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3D Barcode Modulation Method for Data Transmission in Mobile Devices

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Abstract: The idea of 3-D scanner tags is of awesome importance for use in remote information transmission between handheld electronic gadgets. In a normal setup, any record on a mobile phone, for instance, can be exchanged to a second wireless through a progression of pictures on the LCD which are then caught and decoded through the second's camera PDA. In this study, another approach for information tweak in 3-D standardized tags is presented, and its execution is assessed in examination to other standard routines for scanner tag adjustment. In this new approach, orthogonal recurrence division multiplexing (OFDM) adjustment is utilized together with differential stage movement keying (DPSK) over contiguous recurrence area components. A particular point of this study is to build up a framework that is demonstrated tolerant to camera developments, picture obscure, and light spillage inside of neighboring pixels of a LCD.

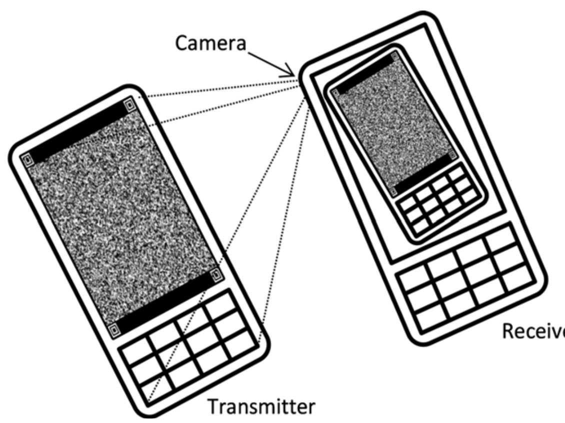
Keywords: Barcode, data transfer, differential phase shift keying, orthogonal frequency-division multiplexing (OFDM) modulation.

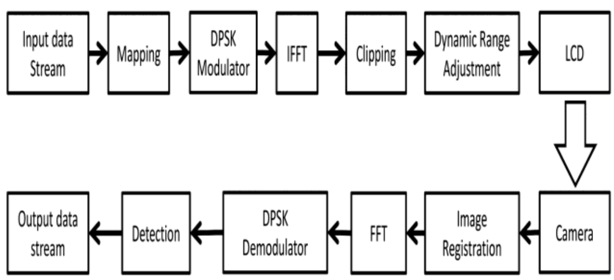
I. INTRODUCTION

BARCODES have assumed an extraordinary part in encouraging numerous distinguishing proof procedures since their development in 1952 [1]. Truth be told scanner tag is a straightforward and savvy strategy for putting away machine discernable computerized information on paper or item bundles. As squeezing needs to exchange considerably more information speedier and with high dependability have risen, there have been numerous enhancements that were made on the first scanner tag outline. Innovation of two dimensional (2D) or framework scanner tags opened another front for these practical codes and their application in more intricate information exchange situations like putting away contact information, URLs in addition to other things, in which QR codes [2] have turned out to be progressively well known. An examination of 2D scanner tag for every formance camera telephone applications can be found in [3].

A significant part of the endeavors in lattice scanner tag advancement have been devoted to standardized identifications showed on a bit of paper as that is the way they are typically utilized. With the substitution of books with tablets and digital book perusers one could examine that re-arrangement of the paper with LCD may open another promising front for more extensive uses of 2D scanner tags as a mean of information exchange. In addition not at all like the static paper, the LCD might display time-differing standardized identifications for the inevitable exchange of floods of information to the accepting electronic device(s) as portrayed in Fig. 1. This thought has been actualized in [4] where transmission of information between two phones through a progression of 2D QR codes is examined, accomplishing bit rates of under 10 kbps for cutting edge cell phones. Later the thought was further created in [5] in which a PC screen and a computerized camera are utilized for transmission and gathering with bit rates of more than 14 Mbps accomplished in docked transmitter and recipient conditions over distances of up to 4 meters. In any case, this rate drops to a little more than 2 Mbps when the separation is expanded to 14 meters.

