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Image Processing and Numerical Methods in QR (Quick Response) Code efficient Decoding Using direct linear transformation method

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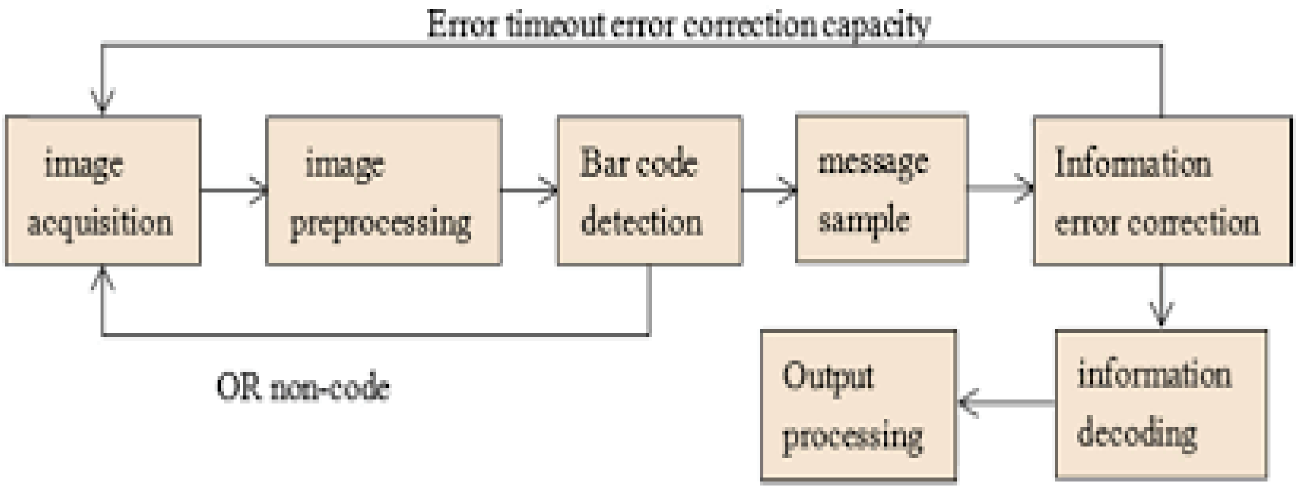
Abstract

The importance of numerical methods for image processing for reliable and efficient rapid response (QR) code decoding is investigated in this work. From image capture to data extraction, the process uses a number of cutting-edge methods to tackle real-world issues including noise, distortion, and changing illumination. The main stages of image processing are described, including perspective correction methods like homography estimation to precisely divide code blocks, feature detection algorithms to find the QR code inside the image, and preprocessing to improve contrast and lower noise. It also covers numerical techniques, such as statistical threshold algorithms, matrices for geometric transformations, and interpolation methods for image alignment and resizing. The study emphasizes how computational and numerical techniques work together to guarantee that QR codes

1. Introduction

1.1. Overview

Since they offer a versatile way to encode data in a variety of contexts, including marketing, inventory control, and mobile apps, QR codes have become more and more ingrained in our daily lives. The need for efficient decoding systems that can analyze photos taken in challenging circumstances is growing along with their popularity. The image processing and mathematics approaches used in QR code decoding are examined in this work, with a focus on how these approaches handle typical problems including image noise, geometric aberrations, and changing lighting.



2. QR Code Structure and Decoding Process

2.1 QR Code Structure

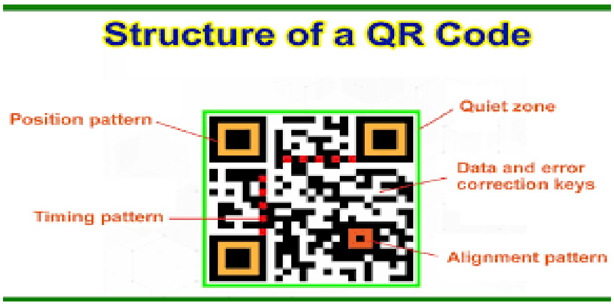


Fig 1: QR code Structure

A QR code consists of a square grid of black and white modules.

