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A Comprehensive Study on QR Codes

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Abstract: *QR code means Quick Response Code. It is one of the most popular types of barcode. A QR code is a two- dimensional (2D) matrix that means both horizontal and vertical direction. That is why it stores a huge amount of data than a Barcode, which is a one dimensional (1D) matrix (only horizontal direction). The QR code is classified into two types: the Static QR code and the Dynamic QR code. There are many variants of QR code, like QR code Model 1 and Model 2, Micro QR code, Rectangular Micro QR code, Frame QR, iQR code, Secure QR code, HCC2D etc. The QR code provides security, fast and omnidirectional scanning (allowing users to read code quickly from any direction), huge data storage capacity and most important error correction capability (to read data if code is dirty or damaged). The most important thing is, now these days, no particular device is needed to scan QR codes. The QR code can be scanned using a smartphone as well. That means as Smartphone users increase, QR codes will become more popular. In this paper we will widely discuss the basics of the QR code, its types, encoding and decoding process of the QR code, uses of QR codes etc*

Keywords: QR code, Barcode, Types of QR code, Classificationof QR code, ECC of QR code.

I. INTRODUCTION

QR code (Quick Response Code) is the type of barcode that stores the data in the square grid of series of dots (represent 1) and blank spaces (represent 0). These black and white dots refer to modules. A QR code is made up of black modules set in a square pattern against a white background. QR means 'Quick Response', which indicates the code can be read quickly. The data encoded in a QR code may be text, a URL or other types of information and code is designed to decode this data at high speed. The QR code is advanced, versatile, easy to use, two-dimensional, faster and stores larger amounts of data than the one-dimensional barcode. The QR code is designed to store large data and is easily read by smartphone cameras. That is why the QR code is gaining more popularity in various streams like advertising, security, academic etc. It is widely used in today's life for various purposes, like sharing product details, sharing Wi-Fi details, sharing URLs, sharing menu cards, sharing vCards or contact details, being used for brand awareness and advertising, making payment, sharing social media platforms etc. Its popularity is rapidly increasing worldwide. Nowadays, QR codes are commonly scanned and recognized using mobile phones equipped with built-in cameras.

During the 1970s, while barcodes were gaining popularity, their limitations in data capacity (it can hold only 20 alphanumeric characters) and scanning direction highlighted the necessity for a more advanced barcode system. So, Denso Wave created QR codes in 1994 initially to track vehicle parts during manufacturing. Denso Wave is a Japanese company and a subsidiary of Toyota. The QR code's design was inspired by the black-and-white pattern of stones on a Go board, aiming to overcome the limitations of traditional barcodes. In 2002, the first mobile phones with built-in QR code reading capabilities were launched in Japan, significantly boosting public awareness and usage of QR codes. During the 2010s, QR codes gained popularity worldwide as smartphone ownership increased. They became widely used for various purposes, including marketing, payments, and sharing information.

Due to its ability to encode information in both horizontal and vertical directions, QR code can store the same amount of data in about one-tenth the space of a traditional barcode. For smaller print sizes, there are Micro QR Codes available that provide a more compact option. Originally designed for tracking parts in vehicle manufacturing, QR codes now serve diverse purposes, including commercial tracking, entertainment, in-store product labelling etc. Users can scan QR codes to access URLs or receive text information. Users can generate the QR code using available online tools or apps that allow users to download QR codes in formats like PNG, JPG etc. for various applications.

