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A SYSTEMATIC LITERATURE REVIEW ON QR CODE DETECTION AND PRE-PROCESSING

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Abstract- Quick Response (QR) codes have become an important component to enable various technical solutions and are being used by millions of people around the world every day. With the tremendous increase in usage of QR codes and the growing number of applications mostly including sensitive tasks such as payment and ticketing, it becomes vital to understand the current state of the technology, its implementation, limitations, and scope for future work. The present paper is aimed at fulfilling this purpose and provides an analysis of the latest advancements in QR code detection and pre-processing technologies. The study also reveals the multi-step process of QR code recognition, by this paper it is achieved to help organizations in optimally adopting the technology for their respective needs.

Keywords: QR Code, Barcode, Detection, Review.

1. INTRODUCTION

Quick Response (QR) code is a two-dimensional barcode using the ISO/IEC 18004:2006 (it is revised in 18004:2015) standard [1]. A QR code is generated by following certain protocols, the same of which are utilized for its decoding. While generation of a QR code is a straightforward process, the main challenge lies in recognizing it with greater accuracy and speed. Getting information from a QR code in real world environments comprises of three vital steps: localisation, image pre-processing and decoding. Localisation refers to the detection of a QR code and its exact coordinates or location in an image. Image pre-processing is an intermediate step where the detected QR code's image is improved to reduce blur, noise, distortion, angular perspective, etc to enable accurate decoding. Decoding is the final step where the information/data is retrieved and relies on the main standard architecture of the QR code [2]. The maximum work and innovation has been done for the former two steps, hence, the review shall focus on them with greater focus.

The analysis has been systematically divided into sections and subsections based on their tasks to make it the most suitable for its primary purpose of assisting in optimal adoption and future innovation. The reason behind this approach and the understanding that it perfectly complements our purpose lies in the fact that the expressed tasks in the QR code recognition workflow (localization, pre-processing, and decoding) are independent and enjoy different benefits with different algorithms. Hence, knowing the strengths of respective algorithms will help in choosing the most suited for every step with respect to the organization's needs. The methodology for Systematic Literature Review and detailed in this paper is explained in Section 2. Following, the main review is given in Section 3. The overview and the conclusions are given in Section 4 and 5 respectively.

2. SLR METHODOLOGY

The Systematic Literature Review (SLR) is being done to understand and analyse the latest advancements in QR code detection and pre-processing. It is to be noted that there are very few literature reviews on this topic which makes the study and advancement in this field rather difficult for future innovation. Therefore, the current systematic literature review being done even more meaningful. While studying this review, it shall become clear to the reader that in essence, no algorithm is the definite choice for any task and it is directly dependent upon the intended application. The presented SLR has been inspired in its layout and design from [3] and [4] for their simplicity and effective presentation. It shall be noted, that even though [3] and [4] are reviews on image captioning and not QR code detection, they have been used for inspiration in design/structure of an SLR and not the content. In addition, almost all the design decisions have been taken with respective to the study in particular, to be able to best present the data retrieved and our analysis of it.

2.1. Search Sources

Digital libraries and the internet have been utilised to accumulate the journals, conference papers, industry standard source codes and documentation for study on QR detection. The libraries used are as follows:

1. IEEE Xplore [5]
2. ACM Digital Library [6]
3. IET Digital Library [7]
4. Sci-Hub [8]
5. arXiv [9]

For this SLR to be relevant and to best highlight the latest advancements, research papers from 2016-2019 have been preferred for the content and review. However, it is also studied some important landmark research papers outside of this time range (e.g. "Fast component-based QR code detection in arbitrarily acquired images" by Belussi and Hirata, 2013 [10]) to get better understanding from roots of these advancements.

2.2. Parametric Findings

The following parameters have been carefully formulated through the present study of the technology and will help in the optimal structural division as described in introduction.

These parameters are found as the major topics of focus in the research papers studied.

1. Detection/localization
   • Time
   • Accuracy
2. Pre-processing
   • Angular perspective
   • Motion and blur
   • Illumination variance.

3. REVIEW

As mentioned earlier, the literature review is done parameter-by-parameter. Each parameter and the work is done to solve their challenges will be analysed and presented in detail in the following subsections. Before going in-depth about the localisation and pre-processing details, first, the basics of QR code will be discussed to make understanding this paper as well as further works to be done simple.