Key features include:

2.2 Finder Patterns:

One distinguishing feature of the QR code is the detector shape that may be found at the top left, front center, and bottom right corners. Three squares are placed one on top of the other so that any of these detector types.

- Outer square: 7×7 blocks (black)

- Middle square: 5×5 blocks (white)

- Inner square: 3×3 blocks (black)

This configuration, frequently referred to as a "1-1-3-1-1" ratio, establishes a pattern that is readily identifiable by scanners, even when the QR code is subjected to rotation or tilting at an angle.

2.2.1. Alignment patterns

The small rectangles in QR codes help users, particularly taller ones, adjust for perspective distortions. These components enable the code to be properly aligned, so that it can be successfully scanned even when angled or on a curved surface. These shapes are crucial to preserving the readability of the code and are positioned strategically in the lower right corner.

2.2.2. Timing Patterns:

Scanners can determine the size and phase direction of the information grid with the help of the QR codes' alternating black and white squares in the time domain. This component is especially important if the code is distorted or misaligned because it may make it more difficult to comprehend correctly. It also provides details on the mistake correction grade and QR code production.

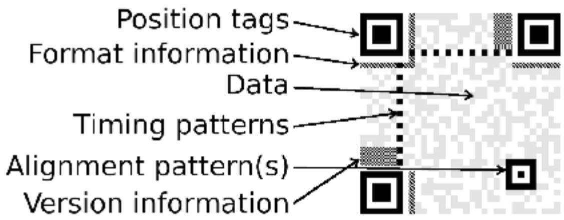


Fig 2:Timing Pattern

2.3. QR Code Decoding Process

In order to decipher a QR code, you usually need to do the following: First, you take a picture of the code's QR code with a camera or scanner. After that, you reduce background interference and enhance image clarity. Then, by searching for specific patterns in the image itself, one can determine the location and direction of the QR code. After that, any geometric distortions are corrected using a technique known as homography. After that, the picture in grayscale is converted to binary, a format consisting of black and white squares. You next analyze these squares and decode the data using Reed-Solomon error correction. Finally, the data that has been encoded is extracted.

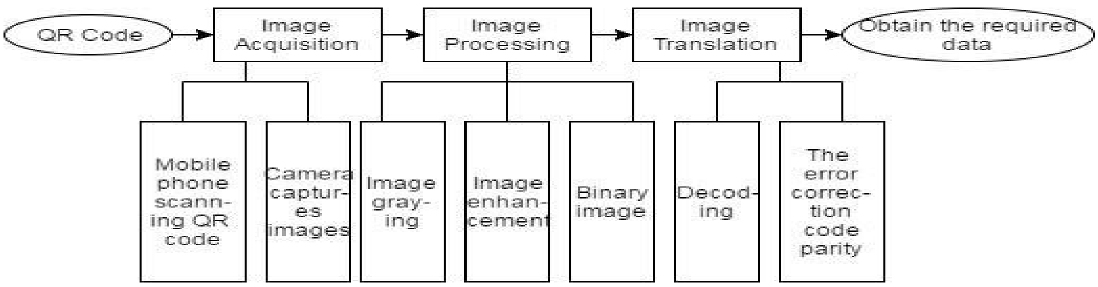


Fig 3:QR code Decoding Process

3. Image Processing Techniques and Numerical Methods

3.1. Grayscale image processing

A lot of information is contained in color photos, which are the subject of this writing. Nevertheless, these pictures can be difficult to manage and require a lot of storage space. In this process, calculations are also essential. The color data must be converted into a more straightforward format in order to facilitate things. The first step is to turn the QR code into a grayscale picture. . IR = 0.3the value of R + 0.59G + 0.11B is the equation for this conversion, where I denotes the perceived color effects and R, G, and B represent the red, green, and blue parts, respectively.