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A QR code system has two main parts, which are an encoder and a decoder. Encoder transforms text, URLs, or other data into a QR code. When scanned by a smartphone or QR code reader, the decoder interprets the pattern of black and white squares to access and show the encoded information (as shown in fig no. 1). Scanning a QR code allows instant access to the encoded content, such as opening a website or displaying text

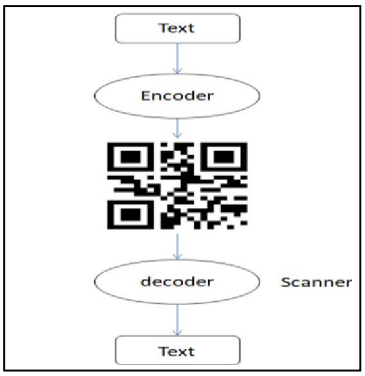

Fig no. 1

II. STORAGE CAPACITY AND VERSIONS

To efficiently store data, QR codes use four standardized modes of encoding: numeric, alphanumeric, byte or binary, and kanji. Numeric data includes only numbers (0- 9). Alphanumeric data include numbers (0-9), uppercase letters (A-Z), and special characters (space, $, %, *, +, -,. , /, :). Byte or binary data encodes characters in binary format and Kanji data includes Japanese characters using the Shift JIS X 0208 character set. As the data volume grows, the QR code requires more modules, leading to larger QR codes. QR codes has versions from Version 1 to Version 40, each with a distinct module configuration. Modules refer to the pattern of black and white dots of the QR code. Version 1 has a 21 × 21 modules configuration, version 2 has a 25 x 25 modules configuration, version 3 has a 29 x 29 modules configuration, version 4 has a 33 x 33 modules configuration, version 10 has a 57 x 57 modules configuration, version 25 has 117x117 modules configuration, while Version 40 has a 177 × 177 modules configuration as shown in fig 2.

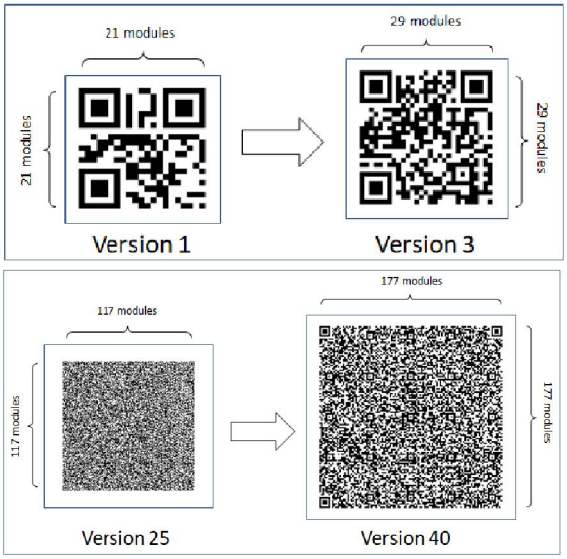

Fig no. 2

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Data	Capacity
Numeric	7089
Alphanumeric	4296
Binary/Byte	2953
Kanji	1817

Table 1

III. CLASSIFICATION OF QR CODE

The QR code is classified into two main categories the StaticQR code and the Dynamic QR code.

Static QR code:

Static QR codes are permanent, once generated then cannot be altered or updated. The static QR code does not allow changing of the embedded data and the code has a fixed destination. A static QR code does not provide the ability to track or analyse scan data. They store data directly within the code, making it suitable for data that does not need updating, such as contact details, plain text, URLs, email addresses, serial numbers, static images, WhatsApp messages, vCards, Google Maps locations, coupon code, Wi-Fi login credentials etc. while Generating Static QR codes, consider your data size carefully. Larger amounts of data will require more modules, which can create a more complex and crowded QR code pattern. Static QR codes do not provide theability to track or analyse scan data.

Types of Static QR code :

QR Code model 1 and model 2 :

The QR code model 1 is the original QR code format. Model 2 is the advanced version of Model 1 and most widely used QR code format. Both are visually similar but model 1 does not contain alignment patterns. QR code model 2 has higher data capacity, up to 7089 numeric characters

Micro QR code :

The micro QR code is the smaller version of the QR code. Therefore, it has only one position detection pattern. It is made by Denso Wave for smaller applications because of its smaller printout size. It has four different versions and the largest version can hold up to 15 bytes of data. It is the most suitable for applications where size is limited.

rMQR code :

The rMQR Code (Rectangular Micro QR code) was invented by Denso Wave in 2022. It is designed as a rectangular version of the QR code, suitable for rectangular areas, and it has the same parameters as the original QR code. The rMQR Code features black squares and white spaces organized in a rectangular grid on a white background. It has one finder pattern and one sub- pattern located in the top-left corner and bottom-right corner respectively.