3.1. QR Code

A QR code is a 2D barcode that was invented by Denso Wave [11] in 1994. Against a 1D barcode, a QR code gives many advantages including high data capacity, small size, kanji and kana capability, dirt and damage resistance, angular invariance and structured appending capability [11]. The details in [1] are vital to understand the core underlying principles behind QR code detection and hence strongly recommended to study in detail to enable further work in them.

A brief overview of the basic architecture and the decoding principles shown in Figure 1 are explained below for a greater understanding of the workflow as well as this paper:

• Position Detection Patterns: These indicate the direction in which the Code is printed. The finder patterns of the QR code are identified to detect it [12]. The principle is that there is a ratio in the number of black/white/black/white/black stripes of 1:1:3:1:1 as shown in Figure 2. This ratio remains the same unaffected by the angle of capturing. Each of the red lines in Figure 2 have the same ratio. The ratio does not depend on the angle. Once it is identified, next step is to confirm whether it is a finder pattern or not [13].

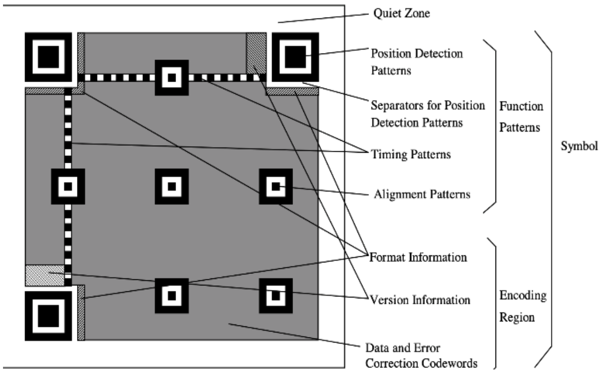

Figure 1. Structure of QR code symbol [1]

Figure 2. Position detector, QR code finder patterns [13]

• Alignment Pattern: This is an additional element which helps with orientation especially in large QR codes [12]. It is useful for handling distortions in QR code (especially nonlinear distortions) [14]. For this purpose, the central coordinate of the pattern is used which is identified with the help of a black isolated cell.

• Timing Patterns: Helps the scanner to determine the size of the data matrix [12]. These are used to identify the central coordinate of the data cell when an error is present [14].

• Version Information: These specify the QR Code version that is being used [12]. The sizes range from 21*21 modules to 177*177 modules for version 1 to 40, increasing in steps of four [1].

• Format Information: The format patterns contain information about the error tolerance and the data mask pattern and make it easier to scan the Code [12]. QR codes have a high error tolerance and can contain their data for up to 30% damage [11][15].

• Data and Error Correction Codes: These codes hold the actual data of the QR code [12]. The area contains data encoded into binary number '0' and '1' [14]. The distribution of these binary numbers is decided using encoding rule.

• Quiet Zone: This spacing is used by the scanner to distinguish the QR Code from its surroundings [12].

The above architecture and structure of a QR code are the standard protocols extensively described in [1], it is strongly recommended studying for a deeper understanding.

3.2. Detection/Localisation of QR Code

Detection and localisation of a QR code are essential and the first-step in the workflow of using them and retrieving information. In their landmark 2013's paper [10], Hirata and Bellusi presented an approach which is able to detect QR codes in a large database of arbitrarily acquired images with high accuracy. This is a highly cited and acclaimed work that has been used by many researchers for their work. The paper presents a two-stage component-based detection approach. The first stage proposes and evaluates a novel use of the Viola- Jones' rapid object detection framework for Finder Pattern (FIP) detection. The second stage proposes an algorithm that applies geometrical restrictions on detected FIPs to decide whether these correspond to corners of QR codes or not. The testing done by the authors showed a promising accuracy of greater than 90% on a dataset of still images. The authors have noted that due to the testing being done on a small dataset, the results may vary with expectations towards improvement. Further work for improvement in real life video applications and uncontrolled environments including distortions is noted. Table 1 gives an overview of the papers studied for localization.