The superior execution of the later usage is accomplished utilizing a more successful adjustment and coding plan for The general thought is to utilize the opposite Fourier change (IFT) of information like OFDM to regulate LCD pixels. While picture obscure and light spillage enormously decreases the execution of QR decoders they have a restricted impact on OFDM balance. Besides their performance corruption is limited to known parts of the decoded information.





This earlier learning on non-uniform slip likelihood may be utilized for versatile mistake rectification coding in view.

Diagram of the algorithm used for data transfer .error correction coding, current study amplifies this thought through extra adjustments on the tweak plan in a manner to relieve LCD-camera relative developments amid the catch of a solitary edge, which re-sults in movement obscure mutilation on the caught pictures. This sort of contortion as would be itemized later seriously corrupts the execution of Quadrature Phase Shift Keying (QPSK) modulated OFDM signals.

The required development resilience is accomplished by placing information in stage contrasts of neighboring recurrence segments prompting a DPSK-OFDM plan which would be called just the DPSK technique all through this study. Watching that any stage contortion because of movement obscure would influence neighboring recurrence segments unimportantly, information may be transmitted dependably even in the region of high LCD, camera relative movement. A framework's graph imagined is appeared in Fig. 2. This technique additionally wipes out the direct estimation prerequisites bringing about lower preparing force.

To expand information transmission rate, one ought to consider ex-tracting most extreme information from a solitary picture appeared on a LCD and after that build the rate at which continuous edges will be decoded. In light of this issue, any system that is in-troduced ought to productively use the accessible data transfer capacity con-sidering movement twists.

Past studies have shown the plausibility of such frameworks and have tended to the impacts of single twists like direct misalignment [9], defocus obscure [10] and igniting [11] on the balance techniques under thought, yet they have not gave a similar evaluation of these frameworks in a controlled situation. In addition, no examinations were presented in defense of LCD camera movements which extraordinarily influence the performance of the framework in applications that include handheld camera-telephone recipients. As an outcome, this study introduction duces DPSK-OFDM as a method for relieving LCD camera motion bends and sets a progression of recreations in light of mathematical displaying for obscure and movement on the got pictures in a manner that the mutilation would be the same for PAM (Pulse Amplitude Modulation), QPSK-OFDM and DPSK-OFDM modulations. Thus, a solid examination can be made between these real tweak techniques paying little respect to different parameters influencing the execution of such reasonable frameworks.

II. DATA TRANSFER CAPACITY

There are many factors affecting the amount of data that can be extracted from a particular LCD, some of them depend on the LCD design itself and others on the camera working as the receiver. Moreover, there are some limitations due to the system's processing capability and power consumption.

Despite the fact that by and by, it may be trying to acquire a reasonable appraisal of the framework's execution, it is critical to realize what influences the exchange rate and what should be possible about every constraining element in this information transmission medium. The information limit of a LCD may be computed by considering for occasion the greatest number of bits in a crude picture as appeared on the LCD. A showcase having the lines and segments, demonstrating a shading picture in channels (normally for red, green and blue) and shading bit profundity of bits per channel would have the most extreme data of:

This is the most extreme data that can be appeared on the LCD on a solitary picture because of the discrete way of the information appeared. A revive rate of for the LCD prompts an information rate of For a cutting edge wireless with a high determination dis-play having 16M hues, the parameters would be, and Hz bringing about M bits and Gbps, which is a greatly high information rate notwithstanding when contrasted with current radio recurrence wire-less advances. Lamentably, this rate can't be accomplished because of the confinements as portrayed in the following Sections II A–D.

