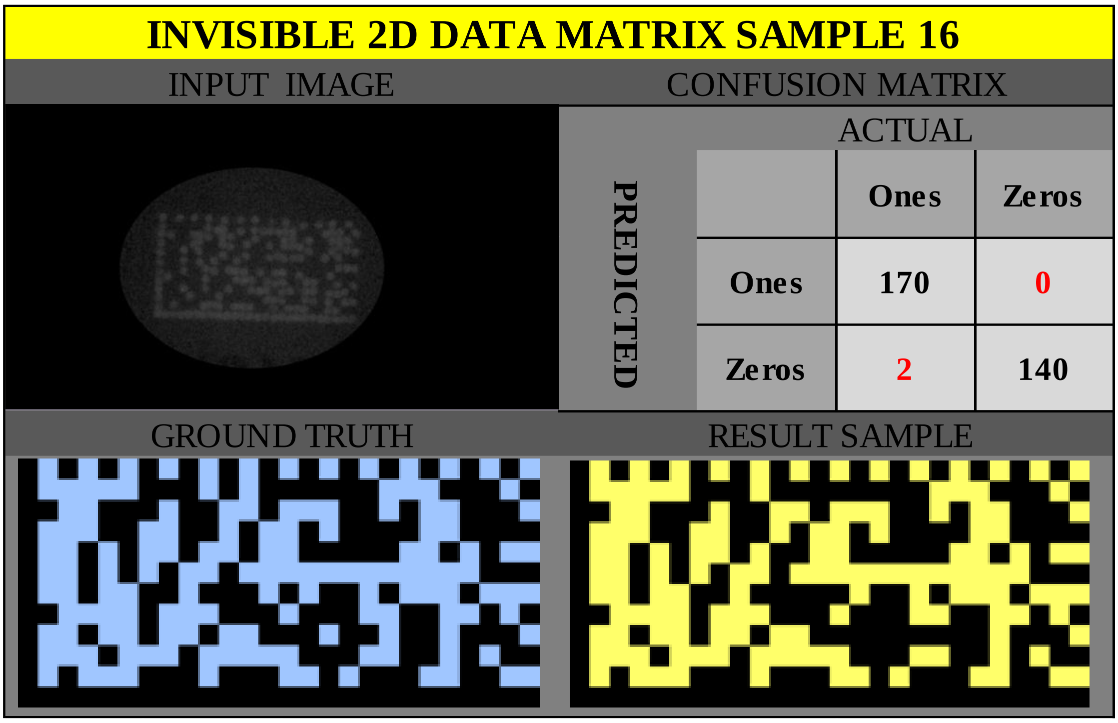


Figure 4.30: 16th Test Image Captured with the Smart Phone Camera

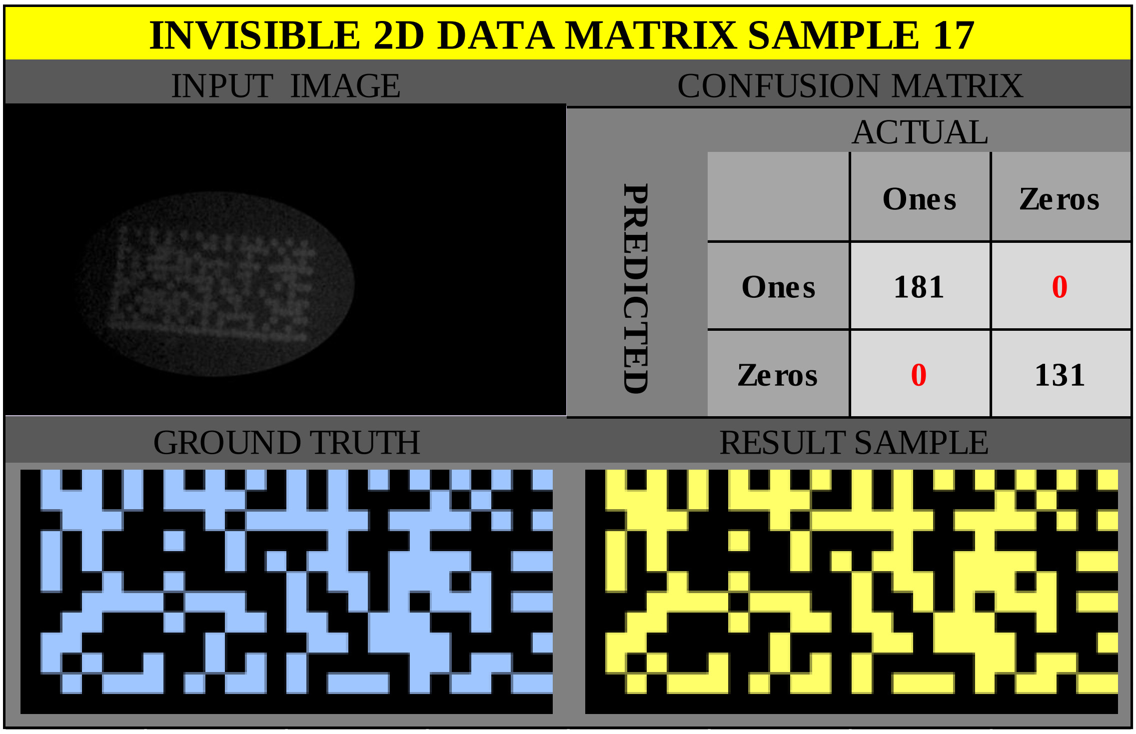


Figure 4.31: 17th Test Image Captured with the Smart Phone Camera

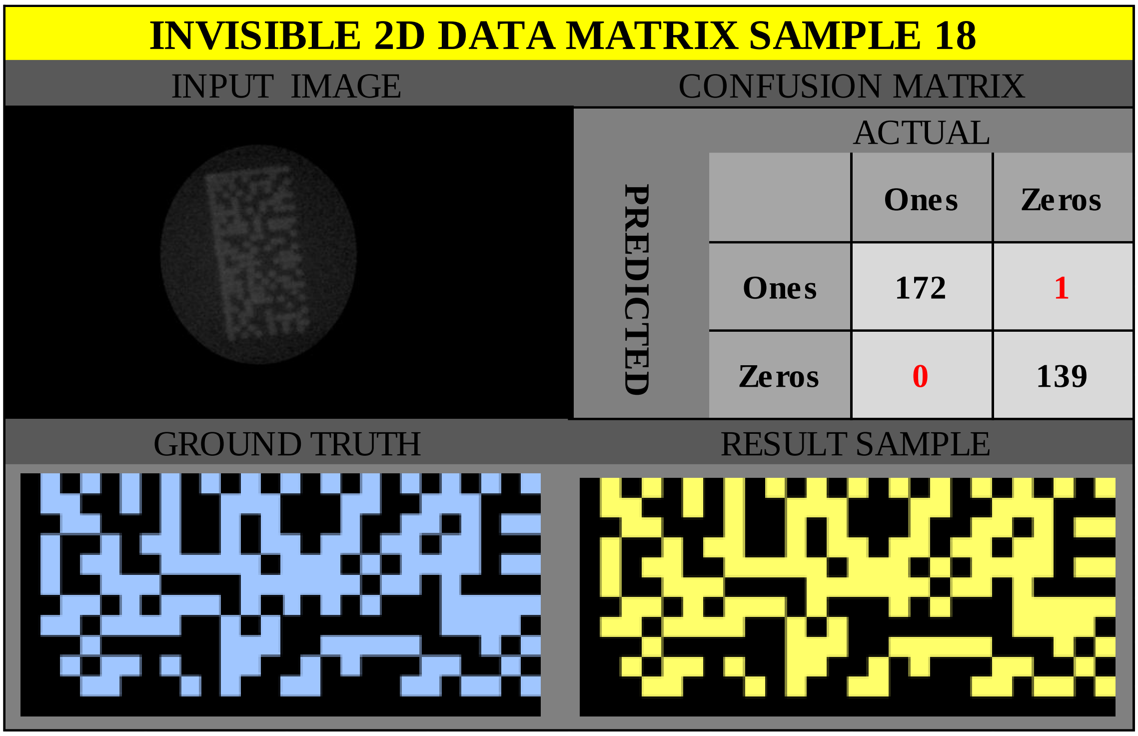


Figure 4.32: 18th Test Image Captured with the Smart Phone Camera

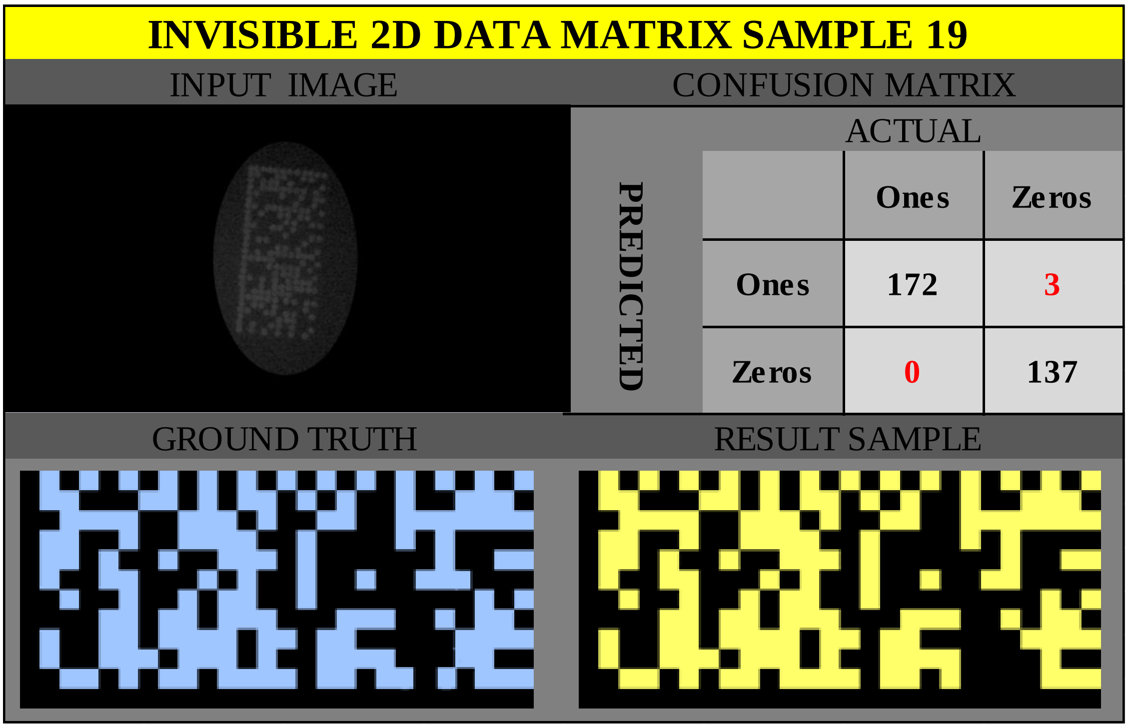


Figure 4.33: 19th Test Image Captured with the Smart Phone Camera

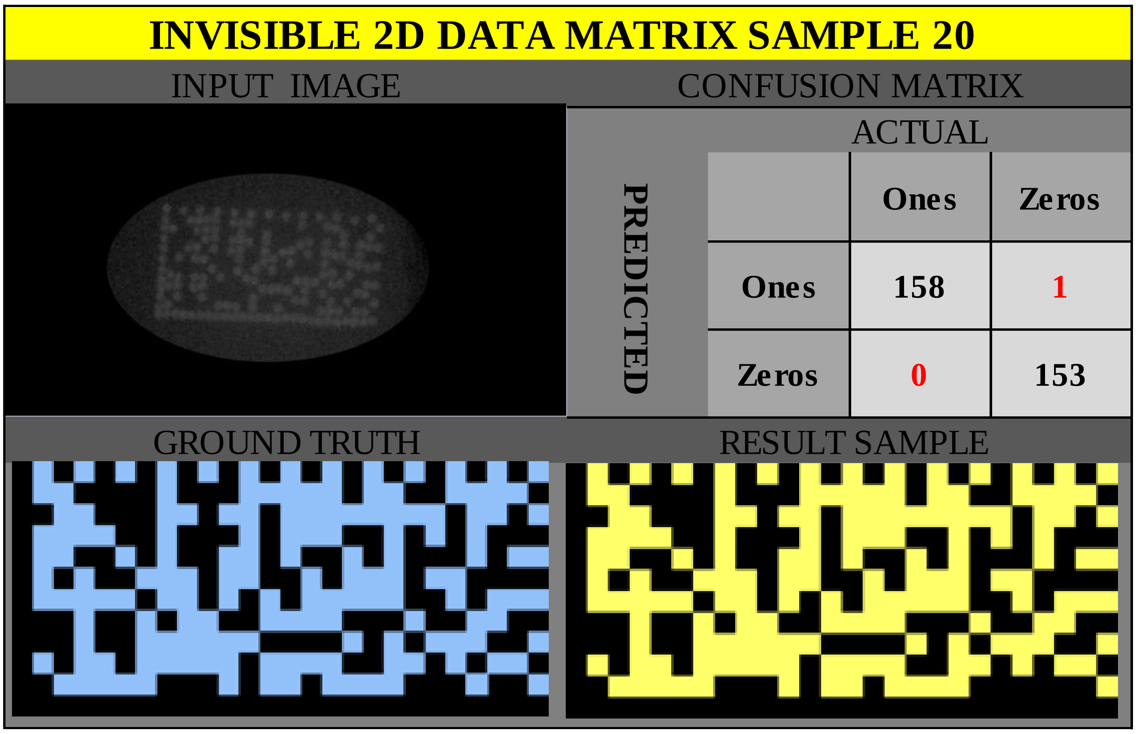


Figure 4.34: 20th Test Image Captured with the Smart Phone Camera