Frame QR code :

Frame QR is a type of QR code that features a "canvas area" in the centre, allowing for flexible use. This area allows for the arrangement of graphics, text, and other elements. Frame QR codes seamlessly integrate into designs and maintain the visual integrity of illustrations, photos, and other elements without any disturbance. FrameQR codes can be customized with different frame shapes and colours, making them versatile for applications such as promotions, authentication, and other uses.

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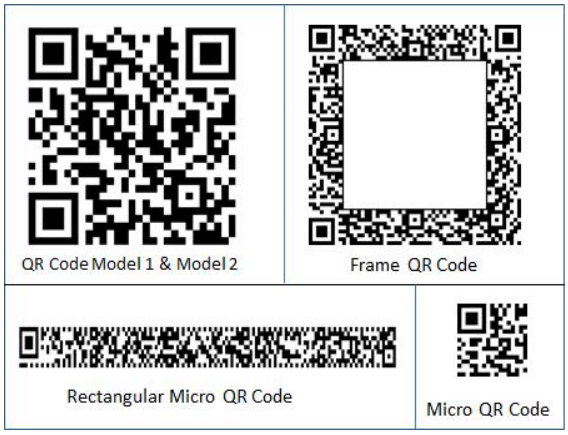

FIG no 3

Dynamic QR code

Dynamic QR codes are more advanced than static ones, as they include a short redirectional URL embeddedin the code. Dynamic QR codes can store a unique short URL that directs scanners to current embedded data and allows updates without generating a new code. This innovative feature enables updating the information without needing to generate a new code, and it overcomes the limitations of static code. The use of a short URL ensures that the size of data does not affectthe QR code's module count. These QR codes also provide tracking and analytics capabilities, providing details such as scan numbers, scan times, scan locations etc. Additionally, dynamic QR codes can be edited even after being printed, allowing for changes in both function and content as needed. Dynamic QR codes are particularly beneficial for marketing campaigns, sales promotions, seasonal events, and any situation requiring flexible and updatable information. They are customizable for diverse marketing purposes and are effective tools in event registration and inventory management applications.

Types of Dynamic QR code :

iQR code :

The iQR Code is developed by Denso Wave. IT is a two- dimensional (2D) matrix code that is easy to read, stores more data and smaller than regular QR Codes and Micro QR Codes. It can store larger information than the regularQR code in 30% less space. iQR codes are designed to be either square or rectangular, offering flexibility for situations where a longer, narrower shape is more practical. Square iQR codes have 61 versions, while rectangular codes have 15 versions. The smallest square iQR code has 9 × 9 modules and the rectangular code has 19 × 5 modules.

Secure QR code :

The Secure Quick Response Code (SQRC) was created to store private information securely. These QR codes can store both public and private data, with the private data accessible only through a dedicated reader using the cryptographic key and SQRC appears identical to regular QR Codes. It can effectively prevent forgery and tampering as well as ensure data protection. For reading and generating the SQRC there is no need for extra Encryption and Decryption Functions.

HCC2D

HCC2D means High Capacity Colored 2- Dimensional code developed base QR code to enhance data density using colors, all while ensuring that the QR code remains reliable even when distorted. Unlike traditional QR codes that rely on brightness, HCC2D codes need to manage color distortions during decoding. They use a color Palette Pattern alongside the Encoding Region to maintain consistency in how color distortions are handled. This helps train machine learning classifiers withreplicated color palettes to ensure precise decoding.