A. Camera Limitations

A propelled camera could be considered as a device which tunnel itally tests a 2D signal. For right testing of persistent housings in time, camera catch rate should be 2 times the display restore rate) unless there is a synchronization system set up to authorize the camera shade when the photo is stabilized on the showcase (accurately between packaging changes). As it is not usually the circumstance, if the camera catch rate is for example Hz then the showcase empower rate couldn't surpass 4 Hz. To satisfy the Nyquist criteria for picture determination, each pixel of the photo showed up on the LCD should be tried by 2 or more pixels in the camera [12]. The photo sensor uses foreordained number of bits per channel for change of each shading pixel, coming to fruition into quantization confusion. To limit the effect of this hullabaloo on the general acknowledgment execution it should be maintained dB underneath structure noise level [13], which of course must be kept up well underneath sign power level, dependent upon the regulation method used, with a particular deciding objective to have satisfactory piece misstep rates (BER) [14].

TABLE I READ RATE OF QR CODES IN DOCKED AND HANDHELD CONDITIONS

QR Version	V1	V6	V11	V16	V21
QR Size	21×21	41×41	61×61	81×81	101×101
Docked	100%	100%	97%	99%	10%
Handheld	100%	100%	84%	71%	6%

B. Power Limitations

The limit of each correspondence channel relies on upon the signal's force sent through that medium as anticipated by Shannon hypothesis [15], and for this situation the

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force distance and angle between camera and LCD (perspective distortion);

- camera and subject relative motion;
- out of focus lens;
- compression distortions;
- unwanted ambient light sources;
- dirt and permanent marks on the LCD;
- noise (primarily additive Gaussian noise).

Moreover, nonlinear distortions exist in a typical optical wireless data transmission setup due to transmitter and receiver physical limitations that are discussed in [21]. These undesir- able effects should be addressed to ensure the feasibility of the algorithm under realistic scenarios, while preserving the ability for attaining high data transfer rates.

Thus the average power of $\mathbf{D}_a$is maximized for LCD projec- tion.

Finder Patterns: Proper demodulation of data requires pre- cise extraction of the modulated data from captured image and compensating for any perspective distortions. General finder patterns used with 2D barcodes may be used here like the 1, 1, 3, 1, 1 pattern used in QR-codes, for which fast and efficient detection algorithms have already been developed in [25] and [26]. A sample image generated by the preceding method is shown in Fig. 6 as it would be shown on the LCD of the transmitting device.

III. PSK-OFDM

While LCD innovation is enhancing pixel to pixel isola-tion, a picture's percentage catch bends still remain, bringing about neighboring pixels of the standardized identification stir up in the picture and re-sulting in some sort of Inter Symbol Interference. The fundamental thought in determining this issue is to translate the standardized tag picture as a remote radio sign for which ISI lessening strategies have al-prepared been demonstrated fruitful. One of the best and most achievable regulation strategies equipped for adapting to serious conditions in band restricted correspondence channels is the purported Orthogonal Frequency Division Multiplexing or OFDM [22]. The a general thought is that when managing band-restricted, force con-strained, multipath channels, it is more effective to exchange a group of tight band signals in parallel rather than a solitary high transfer speed signal. Similarities of Barcode and Wireless RF Channel

For simplicity each 2D image is reformulated into a 1D row vector containing all pixels in the 2D image. Each row can be considered as a time domain signal which has Pulse Ampli- tude Modulation (zeros are black and ones are white pixels). Consider taking a picture of this single row, in a band limited channel which has a combination of camera focus problems, resolution limitations, light leakage from white to black pixels, among other things. Moreover in a multipath channel in which the camera moves during image capture and mixes up the image of several neighboring pixels, the resulting image will suffer from high ISI. To solve these problems in a time domain radio signal, OFDM method is used to essentially divide the channel into multiple orthogonal low bandwidth channels and the low rate data is sent into these channels in parallel. So in case of the 1D data the inverse Fourier transform is used for displaying the data instead of using the PAM modulated process, where Her- mitian symmetry conditions should be met to have real-valued outputs. As a result, most artifacts only affect the high frequency components leaving low frequency components intact for data transmission.

This idea may be generalized to 2D signals to meet the requirement for transferring the entire image at once. Instead of 1D inverse Fourier transform, the 2D version is used such that the effect of artifacts acting on two axes would be confined to high frequency components. The exact modulation scheme will be discussed later in this study.