Table 1. Overview of localization papers

Reference (Relevant Papers)	Technology	Result
L.F.F. Bellusi et al. 2013 [10]	Viola-Jones and geo metrical restrictions	Above 90% accuracy on still images
T. Grósz et al. 2014 [16]	Deep neural networks	Above 93% precision
L. Tong et al. 2014 [17]	Local features	Avg. detection time 27ms
A. Mehta 2015 [18]	-	Review on QR detection
P. Bodnar 2015 [2]	-	Review on localisation
O. Lopez-Rincon et al. 2017 [19]	binary large objects (BLOB)	80-100% detection rate in uncontrolled environments
D.K. Hansen et al. 2017 [20]	Deep Learning YOLO	1.0 detection rate and above 94% accuracy with bounding box
S. Li et al. 2018 [21]	Run-length coding, calculated using modified Knuth- Morris-Pratt (KMP) algorithm [22]	Angle invariant. Linear time complexity of KMP algorithm, avg. detection time 55ms
B. Jiang et al. 2019 [23]	Subregion detection algorithm. Batch Reading	Can detect 160-180 version 1-L QR codes. 90-95% accuracy. Speed up of 25x (10-14s).
L. Blanger et al. 2019 [24]	Deep Learning	81% recall and 1/3 false positives of FastQR
J. Zhang et al. 2020 [25]	Regression and multi-scale pyramid pooling	One of the highest detection rates, mean average precision = 8.79

In 2014, two new notable methods are proposed for localization including the use of deep neural networks and local features such as binary pattern, contours, and pattern ratio respectively for detection [16][17]. T. Grosz et al. conclude from their experiments that usage of neural networks is a robust, reliable approach for fast QR code localization. They also observed that DRNs perform better than ANNs in general and that the block size doesn't interfere with the DRN accuracy significantly [16].

On the other hand, L. Tong et al. focuses on the overall execution time and are able to reduce the detection time from 39 ms [26] to 27 ms on average using their approach that uses Local Binary Patterns for accurate detection [17].

In [2], P. Bodnar summarizes and presents various different localization methods in his analysis. Some notable methods mentioned are as follows:

- Localization with global image data
  - Using scan line features
  - Using Hough transform
  - Using mathematical morphology
- Localization with neural networks
  - Conventional neural networks
  - Deep neural networks

The author notes that among the algorithms that rely on global image data, the scan line algorithm is extremely fast while the latter two outperform state-of-the-art algorithms in terms of accuracy and recall [2]. The author also notes the use of other algorithms that utilize cascade classifiers, cell histograms and fuzzy inference systems.

Lopez-Rincon et al. [19] presents a BLOB based approach for QR code detection in uncontrolled environments. This paper seeks to contribute to fast and precise detection of QR codes in difficult scenarios and overcome the challenges that are present in conventional algorithms and achieve high detection rates in various environments. Some environments from their paper are listed below along with detection accuracy:

- Local Dataset Used by original author [19]

1. Variable Illumination
   - Weak contrast (100%)
   - Very weak contrast (98%)
   - Highly varied illumination (70%)
   - Significantly noised image (56%)
2. Distortion, rotation, blur, and perspective
   - Rotation and weak distortion (100%)
   - Strong distortion (80%)
   - Strong distortion and blur (20%)
   - In perspective with slope between 45 & 60 degrees (85%)
3. Multiple QR codes in one image
   - Variable illumination (100%)

Hansen et al. 2017 [20] adopts the deep learning based detector of YOLO (You Only Look Once) [27] for detection of 1D and 2D barcodes. They are also able to achieve image preprocessing in terms of rotation using the same model and are able to increase the decoding performance based on tests performed using the ZXing [28] and Zbar [29] open-source library for QR code decoding. This work shows one of the simplest and perhaps the most promising techniques for barcode localization and rotation for everyday use. The authors use Soros [30] and Dubeska [31] barcode datasets for testing and achieve a laudable 1.0 detection rate with bounding boxes for algorithm and a 95% average accuracy.

Figure 3 shows the comparison in execution time of the best performing algorithms for QR code detection. It shall be noted that the figures presented are the best values noted by the respective authors. While they give a good estimate, it is observed that they are prone to significantly vary with the dataset and with the computing machine too.