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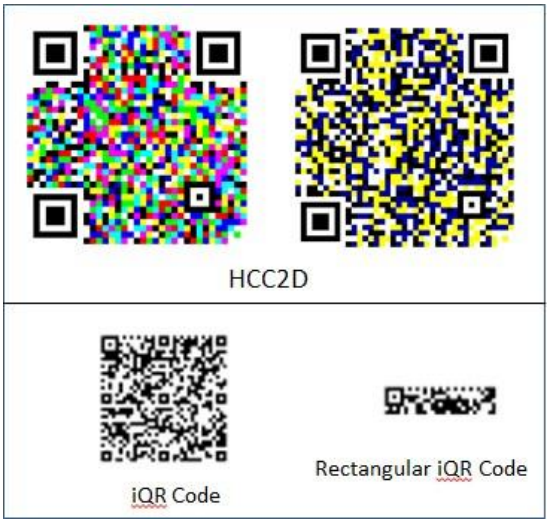

Fig no. 4

IV. DESIGN OF QR CODE

The design of a QR code is two-dimensional (vertical and horizontal). It is designed to store data that can easily be scanned and decoded using various devices like smartphones and QR code readers. The structure of the QR code consists of two main components, each with a specific function: Encodingregion and Function pattern.

Function Pattern :

Quiet zone :

The Quiet Zone is a blank space around the QR code that helps scanners to differentiate the code from itsbackground.

Finder Pattern :

Finder patterns are squares located at the three corners of the QR code. These are the special position detection patterns that help the scanner to align, recognize and detect the QR code. Each finder pattern consists of three nested squares. The outer square is dark and consists 7 x 7 modules, the inner square is light, consists 5 x 5 modules and the center square is dark andit consists 3 x 3 modules.

Separator :

Separators are one-module areas of white space in the QR code that surround each finder pattern, help to identify the encoding region and ensure accuratedetection and reading by scanners.

Timing Pattern :

Timing patterns consist of alternating dark and light modules arranged horizontally and vertically within the QR code. It is located between the separators, the horizontal timing pattern is in the 6th row and the vertical is in the 6th column. The timing patterns helpthe QR code scanner accurately interpret the size, density, coordinates, and version information of the QR code.

Alignment pattern :

Alignment patterns in QR codes consist of small square patterns designed to determine accurate positioning and alignment during scanning. These patterns play an important role in larger QR codes to ensure proper orientation and readability. The outer square consists of each alignment pattern consists of 5 × 5 dark modules, the inner square consists of 3 × 3 light modules, and a single dark module at the centre.

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Encoding Region :

Format information :

Format information located after the separator in the QR code. IT contains critical information like error correction level, mask pattern. This information helps in simplifying scanning of the code.

Version Information :

QR codes have 1 to 40 versions. This encoding region helps to specify the exact version number of QR code and determining its size and data capacity. Even though QR codes offer up to 40 different versions, versions 1 to 7 are the most frequently used.

Data and error correction code

This is the main region where encoded information like contact details, URLs, text and other specific data is stored. To store this encoded data, 6 x 3 modules above the bottom left finder pattern and 3 x 6 modules to the top right finder pattern is used. This region also contains error correction code information.

