

Evaluation of Barcode Decoding Performance using ZXING Library

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ABSTRACT

In this paper a reliable, valid and generic software environment is introduced which offers the possibility to evaluate and compare different Optical Transmission Patterns (OTPs). This framework generates a huge library of evaluation images applying synthetically all distortions one should expect for a real-world application. The synthetic analysis environment is based on OpenGL, which enables three-dimensional operations covering for example perspective projections as well as dynamic three-dimensional modifications through vertex programs and tessellation. We examined most common OTPs, like the QR-Code, MaxiCode and EAN-13. To evaluate the expressiveness of the OpenGL environment, we build a mechanical device offering practical results, which can be confronted with our theoretical results. We found out that QR-Code delivers the best decoding results but still suffers from decoding problems within certain angles. Moreover we could prove that the results of the OpenGL environment highly correlate with the practical results.

Keywords

Optical Transmission Pattern, Barcode, ZXing, QR-Code

1. INTRODUCTION

Pervasive computing applications are based on a tight coupling of physical and virtual spaces. Digital assets and physical objects start to interact. A basic enabler for pervasive computing applications is pervasive internet access and pervasive location awareness. Then digital objects can be embedded into the real world based on their location and their properties can be managed

on the Internet-of-Things. Unfortunately, both enabler technologies, namely location-awareness and pervasive network access, are not yet available inside buildings. For this application domain, a more direct interaction between digital and physical world is needed. One way to achieve at least one direction, namely location and context-awareness is through the deployment of visual markers, which encode both location and content of a virtual object. The simplest yet effective realization of such markers is through the use of barcodes, which we call Optical Transmission Patterns (OTPs).

OTPs are machine readable codes, usually scanned with hand-held scanners or with cameras integrated in modern smart-phones. These patterns can be organized in one dimension, like EAN-13, or in two dimensions as for example within Quick Response Codes (QR-Codes). The main difference between 1D and 2D barcodes is the amount of data they encode and the error correction they offer. Due to the limited data capacity offered by 1D barcodes various 2D barcode patterns have been developed and introduced, using different shapes for their symbols, different colors and different orientation detection patterns. One example is the High Capacity Color Barcode (HCCB) [6], which encodes data within the color domain. Each symbol is represented by a triangle of a certain color. Though this approach is promising, it has major difficulties while decoding in noisy environments. Hence, most codes rely on a binary representation in the color domain, which is also easy to print on cheap printers. The most common OTPs are the QR-Code [3], the DataMatrix [1] and the MaxiCode [2].

In the case that such transmission patterns are scanned with smart-phones and their integrated camera many

influences can affect the quality of the image the decoder has to work with. In case the pattern is not scanned in optimum quality the decoder should still be able to decode the data correctly. Quality can be dramatically reduced by distortions during the scan process. Common distortions are user's motion resulting in blur, perspective distortions depending on the relative orientation of camera and transmission code, lighting conditions resulting in difficulties in distinguishing light and dark regions as well as Gaussian blur due to focusing problems as well as reflections for the case, a code is transmitted from a display. Therefore, it is important to spot weaknesses as well as the strength within the different scan patterns and common decoder implementations. Especially in the scenario where barcodes are scanned from a screen such distortions have great impact on reliability and user acceptance. In this paper we are introducing a generic evaluation environment where distortions can be applied to OTPs. Subsequently the impact on encoding can be evaluated in order to perform optimizations on decoding algorithms. As a basic example, we chose to analyze the behavior of the QR-Code, the EAN-13, and the MaxiCode.

In the next Section 2, we briefly review related work, Section 3 presents the concepts of our evaluation environment, and Section 4 gives some preliminary results on the performance of QR-Code, MaxiCode and EAN-13 decoded by using the widely used ZXing library. Finally, Section 5 concludes this work.

2. RELATED WORK

Any kind of optical information transmission can be found almost everywhere and can be seen as an alternative to radio frequency communication. There are various types of optical transmissions such as Free Space Optics (FSO), Visible Light Communication (VLC) or Optical Transmission Patterns (OTPs).