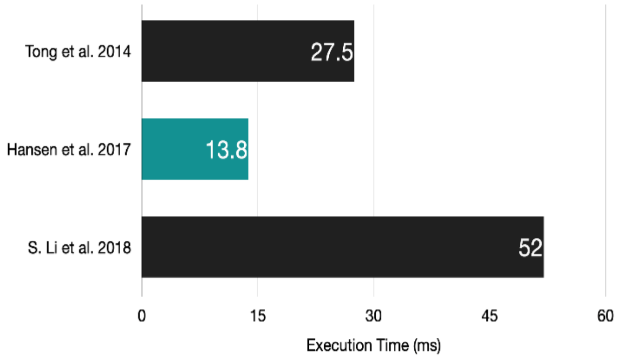

Figure 3. Detection time comparison of highest performing algorithms

S. Li et al. 2018 [21] presented a fast detection method of QR code based on run-length coding in their paper. The presented algorithm is executed after the image binarization is completed for which the authors prefer the Otsu method of binarization [32] due to its superiority under variable illumination. The detection algorithm utilizing the run-length coding is inspired from [33] and touts its main achievement in significantly reducing the time complexity (and hence the actual execution time) using a modified version of Knuth-Morris-Pratt algorithm [22]. The algorithm proceeds as follows: first the connected component in the binarized image is compacted using run-length coding and the minimal region is determined on the basis of the character of Position Detection Pattern (PDP) [1].

Finally, the coordinates of central PDP are calculated using run-length coding where the calculations are done using KMP. The author makes a special note that the minimal region detected by their algorithm is much smaller than by other algorithms. This should possibly attribute to the overall speed gains along with KMP. Overall, the authors are able to reduce the execution time from an average of 160 ms seen in [34][35][36] to an avg. of 55 ms in their approach. The authors state that the algorithm is suitable for real-life applications due to its speed and the high resolution images usually present nowadays with advanced cameras in most smartphones. However, they still note the need of enabling improvements for detection in low resolution images and keep it for future work.

In 2019, Blanger and Hirata [24] presented an evaluation of deep learning techniques in their paper which focuses on detecting QR codes in natural scenes. The authors showed a novel adaptation of the SSD architecture and compare it against the FastQR method proposed by Bellusi et al. in [10] on their own dataset. Blanger and Hirata note a substantial improvement in their tests against the approach in [10] where Hirata was a co-author. The results are shown in Table 2.

For recall, higher is better, and for false positives, lower is better. Hence, the authors conclude that the new approach is a definite improvement over the old model while also noting the easily observable more challenging nature of their dataset. The authors also pledge to make this dataset, which they claim to be one of the most comprehensive datasets for QR code, publicly available.

Table 2. Results of Blanger et al. [24] against Bellusi et al. [10]

	Recall	False Positives Count
FastQR [10]	51.3%	186
FastQR (shallow) [10]	55.7%	400
Proposed Model [24]	81.0%	66

For recall, higher is better, and for false positives, lower is better. Hence, the authors conclude that the new approach is a definite improvement over the old model while also noting the easily observable more challenging nature of their dataset. The authors also pledge to make this dataset, which they claim to be one of the most comprehensive datasets for QR code, publicly available.

J. Zhang et al. 2020 [25] present a two layered approach for detection of barcodes (this includes QR codes) which is not only able to provide a better detection accuracy but is also shown to be robust in complex environments and against image distortions. The first layer is a quadrilateral bounding box layer to finely localize barcodes. The second layer is a multi-scale spatial pyramid pooling layer (MSPP) to detect small barcodes. The authors have done a series of tests and have quantitatively compared their algorithm to various other algorithms including [20][30][31] and [37] among others. Zhang et al. observes that the mean average precision (mAP) value achieved by their algorithm (0.879) is the highest among all. However, here it would like to note that Hansen et al. [20] have reported mAP values as high as 0.949 with bounding boxes. Furthermore, the results have been seen to vary acutely with change in the datasets and computer systems used for testing.

It shall be interesting to compare different deep learning based detectors against a common dataset. While [24] is conclusively more performant than [10] where Hirata is a common researcher, comparing the detection algorithms in [20], [24], and [25] against each other on a common dataset (such as [24]) and on the same processor may give a conclusive preference for the most performant algorithm in terms of accuracy and detection rate.