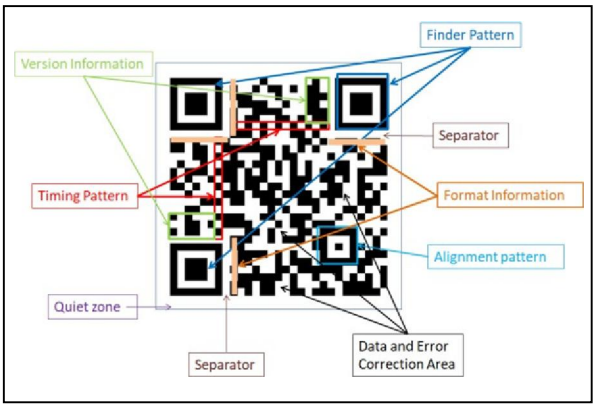

Fig no. 5

V. ENCODING PROCESS OF QR CODE

Encoding means converting the input data into QR code format. During this encoding process, the first data analysis is started to understand the nature and size of the data. The QR code is encode four types of data, that is numeric, alphanumeric, binary/byte and kanji. Each data type converts text into bits (1s and 0s) using different methods optimized for efficiency and uses the shortest string of bits for encoding. The analysed data is encoded into a format that is suitable for QR code representation. After that, QR codes uses error correction to ensure the QR code can read accurately, even when the QR code is dirty or partially damaged. The error correction codewords are generated using the Reed- Solomon error correction method. QR scanners read both error correction codewords and data. By comparing error correction codewords and data, the scanner can verify if the data is read correctly and correct any errors if necessary. After creating the data and error correction codewords, the next step is to combine them for the final message. The next step is module placement, that means arranging the data and error correction codewords correctly in the QR matrix. QR codes can sometimes have patterns that make them harder to scan accurately. To read accurately, the QR code specification includes eight mask patterns. These patterns alter the QR code to make sure scanners can read it more easily. In the final step of encoding, the necessary metadata is added to the QR code. This indicator includes format information that includes error correction as well as mask pattern and version information indicating size and data capability added in the QR code.

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VI. DECODING PROCESS OF QR CODES

The first step of decoding involves identification of light and dark modules of QR code. The dark modules represent "1" bits and light modules represent "0" bits. This involves locating the QR code within the image. The second step is extracting format information, that means decoding the format information from the QR code modules, identifying the masking pattern and apply error correction to ensure accuracy. The next step is determining the version information from the specific areas designated in the QR code. The QR code has 1 to 40 versions. That is why this step is very important to understand its size and version information. In the next step of decoding, remove the mask patterns to reveal the actual data stored in the QR code. The next step is very important for reconstructing the original encoded message by restoring the error correction codewords and data using symbol characters according to the QR code placement rule. After that, error detection and correction is done, using error correction codewords , identifying errors and, if any error is detected, correct it. If there is no error detected, decoding the data codewords start. In the final step of decoding, data codewords are divided into segments, then, using indicators, the characters are decoded, and the original data is reconstructed.

ECC (ERROR CORRECTION CAPABILITY) OF QRCODE :

ECC plays a crucial role in encoding and decoding of QR codes. With the help of the ECC scanner, we can read the code even if the code is dirty or partially damaged. For Error Correction, the QR code uses the Reed-Solomon code. This Reed-Solomon code uses one of 37 different polynomials, with degrees ranging from 7 to 68, depending on which number of error correction bytes are added. For bigger QR codes, the message is split into several Reed–Solomon code blocks and each block can correct up to 15 errors. In ECC there are four levels of error correction: Level L (low), Level M (medium), level Q (quartile), level H (high). As the ECC level increases, the data storage capacity of QR codes is decreased. Every ECC level has an approximate percentage ability error correction as shown in table 2.

Error correction capability of QR code	
Level L	~ 7 %
Level M	~ 15 %
Level Q	~ 25 %
Level H	~ 30 %

Table No. 2

USES OF QR CODES :

Initially, the QR code was only used in tracking vehicle parts, but now these QR codes are widely used in today's life. It is used in marketing and advertising for companies, for providing product information, links to websites and landing pages, to distribute coupons and discounts. It is also used in information sharing, displaying contact information, sharing event details, providing Wi-Fi access. Most importantly, QR codes are used for payment and transactions because they enable contactless and cashless payment. As the use of QR codes is increasing, the users of QR codes are also increasing rapidly.

VII. CONCLUSION

QR codes are versatile and robust tools used for sharing and storing information. Because of the ECC, the QR code is readable even if it is damaged or dirty. Because of this adaptability, it is used in numerous applications. It is highly secure. That is why it is used in payment transactions also. The QR code has become a significant tool in today's life. It is used in each and every possible field for various purposes. In this paper we studied QR codes in detail. We discussed its types and different uses.

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