In general each sub-carrier in an OFDM signal is modulated using M-quadrature amplitude modulation (M-QAM). Thus proper phase shift of each element should be estimated and compensated for before demodulation. This generally requires specific conditions on the channel characteristics like fast fading where pilot tones are used for channel estimation or slow fading where most methods would require multiple symbols in seeking similar channel responses (i.e.. similar transfer functions) [23] and [24].

When using OFDM for transmission of data as images, all the channel equalization computations should be based on a single OFDM frame due to the independent channel response between subsequent frames, unless the frame rate is very high. In fact each frame is distorted by LCD-Camera relative motion during its own capture time. To mitigate this problem the phase differs- ence between adjacent elements is used to convey data. Using DPSK modulation prior to applying the inverse Fourier trans- form in OFDM modulation, data would not have to be stored in the absolute phase of the received elements but rather in its phase difference to the neighboring element, which eliminates the requirement for channel estimation and equalization if the channel response does not vary abruptly between adjacent sub-carriers.

Transmitter:

One of the advantages of using OFDM is its effective com- putation method which uses the Inverse Fast Fourier Transform (IFFT) to modulate input data into orthogonal frequencies. The modulated signal should be real-valued in order to be shown on an LCD, so the input to the IFFT algorithm should have Her- mitian symmetry. This requirement is shown in the following equation:

$$\mathbf{T}(M-m, N-n) \quad = \mathbf{T}(m,n)^* \quad (2)$$

Where,0 ≤m,<M and 0 ≤ n< N denotes the com-plex conjugate operator. Fig. 4 shows $\mathbf{T}$ the elements relationship in order to have a real-valued IFFT for matrix. In this con- figuration, only regions 1 and 2 are used for data transmission independently, and regions 3

$e^{j\frac{1\pi}{4}}, 10$

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and 4 are calculated accordingly to have a real-valued IFFT. Moreover, the symmetry requirements for elements that have been deliberately set to zero would be automatically satisfied.

Constellation Mapping: The input data is decomposed into 2-bit symbols. Each symbol is converted to a complex phase by the following rules:

$$11 \rightarrow e^{j\frac{7\pi}{4}}, 01 \rightarrow e^{j\frac{3\pi}{4}}, 00 \rightarrow e^{j\frac{5\pi}{4}}$$

Therefore, the first bit modulates the real component and the second bit modulates the imaginary component of the phase for each data symbol. These symbols are placed in a $\frac{M-2}{2} * \frac{N-2}{1}$ matrix which contains the absolute phase elements that are going to be modulated using DPSK