3.3. QR Code Image Correction and Pre-Processing

After detection of a QR code, its image is processed to make it suitable for optimal and accurate decoding. This step is commonly called pre-processing. Due to the real-world applications of the QR code, pre-processing becomes vital to not only enhance the accuracy of decoding but also to make it faster and simpler. A. Jones [38] showed how some QR code images may be detected but not decoded successfully; he presented a deblurring algorithm to improve recognition of low resolution images. This subsection shall give the reader a holistic overview of the scope of pre-processing and the work done for overcoming challenges including blurriness, perspective difference in angle, low-resolution image, and general distortion. Table 3 gives an overview of the papers studied for pre-processing.

Table 3. Overview of pre-processing papers

Reference (Relevant Papers)	Technology	Result
K. Suran 2013 [39]	Corner Detection and Convex Hull	Image correction for shooting angle. Up to 70% increase when deflection angle greater than 17 degrees.
G. Soros et al. 2013 [30]	Fast deblurring/image restoration	Removes uniform blur. Up to 10x runtime improvements (avg 0.6s).
Y. van Gennip et al. 2015 [36]	Regularization approach for image correction	Memory and CPU efficient.
A. Singh 2016 [40]	-	Review on image correction
D.K. Hansen et al. 2017 [20]	Regression network based on Darknet19	Predicts rotation for both 1D and 2D (between 45-135 degrees) barcodes.
W. Xuan et al. 2017 [41]	Variance detection (minimum)	Avoids block error, and corrects general and cylindrical distortion.
M. Li et al. 2017 [42]	Uses image gray feature	Accurate corner detection and perspective transformation.
K. Li et al. 2019 [43]	Geometrical correction	Image reconstruction from cylindrical distortions.
B. Wang et al. 2019 [44]	GAN (Generative Adversative Network)	Removes motion blur. One of the highest avg PSNR value (13.541).
Y. He et al. 2019 [45]	Adaptive local binarization	One of the highest detection rate in uneven illumination (95.65%).

In 2013, Suran [39] presented a paper aimed at reducing the distortion that is expected to be present in real-world environments primarily focusing on the angular deviation produced when shooting with a smartphone camera and aims at correcting it for richer decoding. The algorithm proceeds as follows: First, local threshold and mathematical morphology methods are used to binarize the QR code image with uneven light. Then, the outline of the QR code and the dots on it found and the distorted image is recovered by using perspective collineation. Suran uses corner detection and then applies the convex hull algorithm for geometric correction of image. The results are particularly noteworthy as Suran is able to increase the recognition rate by as much as 68% depending upon the angle of deflection.

Due to distortion being directly proportional to the angle, the same relation is observed in the improvement percentages too. The author notes that while [39] is an important step, in consideration of real world applications further work needs to be done to rectify stronger distortions. In 2015, two different teams, Soros et al. [30] and Gennip et al. [36] described a deblurring algorithm for fast image restoration. Due to new advancements being done in this regard, here discuss only one of them, i.e. [30]. The algorithm presented by Soros et al. based on the standard deblurring procedures including image estimation, kernel estimation, and edge-aware filtering, however, all the steps are carried out in a tight loop with greater speed in this algorithm.

The results of the algorithm were very promising with up to 10x speedups seen in the process when compared to among more than 8 other algorithms. The author notes that the algorithm is specially designed for wearables and mobile devices and hence focuses on speed instead of high quality deblurring. The paper makes some special observations about QR codes and their deblurring/deconvolution environment, the observations are stated as follows [30]:

1. QR codes contain many black and white corners which makes localization easier and more accurate, even in a blurred image.
2. QR codes include a checksum. This is used by the algorithm to terminate when it is correct. Hence, false positives are practically impossible.
3. QR codes contain robust error correction. So, even partially damaged codes can be decoded. Example: when there is slight non-uniform blur in the code area.
4. QR codes have sharp edges. This helps in blur estimation, but poses problems in the blur removal process.
5. QR codes also contain small structures which need to be processed because they can make the blur estimation process prone to errors [46].

Soros et al. [30] have applied many different speed optimizations and constraints, here it is achieved to specifically mention one optimization that they have applied to the fundamental process of kernel estimation. The authors highlight that while the usual method for kernel initialization is a blur function such as Dirac delta. They developed a new grid-shaped kernel initialization which converges much more accurately. The authors also noted that while the grid-shaped kernel converges relatively slower, this can be easily solved by using the data of inertial sensors during image capture.