FSO uses laser beams to transmit light to a receiving station. The most important type of use is as a connection between base stations of a cellular network where a cable connection is no option, Unmanned Aerial Vehicles (UAVs), aircrafts and nomadic communication partners [5]. Within this transmission, sender and receiver have to be well adjusted such that the laser beam is correctly detected at the receiving station.

VLC is mainly used for indoor applications. The information transmission basically works with white LED's transmitting pulsed data and a special optical receiver [9].

OTPs such as barcodes are widely adopted nowadays. A very popular example of use is the barcode. It offers a possibility, to assign some digital information (e.g., a unique identifier) to goods just by printing a special label on the packing. For example shipping and sales departments are using 1D as well as 2D barcodes to

optimize their processes, guarantee reliability and to increase efficiency. In this paper we are focusing on this kind of OTPs. While these classical barcodes are usually aligned in one dimension and relatively easy to decode even with perspective distortions, they have a relatively small capacity. The most important variant, EAN-13, is only able to store a 13 digit number. In 1994, Denso Wave introduced a new type of barcode called Quick-Response-Code (QR-Code), which was able to store much more information inside the code. The first application was to support the management of a car manufacturing process [3]. Nowadays, QR-Codes are widely known and used to promote websites.

Some other patterns were also successful, such as CyberCode [12], the DataMatrix [1] or the MaxiCode [2]. In 2002 the J-Phone was introduced, which is considered to be the first cellular phone, which was able to read 1D and 2D barcodes with its integrated camera [7]. Nowadays, all smart-phones are equipped with a camera which enables decoding of barcodes. The decoding performance of such systems depends on many factors such as the *detectability* of the code, an image segmentation operation, where the barcode has to be distinguished from its surroundings, the *decodability* of the code, which depends on many factors such as stability against rotation, blur, perspective distortion, illumination, shadows and on the internal redundancy of such codes including error detection as well as error correction codes.

Though the QR-Code is widely deployed and accepted and ubiquitous applications nowadays often rely on having some sort of internet access, making the communication of a website address sufficient for deploying complex multimedia information such as a video, the coding and decoding of digital information in markers is still a very active research project. A recent system called PixNet [11] for example, applies the well-known paradigm of orthogonal frequency division multiplexing (OFDM) to reach high data rates on a display to camera communication scheme.

3. EVALUATION OF OPTICAL TRANSMISSION PATTERNS (OTPS)

Due to the complexities in optical information transmission and distortion, the evaluation of such systems is often very difficult and the comparison between research results of different research groups is often impossible. Furthermore, the public libraries used in all major barcode scanner applications could benefit from an isolated and well-defined framework for the evaluation of OTPs.

Such a framework for evaluating and comparing OTPs is the main idea behind this work. Therefore, we want to enable the evaluation of a given transmission pattern, a decoder software or an encoder software in a generic framework.

This framework will generate a huge library of evaluation images applying synthetically all distortions we should expect for a real-world application. Furthermore, relevant combinations of such distortions are evaluated and finally a physical system is described, where a smart-phone is mounted on a moving arm. This system is then used to compare the results obtained from synthetic image distortion with a real-world experiment.

The synthetic analysis environment is based on OpenGL, which enables three-dimensional operations covering for example perspective projections as well as dynamic three-dimensional modifications through vertex programs and tessellation. Furthermore, it is relatively easy to operate on the transmission code itself, which is typically some texture in a three-dimensional scene, or on the projected scene using pixel shaders. In this way, Gaussian blur or subpixel misalignment can be easily evaluated while the complete environment keeps fast enough for a large-scale evaluation through hardware acceleration of merely all operations [10].

The decoding of the modified transmission code is done by ZXing an open source software which supports decoding and encoding for various 1D/2D barcodes. ZXing focuses on built-in cameras on mobile-phones being able to decode most codes directly on the device without the need of server communication [4].

3.1 OpenGL Environment

For a basic evaluation, the barcode is displayed as a texture in OpenGL and rotated in all three dimensions. Both x- and y-rotation are passed through in steps of one degree, ranging from -90° to $+90^\circ$, whereas the z-rotation is done in steps of 6° ranging from 0° to 360° . This selection is suitable to cover all the major angles of 0° , 90° , 180° and 270° and gives an impression of the robustness of the barcode with respect to rotating it around its normal. Each possible combination of rotations is stored in form of a screenshot, resulting in a total of 1944000 images with a resolution of 1024×768 pixels. Figure 1 shows such a screenshot rotated $+15^\circ$ in x-direction, -17° in y-direction and 78° in z-direction.