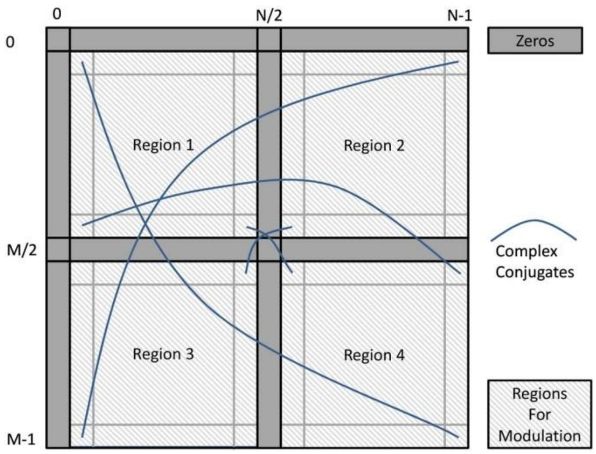

Fig.4. Hermitian symmetric matrix used for DPSK-OFDM modulation

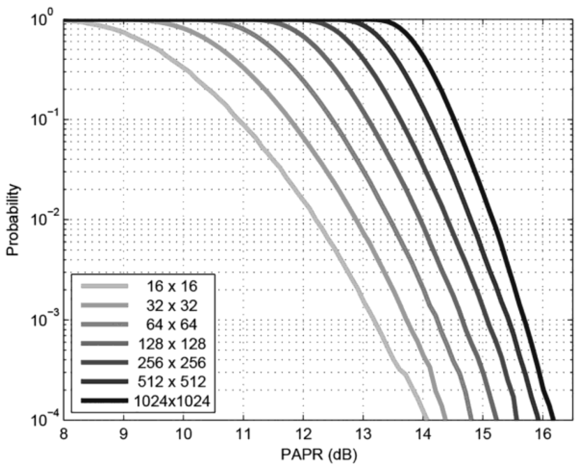

Fig.5. Probability that the OFDM modulated 2D signal has a PAPR greater than a certain value for different image sizes.

The IFFT of this matrix would have real-valued output on display. Bended lines show location of complex conjugate pairs.

$$\mathbf{T}$$
$$\mathbf{T}(0,0) = 0$$

Inverse FFT: Considering is the frequency domain representation of the signal, the IFFT is applied on it to have the time domain signal referred to as $\mathbf{D}_i$.This signal would have zero mean because, so it should be adjusted in order to use the full dynamic range of pixels

PAPR Adjustment: $\mathbf{D}_i$ is a real-valued 2D signal with high peak to average ratios. In fact, the probability of having a high PAPR increases as the number of frequency components increases as can be seen in Fig. 5. There are several methods to limit the PAPR of OFDM signals which might be applied here with slight modifications for 2D signals. One of the most practical methods would be soft clipping of the signal in which a threshold level of A_{max}based on signal average power level is set such that:

$$\text{ClippRatio} = \frac{A_{\max}}{\sqrt{P_{\text{avg}}}}$$

where P_{avg} is average power per element in the OFDM signal before clipping. Any components with higher amplitude
■$_{max}$ Are consequently clipped to ■$_{max}$ resulting in a **2D ma- trix** $\mathbf{D}_c$.

Amplitude Adjustment: The pixel levels in the PAPR adjusted image need to be transformed into LCD dynamic range levels for efficient utilization of transmission power. Normally the intensity levels on the LCD goes from 0 to I_{max}. So $\mathbf{D}_c$values are transformed linearly to this range using the following equation:

$$\mathbf{D}_a(i,j) = \frac{\mathbf{D}_c(i,j) - \text{Min}(\mathbf{D}_c)}{\text{Max}(\mathbf{D}_c) - \text{Min}(\mathbf{D}_c)} I_{\max}$$

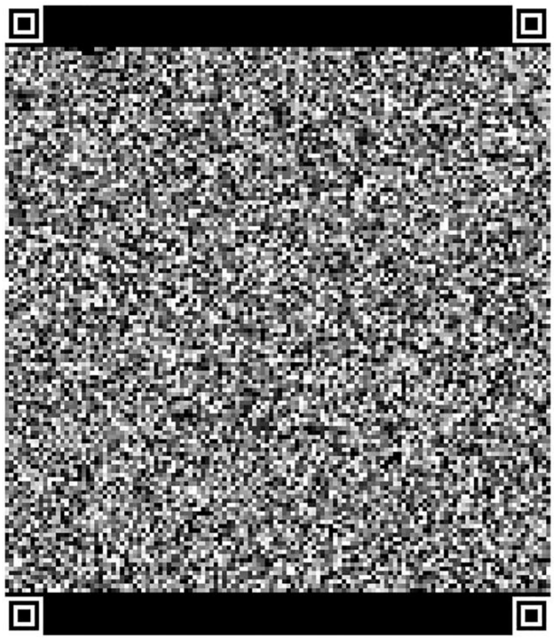

Fig. 6. Final image shown on the LCD after applying the DPSK- OFDM modulation algorithm

A. Cyclic Extension

OFDM systems require cyclic extension to prevent inter car- rier interference (ICI) [27]. To be sufficient, the length

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of the added cyclic extension must be more than the time spread of the channel. In case of the 2D barcode, periodic extension of the image generated by 2D-IFFT is required to prevent ICI. The length of this extension is determined by the impulse re- sponse of the channel, which in turn depends on the image blur and the amount of movement anticipated between LCD and camera. However, since in this study the channel response is modeled in the frequency domain, frequency domain filtering [12] is applied on the barcode, and effective cyclic extension is achieved by frequency domain multiplication which results in time domain cyclic convolution. Hence in all the following simulations the length of the cyclic extension is the same for DPSK-OFDM and QPSK-OFDM ensuring ICI elimination in the longest channel responses simulated.