In his review paper, Singh [40] presents the common workflow for image pre-processing in special regard to the angular distortion. The workflow nicely reflects the algorithm presented by Suran [39] too and is shown in Figure 4.

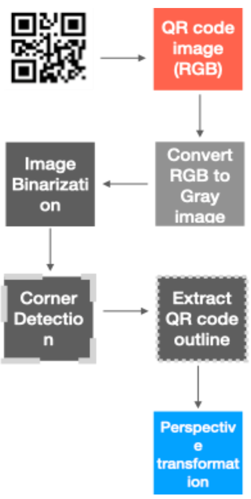

Figure 4. QR code image pre-processing flow diagram [40]

Hansen et al. [20] have used the Darknet19 [47] architecture for developing a network that predicts the required 2D angular rotation and performs it. Hansen et al. noted that in 2D barcodes, applying image rotation may lead to longer execution times but significantly increases the detection accuracy too. The results presented in the paper [20] show that while the execution times increase by a small margin of 20 ms, the accuracy improvement goes up by as much as 20%.

Along with [20], two other methods are also presented for image correction [41][42] out of which [42] is particularly notable for its approach. M Li et al. [42] presents the use of image gray feature to get the accurate vertices and then are able to apply accurate image correction based on projection transformation. The work is particularly notable because the authors are able to tackle angular distortion as well as light distortion with their correction. Their algorithm achieves an average of above 90% detection for various angles and also for different illumination intensities (0, 1, 2). The authors prove the superiority of their method by noting that the accuracy achieved by convex hull correction [39] is around 88% compared to 92% achieved by theirs. However, it shall also be noted that the algorithm isn't able to help when the illumination level is very low (-1) with just 6% accuracy. Hence, further work is needed for very dark environments. A simple and widely adopted industry fix is to use flashlight (built into almost every smartphone) to increase illumination. Figure 5 shows the best performing detection accuracy algorithms for both - 2D and 3D angular rotation.

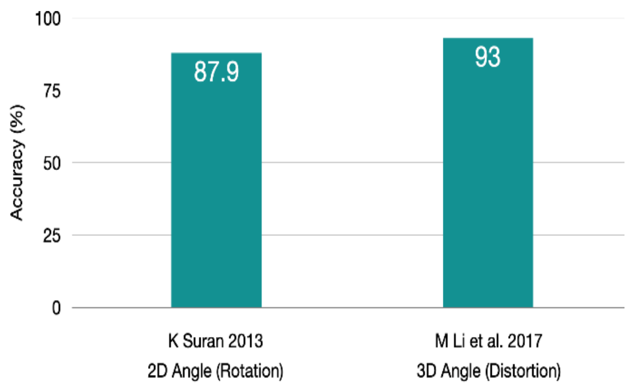

Figure 5. Detection accuracy achieved by highest performing 2D and 3D angular correction algorithms

B. Wang et al. in their paper [44] have presented, use of GANs to remove motion blur from QR code images for accurate decoding. The authors have drawn comparisons with the traditional deblurring algorithm and have made some notable points. The authors state the difference as follows: "Compared with the traditional deblurring algorithm, this method eliminates the process of blur kernel estimation, directly restores the motion blurred image." The authors have done tests and have drawn comparison between their algorithm against DelurGAN by Kupyn et al. [48] and Gong D2017 [49] on the basis of peak signal-to-noise ratio (PSNR) values. PSNR is an objective index for evaluating images. Generally, higher the value of PSNR, smaller the difference between the restored image and the original image (hence, higher is better). The results from their findings are shown in Table 4.

Table 4. Comparison of PSNR values, Wang et al. [44]

Algorithm	PSNR Average (Higher is better)
DeblurGAN [48]	10.106
Gong D2017 [49]	10.517
Proposed Model [44]	13.541

The GAN model proposed by the authors is shown to have a higher performance while having the same execution time as that of the Deblur GAN at around 0.978 ms. The authors note that their scope for future work in making correction of higher degrees of blurriness effective.