3.2 Decoding of Barcodes with ZXing

For the creation and decoding of the barcodes, open source encoders like qrencodelib [8] and the decoder ZXing were used. For instance the QR-Code encoding parameters are shown in Table 1.

The resulting codes were rotated in the OpenGL environment and the screenshots were stored according to Section 3.1. Subsequently, the ZXing decoder was utilized to decode every single stored image. For the evaluation, a heat-map was created for each step in the z-rotation axis (see Figure 2), where each dot represents the result of decoding a single screenshot with ZXing. The coding scheme is displayed in Table 2. While not

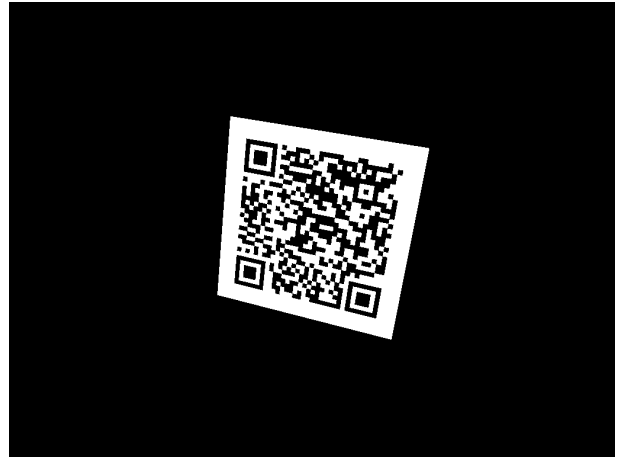


Figure 1: A screenshot of a rotated QR-Code rendered by the OpenGL environment.

Description	Parameter
Code Size	L
Error Correction	H
Encoding	UTF-8
Dotsize	16
Distortion	No distortion applied

Table 1: The parameters for code generation with qrencode.

taking into account various lighting conditions, focus, or reflections, the test environment offers a basis for comparing different codes with respect to robustness in case of angular distortion.

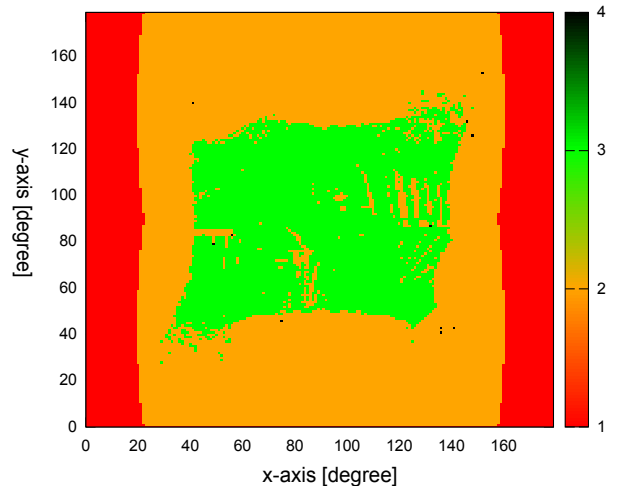


Figure 2: Heat-map for a QR-Code with zero z-rotation.