B. Receiver

After displaying the generated image of Fig. 6, the receiver uses its camera for sampling and registering the acquired image so that a fairly acceptable copy of $\mathbf{D}_a$ is created at the receiver end. The effects of interference, noise and distortions encoun- tered in this step are addressed in the simulation section. To ob- tain the transmitted data successfully, the following steps should be taken into consideration at the receiver end:

Image Capture: Digital camera and display systems have a limited refresh rate which tends to be more than 23 Hz for dif- ferent standards. In a synchronous system the camera can cap- ture each displayed frame at the exact moment when it is fully stable. However if the receiver does not know when a new frame is ready on the display, the sampling rate should be at least twice the display rate to ensure capture of at least one accept- able frame. Moreover the relative distance and angle between camera and display is bounded by the Nyquist criteria where each pixel on the display frame should map into a minimum of 2×2 block in the camera.

Image Registration: The first step in processing the captured image is to extract the displayed image from background which depends on predefined finder patterns put into the image. For example, data matrix guidance lines are used in [5]. Because measurement errors in finder pattern location and perspective correction errors are not part of this study, the simulated images and their distorted received signals are ideally registered iso- lating the effects of blur and camera movement on error rate of different schemes.

FFT: Applying Fast Fourier Transform on the registered image results in frequency domain data which is comprised of the differential phase modulated elements stored in $\mathbf{R}_f$matrix. DPSK Demodulation: The original constellation mapped data can be extracted using phase differences between respective elements, but first data corresponding to regions 1 and 2 should be concatenated together to form matrix $\mathbf{R}$ corresponding to the transmitted matrix T.

The resulting $\mathbf{R}_d$ would be a distorted copy of in transmitter path.

$$\mathbf{R}_d(0,0) \quad \mathbf{R}(0,0)$$
$$\mathbf{R}_d(0,n) \quad \mathbf{R}(0,n) \quad \mathbf{R}^*(0,n-1)0$$
$$\mathbf{R}_d(m,n) = \mathbf{R}(m,n) \times \mathbf{R}^*(m-1,n)0 \quad \mathbf{S}$$
$$\frac{M}{2} - 1$$

Detection: Now that the phase differences have been ex- tracted, each input bit may be calculated using the constellation map of the transmitter. Each element is evaluated using its real and imaginary components. The sign of the real component de- termines the first bit and the sign of the imaginary component determines the second bit.

Error Correction

Error correction coding is often used in communication sys- tems to correct for the different number of bits lost in the trans- mission process. For example, Reed-Solomon (RS) coding is used in QR codes, where depending on the level of error correc- tion used, error rates of 7% up to 30% can be corrected at the receiver end [2]. While the selection of error correction coding has a great influence on the overall performance of the com- munication system, they are generally used on top of the mod- ulation-demodulation scheme and after source coding. There- fore, based on the achievable error rates without error correc- tion coding, one can select an appropriate coding scheme to create a reliable communication channel. As a result, when con- sidering the BER performance plots provided in the simulation section (IV), it should be noted that error rates in excess of 30% are not correctable even with the most redundant RS codes de- fined in [2] and would consequently be considered a non-reliable channel for this kind of transmission.

Computational Complexity

An important issue regarding the applicability of such a system would be the computational power required to imple- ment the system. Although a thorough investigation of such requirements and any optimization process can be subject to fur- ther study, it should be noted that the proposed DQPSK-OFDM system has a limited processing overhead compared to the equivalent QPSK-OFDM system which is already implemented and tested. More specifically, on the transmitter side, although the differential modulation is described by complex multipli- cations, it can be easily implemented using a small look-up table taking current phase and data to be modulated as inputs. However, in the receiver side about $M \times N$ multiplications are required to extract phase differences before detection which is not prohibitive compared to the complexity of the 2D FFT preceding it which is in the order of M*N*log(M*N).