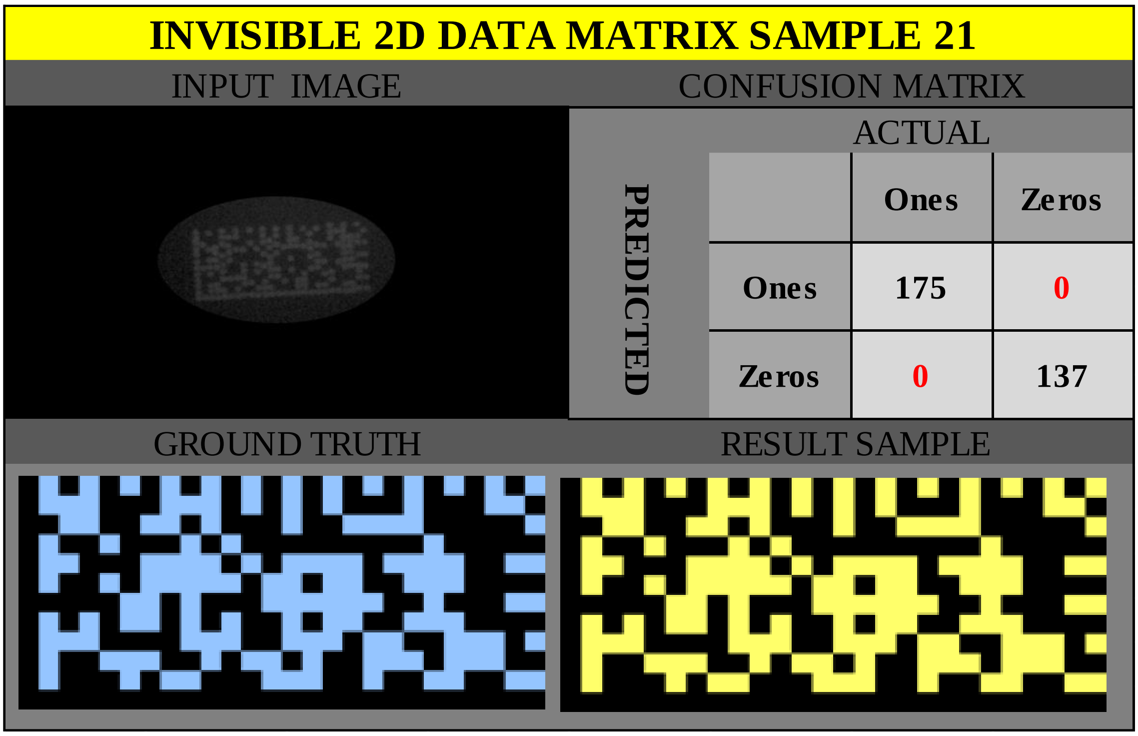


Figure 4.35: 21th Test Image Captured with the Smart Phone Camera

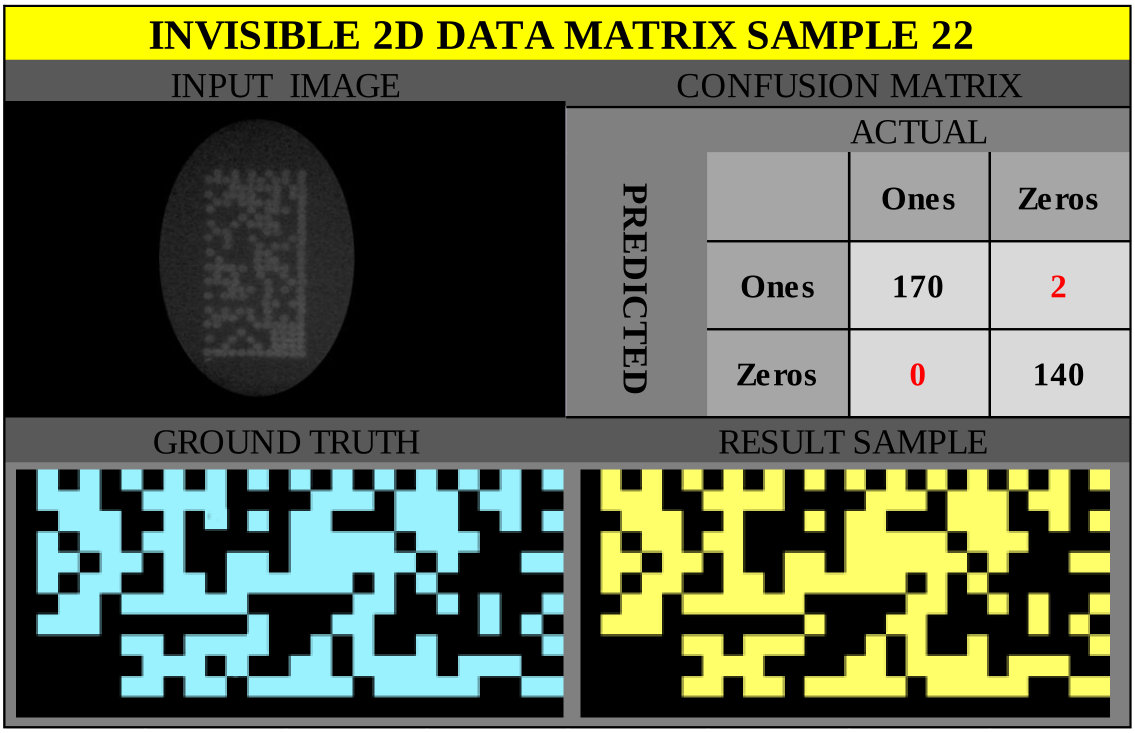


Figure 4.36: 22th Test Image Captured with the Smart Phone Camera

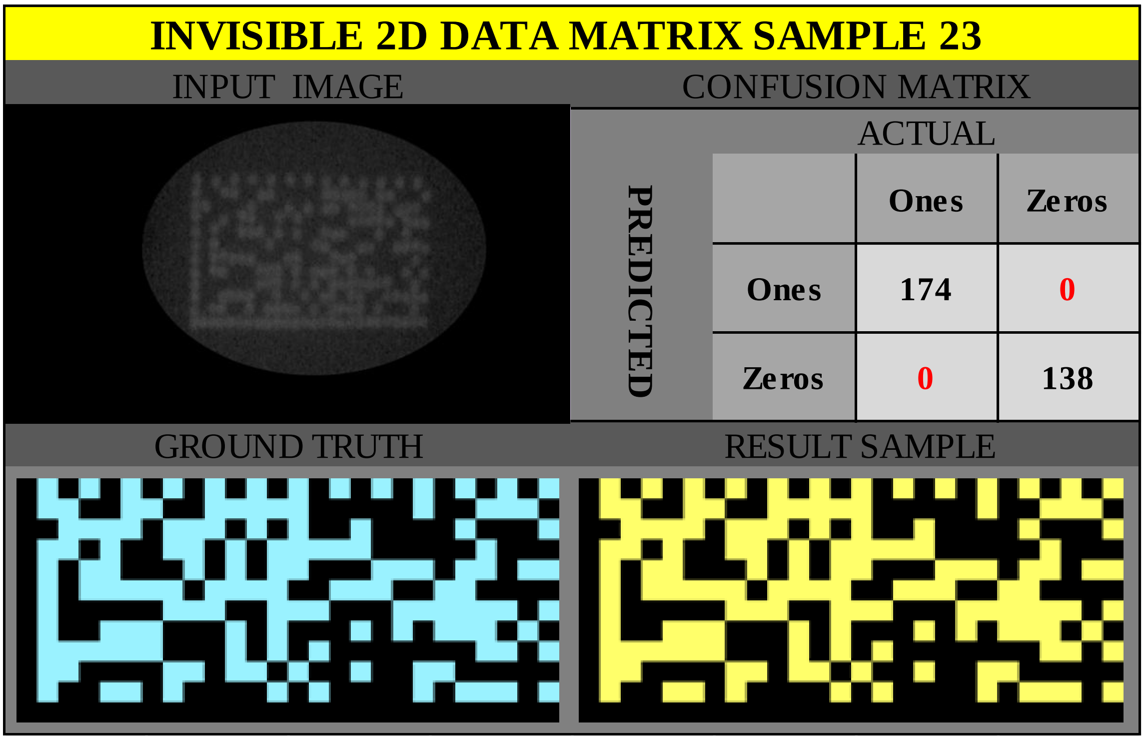


Figure 4.37: 23rd Test Image Captured with the Smart Phone Camera

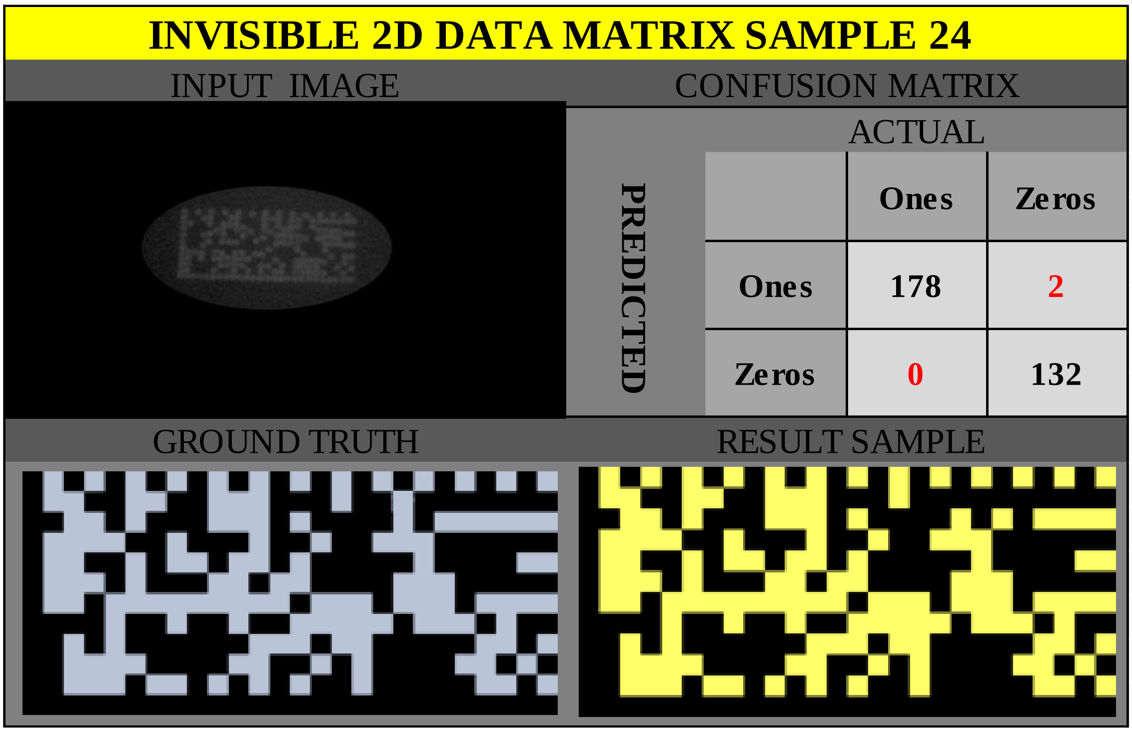


Figure 4.38: 24th Test Image Captured with the Smart Phone Camera

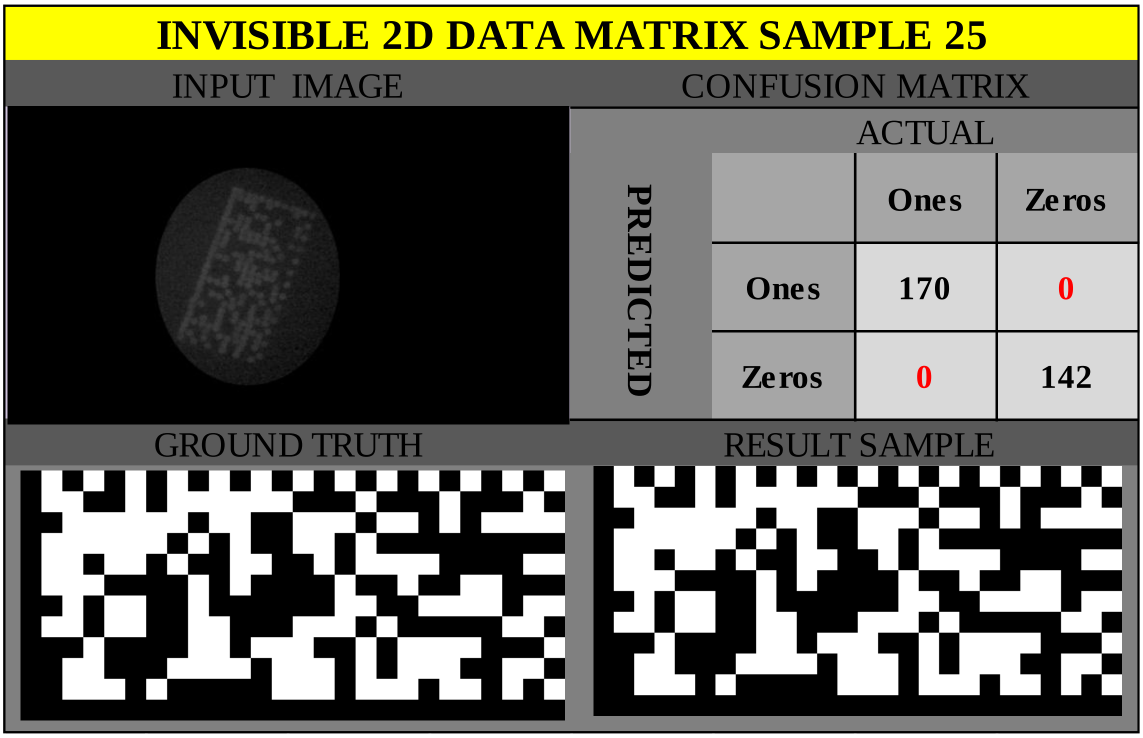


Figure 4.39: 25th Test Image Captured with the Smart Phone Camera