4. RESULTS

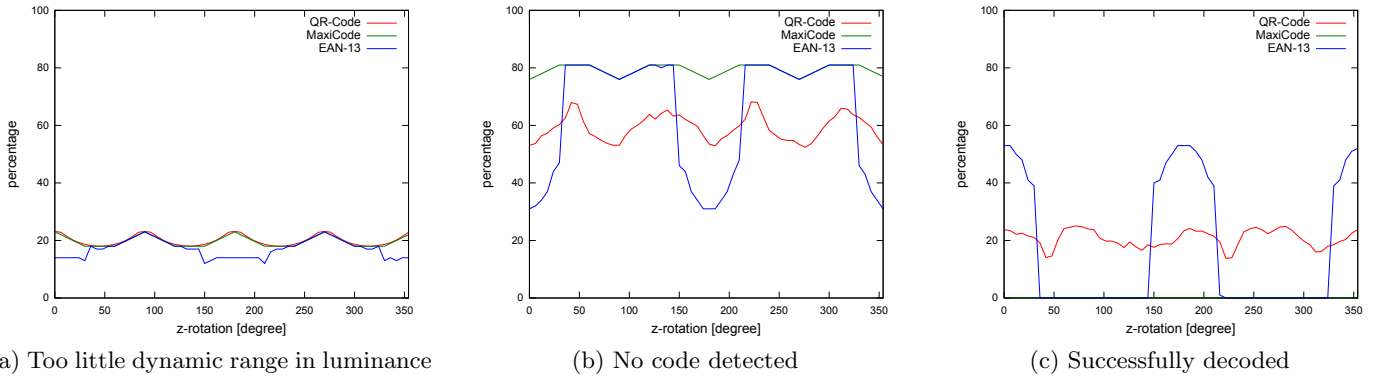


Figure 3: Comparison of different result types concerning amount.

Stored Number	Result of ZXing
1	Too little dynamic range in luminance
2	No code detected
3	Successfully decoded
4	PNG not readable or error correction not recognizable

Table 2: Coding scheme for heat-map.

The evaluation of different barcodes with respect to robustness is achieved in two ways. First, the OpenGL environment is used for testing the impact of rotation in all three axes, then a real world setup with two smart-phones is used to prove the expressiveness of the OpenGL results.

As said before, a total of 1944000 images with a resolution of 1024 x 768 pixels were created, rotated from -90° till $+90^\circ$ in x- and y-axis and from 0° to 354° in 6° steps in the z-axis. Those images were decoded with the ZXing library giving some insight into the rotational robustness of barcodes.

The first result is the susceptibility of QR-Codes and the ZXing library to rotation, especially to rotation around the z-axis. Rotating the QR-Code within x and y one might expect a green rectangle with sharp edges, but our results show that two edges are frayed within the range of $x[30;50]$ and $y[30;50]$ as well as at $x[120;140]$ and $y[120;140]$. Surprisingly, the other two edges at the range of $x[30;50]$ and $y[120;140]$ are not frayed. Thus, we assume that the perspective distortion and the anchorpoint detection within ZXing is not rotation invariant, even in the simple case when the QR-Code is not rotated around the z-axis (see Figure 2).

When rotating around the z-axis, one would expect a rotated version of the heat-map. This is also not the case as can be depicted in Figure 4. The figure shows the decoding results of QR-Codes rotated 42°

around the z-axis and all possible rotations in 1° steps around the other two axes. The heat-map shows the serious problems of the ZXing decoder with QR-Codes which are rotated around the z-axis. However, some QR-Codes at certain angles, which could not have been decoded before, now become decodable. This is the case in the range of $x[40;60]$ and $y[19;21]$ where no code was detected in the previous heat-map in Figure 2.

Figure 3 shows the result for all three evaluated OTPs, namely the QR-Code, MaxiCode and EAN-13. It depicts the total number in percent of screenshots which could be decoded, where not detected, or had too little dynamic range in luminance. Examining the QR-Code the decoding rate is maximal, when it is aligned along the x- and y-axis (rotated 0° , 90° , 180° , or 270° around the z-axis) and is minimal, when rotated 45° , 135° , 225° , or 315° , which we call the problematic angles. Nevertheless, we observed a global maximum of successful decodings at 90° instead of at 0° which could mean that the normal method of taking a photo of a QR-Code is not the best. MaxiCode suffers from great problems in all three possible decoding results. The most concerning result is that of successfully decoded codes. Here it is approximately zero percent. A closer look at the evaluation results shows, that decoding works only for the major angles 0° , 90° , 180° and 270° , except of some outliers. Concerning these angles the average successful decoding rate is about 0,0035 %, which is much worse compared to the other transmission patterns. In contrast to these results EAN-13 surprises with a quietly good decoding at certain angles but than being not able to scan anything at long ranges of z-rotation. This can be explained by the single line scan pattern ZXing is using for EAN-13. To sum it up, the results show that QR-Code is quiet good over the whole range of z-rotation. MaxiCode suffers from real problems all over the rotation and is not resistible against rotation. EAN-13 is at some angles much better than QR-Code but still is not able to scan anything at certain z-angles. Note that the ZXing decoder is deterministic meaning