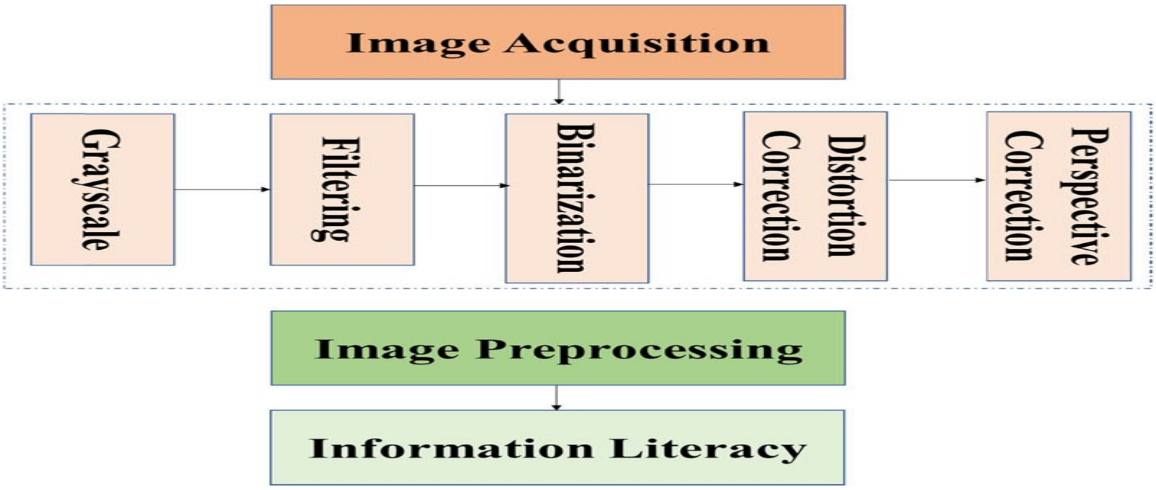


Fig 4: QR image Acquisition

3.2. Image median filtering

Image median filtering is a method to improve the accuracy of two-dimensional codes, which often detect various forms of interference during collection. This noise can lead to issues like distorted edges and isolated interference sites. It is essential to use a filtering technique that lowers noise in order to decode these codes more effectively. It has been demonstrated that median filtering works well since it sharpens the edges of images while simultaneously removing noise. The median filter window's dimensions and form have a big impact on the result. Features and ancillary information may be obscured by an excessively large window.

. Utilizing a square window produces the greatest results because a QR code's core structure is square. According to experiments, the median filter works best with a 3x3 square window. For example, Figure 3 shows the enhancements following the application of the 3x3 window filter, whereas Figure 2 shows the linear code picture before to filtering.

Original image

Filtering image of 3x3 rectangular window

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Fig 5: QR image Filtering

3.3 Image Rotation

QR codes can be recognized from any angle; so technically, there's no need to fix a tilted image. However, if tilt correction isn't applied, the exact position and angle of the QR code symbols need to be determined using the sequence of characters from the position detection model to align the shapes, which can take a lot of computing time.

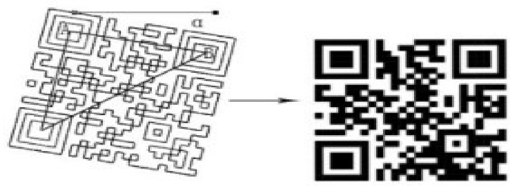

Fig 6: QR image Rotation

In order to quickly identify images without tilt, this research proposes a method that rotates the image before recognition. By eliminating the necessity for shape matching and tilt angle changes, this method saves time, lessens the additional work required to identify slanted images, and facilitates the decoding procedure that follows.

3.4 Pre-processing

Noise Reduction:

Gaussian Filtering: A common technique to reduce high-frequency noise. The Gaussian filter kernel is defined as:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Where σ is the standard deviation.

MedianFiltering:

A good technique for eliminating salt-and-pepper noise is median filtering. The center pixel has been swapped out for the average value of the nearby pixels.

ContrastEnhancement:

To enhance contrast, Histogram Equalization modifies the pattern of pixel intensities. Adaptive equalization of histograms (CLAHE) controls noise levels while improving loc al contrast.

3.5 Feature Detection

Given their similarities, the inventor's formula was made public and linked to the picture. Finding square shapes that display particular size proportions is the first step in this approach, which involves evaluating square confines. Given their similarities, the inventor's formula was made public and linked to the image. Finding square shapes with particular size proportions is the first step in this approach, which involves studying rectangular confines.