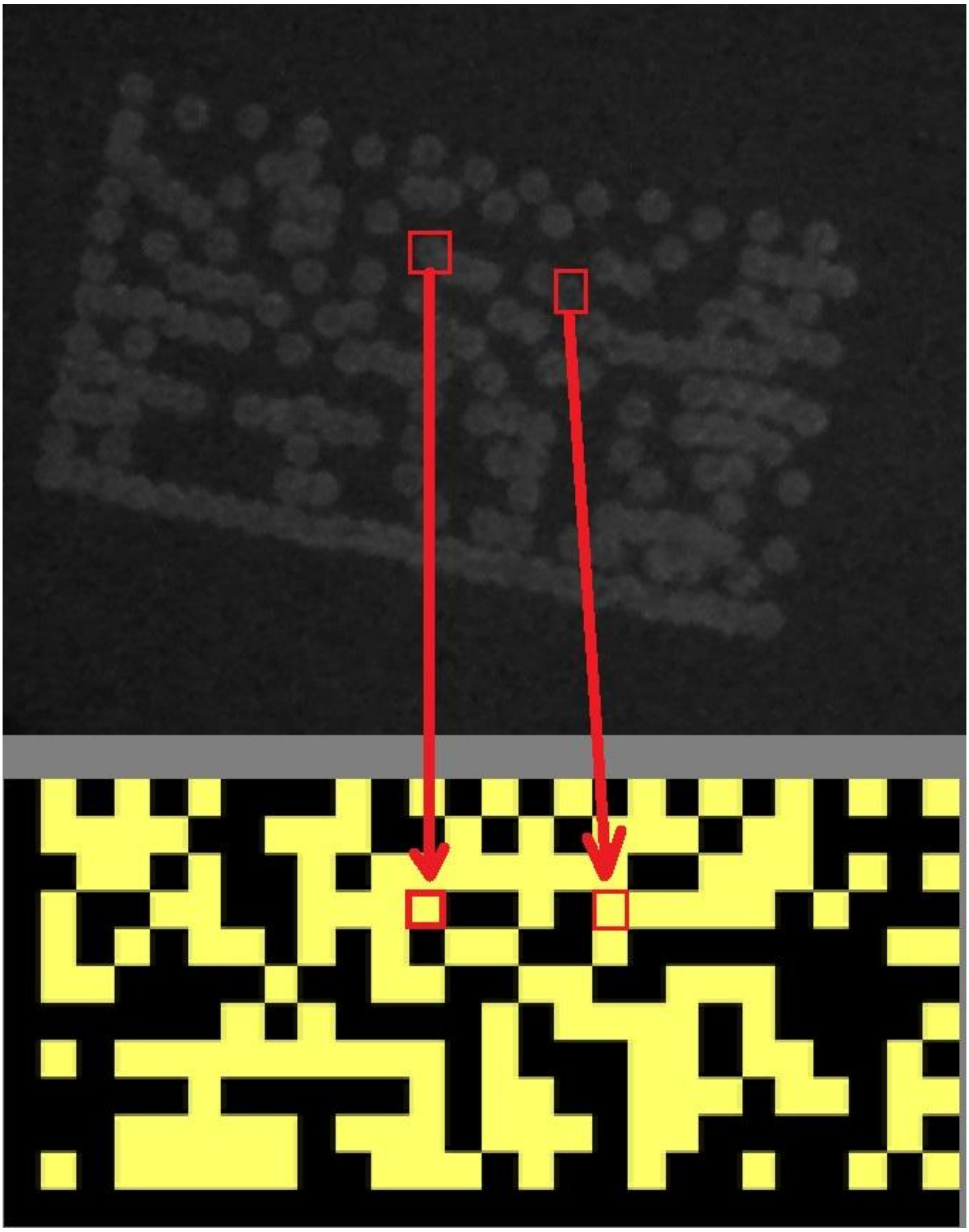


Figure 4.40: Error of Two Dots Missing

Figure 4.40 shows a close look for an example error of two dots missing in the result. The modules at (4, 12) and (4, 17) must be dotted. However, these cells are detected as empty due to the hole at the center of the module and shift in printing.

CHAPTER 5

CONCLUSION

As a conclusion, we worked to detect the invisible 2D Data Matrix by using a smart phone in this thesis. Invisible 2D Data Matrix printed on a special banderol paper with a