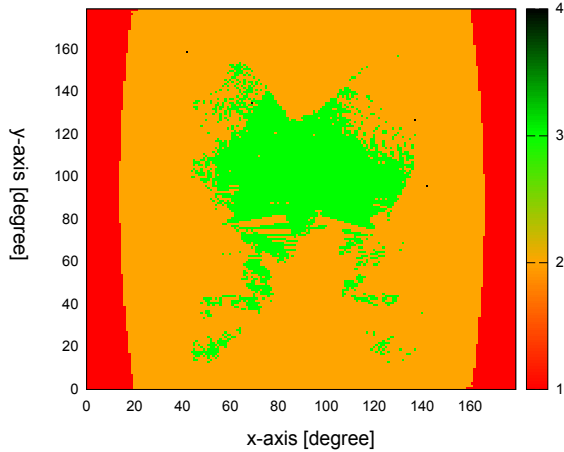


Figure 4: Heatmap for a QR-Code with 42° z-rotation.

that given the same images the decoding result will always be the same. For this purpose we did several runs using our environment and compared the results with each other.

To evaluate the expressiveness of the OpenGL environment, we build a mechanical device for testing the performance of ZXing in a real world scenario on a smart-phone (see Figure 5). We are using two smart-phones, whereby the first phone displays the OTP (compare Figure 5 (b) (1)) and second can be rotated around the first, trying to decode the code with its integrated camera (Figure 5 (b) (2)). To determine the scan angle, a potentiometer is connected to a tube fixed within the ball bearing, holding the swivel arm where the scanning smart-phone is mounted. A microcontroller (compare Figure 5 (b) (4)) does simple analog reading, where the rotation-angle is measured directly with a resolution $<1^\circ$ and displayed on an LCD as shown in Figure 5 (b) (3). The camera-phone mounted on the swivel arm can be rotated around the y-axis. The setup offers less functionality as the OpenGL test environment, but a consistency of the theoretical results with the physical environment can deduce the expressiveness of the previous results.

The experiments with the practical test environment were carried out in a room both with normal daylight and in darkness, where the only light was provided by the screen of the smart-phone displaying the different transmission patterns. The camera of the smart-phone decoding the OTP was triggered for 5 seconds for each degree of horizontal rotation, thus allowing the camera to autofocus. The results (see Figure 6) show a good consistency of the OpenGL test environment with the real world. The practical environment even allows decoding in a slightly larger rotation angle than the OpenGL software environment. However, you can see

a narrow dent at approximately 110° in the practical evaluation at daylight. In that case, a decoding was only successful after 10 seconds and the effect was not reproducible in a second test run, where the decoding was successful within 5 seconds. It might have been a reflection on the surface, but it serves as a good motivation for our software test environment, where random environmental influences can be avoided.

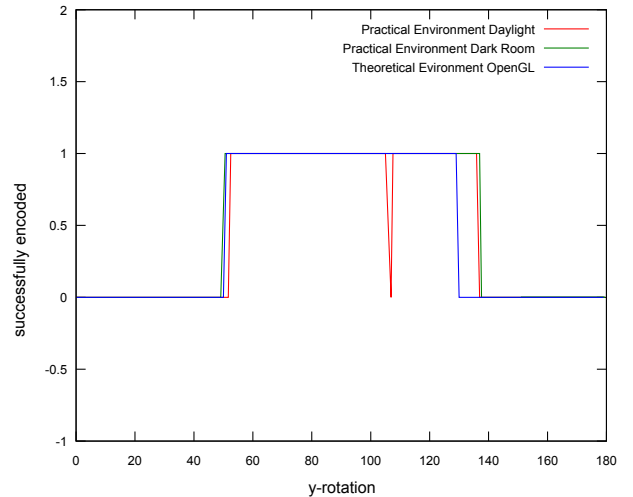


Figure 6: Result of the practical evaluation.