3.6 Perspective Correction

Homography is a way of transforming points from one flat surface to another. This transformation can be expressed using a 3x3 matrix known as H.

$$[x' \; y' \; 1] = \mathbf{H} \, [x \; y \; 1]$$

The process of moving points between one flat surface to another is called homeography. A 3x3 matrix called H can be used to depict this transformation. The updated coordinates are displayed as (x', y'), whereas the previous coordinates are indicated as (x, y). Direct linear conversion (DLT) is one approach that can be used to compute the homography matrix.

3.7 Direct Linear Transform (DLT):

When you have a group of related points (xi,yi) and (xi′,yi′), the DLT algorithm works out the components of H. Each connection between the points produces two

$$x_i' = \frac{h_{11}x_i + h_{12}y_i + h_{13}}{h_{31}x_i + h_{32}y_i + h_{33}}$$

$$y_i' = \frac{h_{21}x_i + h_{22}y_i + h_{23}}{h_{31}x_i + h_{32}y_i + h_{33}}$$

equations.

Where h_{ij} elements of the homography matrix H.

We are rearranging the terms, we get:

$$x_i'(h_{31}x_i + h_{32}y_i + h_{33}) = h_{11}x_i + h_{12}y_i + h_{13}$$

$$y_i'(h_{31}x_i + h_{32}y_i + h_{33}) = h_{21}x_i + h_{22}y_i + h_{23}$$

This can be written in matrix form as:

$$[x_i \quad y_i \quad 1 \quad 0 \quad 0 \quad 0 \quad -x_i'x_i \quad -x_i'y_i \quad -x_i' \backslash 0 \quad 0 \quad 0 \quad x_i \quad y_i \quad 1 \quad -y_i'x_i$$

With at least 4 point correspondences, we can solve for the homography matrix H.

3.8 Binarization

Global Threshold: In this technique, the entire image is subject to a single threshold value. One well-liked way for automatically figuring out the ideal threshold is the Otsu method.
The goal of the Otus method is to lessen the variation between the categories of black and white pixels. By examining every potential value and choosing the one that minimizes the weighted total of the variances of the two groups (foreground and background), it determines the ideal threshold.

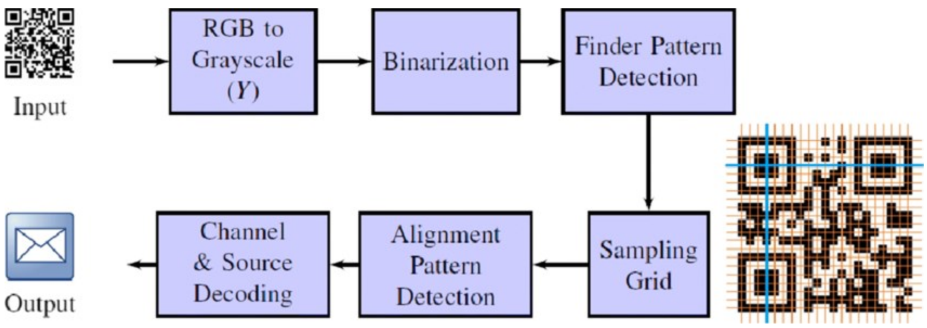

Fig 7 Binarization Input and Output

Adaptive Threshold: This technique works especially well for photos with uneven illumination because it uses different threshold settings for different local areas of the image.
Adaptive Average Threshold The adaptive Gaussian threshold is calculated as a weighted average of the Adaptive Gaussian Threshold: In this case, a Gaussian distribution is used to determine the weights, and the threshold is calculated as a weighted mean of the values of the surrounding pixels.

3.9 Sampling and Decoding

Identify if each square of the QR code is dark or light. Reed-Solomon error correction is a strong method for correcting errors that can retrieve data from corrupted or partially hidden QR codes. It employs polynomial mathematics within a specified field.

4. Conclusion

Processing of images and numerical methods are crucial for the accurate and efficient interpretation of QR codes. QR code readers can handle various picture distortions by numerical techniques such matrix calculations, statistical evaluations, and interpolation, as well as pre-processing, feature identification, perspective adjustment, and binarization. The dependability and durability of QR code technology will be improved by ongoing advances in these areas, guaranteeing its continuous importance in an increasingly digital world.

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