pigmented ink that cannot be seen in daylight with naked eye. Therefore, a special reader is required to capture images of an Invisible 2D Data Matrix. We first developed an apparatus which has LED light and filter on it to capture the invisible Data Matrix. We captured images from 10 alcoholic beverages caps and 15 cigarettes boxes by Samsung GT-N7100 (Note II) to create our datasets. The main issue with the camera of the smart phone is that its capability and specifications are limited when compared with an industrial camera.

In the proposed algorithm, we implemented Hough Transform to detect invisible 2D Data Matrix where the longest line of Hough Transform gives "L" shape finder pattern. After detection of the invisible 2D Data Matrix, we applied the decoding part of the algorithm. Invisible 2D Data Matrix has some problems during printing. Since the printer's printing head moves up-down or right-left orientation on the original data area. Due to the orientation of the cells or dots, the detection and decoding of the invisible data matrix introduces significant problem that should be addressed. We implemented additional technique to overcome these challenging issues. Convex hull and corner detection methods find the location of four corner points accurately. The fourth corner is not dotted every invisible 2D Data Matrix where is located intersection of dashed borders. We draw parallel lines from "L" shape finder patter's corner points to fourth point. The intersection point of these parallel lines gives the fourth corner. We applied the geometric correction to remove the perspective transform distortion what transfer all dots location in to a rectangular shape. Geometric correction algorithm is used to solve the orientation problem and the adaptive threshold is used to solve the quality problem. After localizing the data region of the invisible 2D Data Matrix, each cell is decoded row by row. The estimated centers of the dots helps us to determine the cell is one or zero banderol and then we tried to decode invisible 2D Data Matrix. While processing with our algorithm we faced some challenging issues like image quality and the orientation problem of the invisible 2D Data Matrix's cells or dots.

Finally, the proposed algorithm shows high performance in detection and decoding at the generated dataset of the invisible 2D Data Matrixes. Accuracy of the algorithm rate is 0.99375. This thesis is the first study to detect and decoding invisible 2D Data Matrix by using a smart phone. We hope this study will guide researchers for understanding the challenging issues in the invisible 2D Data Matrix captured by a smart phone.

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