5. CONCLUSION AND FUTURE WORK

In this paper a reliable, valid and generic software environment was introduced which offers the possibility to evaluate and compare different OTPs and the influence of distortions within the decoding process. The environment was implemented in OpenGL allowing for three dimensional rotation of OTPs. During the rotation process screenshots are generated which can then be decoded with an arbitrary decoder. The result gives an impression for the robustness of decoder and barcode with respect to the applied distortions.

Using this test environment, we examined three different transmission patterns, the QR-Code, MaxiCode, and EAN-13, encoded and decoded with open source encoders and the ZXing decoding software. We found out that ZXing has some difficulties with QR-Codes concerning rotation, especially the rotation around the z-axis. Based on our observations, we define the problematic angles to be 45° , 135° , 225° , and 315° which offer a minimum percentage of successfully decoded QR-Codes. Moreover, the z-rotation of 90° has the best decoding probability. Decoding MaxiCode with ZXing suffers from great problems concerning the successfully decoding rate, which is almost 0% even at the major angles at 0° , 90° , 180° and 270° . ZXing decodes EAN-13 surprisingly well, caused by the single line scan pattern.

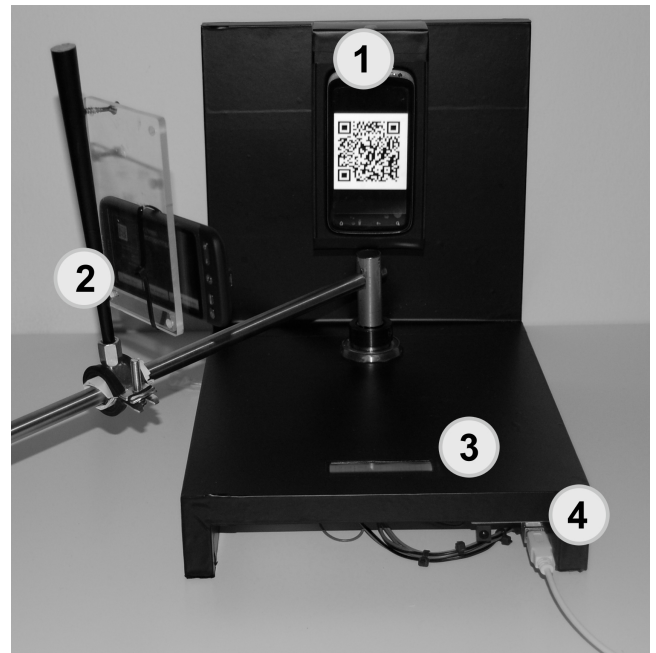
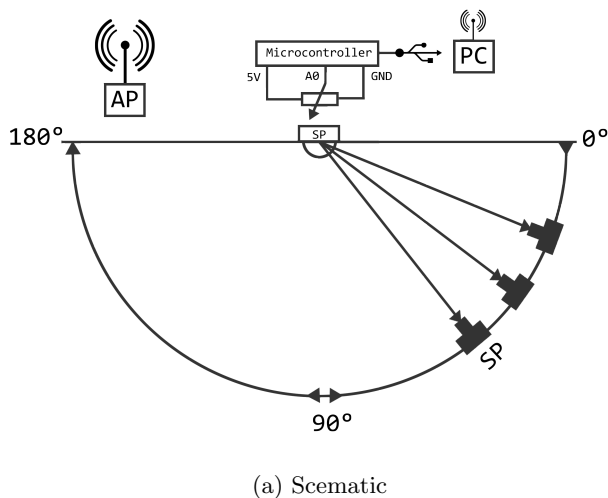


Figure 5: The practical evaluation environment.

But still it suffers from almost 0% of successful scans at certain z-angle rotations. The expressiveness of the results generated by our OpenGL test environment is supported by a practical setting, where a smart-phone camera decodes a barcode displayed on the screen of a second smart-phone.

In future work we focus on improving the decoding process concerning robustness and information density. We try to improve the ankerpoint detection by using graystyle maps during the decoding process to improve the maximum scan angle where decoding is still possible.

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