Y. He et al. 2019 [45], present an improved version of the Sauvola approach [50] for QR code image binarization to deal with uneven illumination. The algorithm uses and improves the adaptive local binarization technique of [50], it features dual windows to describe variable contrast level and window size depending upon illumination levels. The algorithm features a rich set of rules that help in determining the accurate threshold value to distinguish background and foreground of the QR code. The authors use the Dubska dataset [31] for testing against many algorithms including Otsu [32] and Sauvola [50] among others, and even with the original image. The compacted results of their tests are shown in Table 5. It is evident that according to the tests performed by the authors, their method is conclusively superior to other methods. However, it should be noted that the dataset used plays a major role in the test results and real world testing is a must. It is also interesting to see that the original image fares better than all the other algorithms (except the proposed method) which further highlights the need of standardized testing for a greater understanding. Denoising using deep learning is used in other applications as well. In [51] N. Atashafrazeh and A. Farzan explain in their review paper about the approaches used for searching hand written documents which can be recognition based or recognition free. These are machine learning techniques. In [52], G. Latif and A.H. Khan propose a multi-step technique for MR Iage denoising and smoothing. MR image is denoised using deep CNN method in the pre-processing phase. To further reduce the noise, 2D FFT is then applied to the image.

Table 5. Recognition rate comparison results (compacted) [45]

Method	Recognition Rate
Otsu	50.93%
Sauvola	90.06%
Proposed Method	95.65%
Original Image	94.41%

4. OVERVIEW

In this section an overview of all the important papers and the challenge they solve will be given. The papers whose work has been conclusively shown to be bested by newer work have not been included in this table. Table 6 will serve the purpose of being a guide to the best-set of algorithms for any given step in the QR code recognition workflow.

In the Table 6 the comprehensive overview of relevant papers are given. In addition, their research fields, 'x' marking has been used against the paper references to denote that the respective area/domain are discussed in the paper. For review papers, appropriate textual marking has been used.

Table 6. Comprehensive table for relevant papers and their areas

Reference (Relevant papers)	Detection		Pre-processing		
	Time	Accuracy	Angle	Blur	Illumination
Suran et al. 2013 [39]			X		
G. Soros et al. 2013 [30]				X	
Grosz et al. 2014 [16]		X			
Tong. et al. 2014 [17]	X				
Y. Gennip et al. 2015 [36]				X	
P. Bodnar 2015 [2]	Extensive Review				
A. Singh 2016 [40]			Review on pre-processing		
Lopez-Rincon et al. 2017 [19]		X			
Hansen et al. 2017 [20]	X	X	X		
Xuan et al. 2017 [41]			X		X
M Li et al. 2017 [42]			X		X
S. Li et al. 2018 [21]	X				
B. Jiang et al. 2019 [23]	X	X			
Blanger et al. 2019 [24]		X			
K. Li et al. 2019 [43]			X		
Wang et al. 2019 [44]				X	
Y. He et al. 2019 [45]					X
Zhang et al. 2020 [25]		X			

5. CONCLUSION

Owing to the commercial applications of QR codes and the real life scenarios, scanning using a smartphone camera has been the most common method of adoption. This involves three major steps as discussed in the introduction- localisation (detection), pre-processing, and decoding. That means that different algorithms can be applied by the organization concerned for their applications for different stages. Hence, this review shall help in determining the most suitable algorithm for each stage for commercial use and also the fundamental understanding from various aspects for researchers. While conducting this study, one major hurdle faced is the lack of a common trusted and preferred database for researchers. This has made benchmarking of new work difficult against the state-of-the-art algorithms and consequently the comprehensive study the technology too. Many authors including Nina S. Hirata and others have time and again pledged to make their datasets available publicly, and it is important to establish a standard database to produce a conducive environment for future work. With the increasing computational power of mobile devices, focus on time optimization has been less against accuracy, and fairly so. Deep learning has been seen as a preferred technology among researchers for QR code detection, which is also very versatile in terms of the training dataset used. Finally, with the understanding that QR code decoding from a static image is easy to implement and beneficial, it is aimed here to urge organizations to adopt static detection and decoding too for greater possibilities.

For future work, authors would like to implement the different algorithms for QR code detection specifically, and test them all against a variety of datasets on the same computing machine. It is obvious that such tests would give a fair evidence of the best performing algorithms in different aspects including time, accuracy, and environment, and also of the most challenging dataset for researchers.

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