IV. SIMULATION

Current 2D barcodes use PAM as the preferred modulation method [2]. To compare them with the proposed modulator and demodulator, both systems are implemented in MATLAB. A Simple PAM modulator which translates bits into light and dark pixels of an image is compared to the proposed DPSK-OFDM method which uses the described algorithm modulation and demodulation. Furthermore, the performance of QPSK-OFDM [28], which is essentially the same as 4-QAM (Quadrature Am- plitude Modulation) OFDM used in PixNet [5], is compared to the proposed DPSK-OFDM system. The main parameters that are considered include:

- noise and clip ratio;
- low pass filtering;
- Camera movement.

To study the effect of each of these parameters, first a random data stream is modulated to the displayed image using the algorithm under test. Then a controlled distortion is applied to the image before passing it to the receiver. The bit stream at the output of the decoder is compared to the input random stream to count for erroneous bits. This process is repeated several times using various random data streams and the same amount of distortion. The average result would be the bit error rate corresponding to that particular situation and assumed distortion. The process is then repeated for another distortion amount resulting in a plot for bit error rate against distortion.

Noise and Clip Ratio

In a barcode setup where PAM is used to modulate data onto image pixels, the average power is maximized. Consider the maximum amplitude driving a fully "on" pixel is A_p leading to a transmitted energy of P_p. In QR coding which uses bi- nary-PAM, amplitude of each pixel may be either 0 or A_p. Con- sidering that the DC offset is removed, each element would then have an amplitude of $\pm\frac{A_p}{2}$, yielding the following average power per pixel:

$$P_{ave} \quad \frac{P_p}{A_p^2}\frac{}{M \times N}\sum_{m=1}^{M}\sum_{n=1}^{N} A_{mn}^2$$

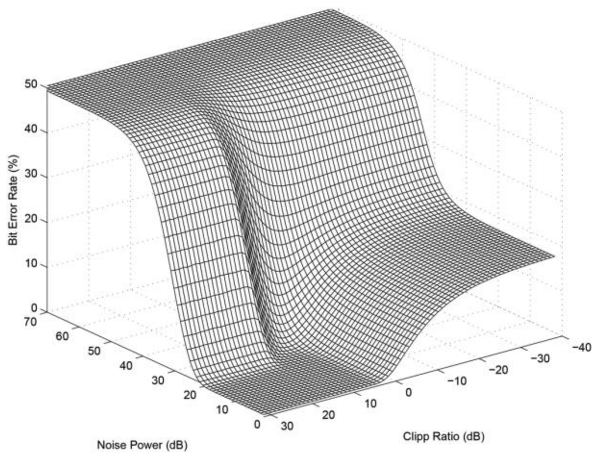

Fig7. Bit error rate vs. clip ratio and noise power. As noise level increases clip ratio should be increased in order to maintain optimum bit error rate.

where A_{mn} is the amplitude of element (m, n). Thus $P_{ave} = \frac{P_p}{4}$. Moreover peak power in a PAM scheme $\frac{P_p}{4}$ would be too. The fact that peak to average power ratio in binary-PAM signal is always 1 no matter what the data is, makes it suitable for situations where there is a limit on peak available power like LCD transmission. On the other hand, OFDM modulation has the intrinsic problem of PAPR which increases with increasing number of elements. In Fig. 5 PAPR for different image sizes is calculated. The figure shows the probability of PAPR being greater than a certain value.

High PAPR and limited peak power enforces a reduction in average power for the signal if it is going to be transmitted as is. Low average power means higher error rate in the presence of noise. To mitigate this problem, PAPR should be decreased as the maximum power is limited by physical constraints of LCD. Here soft clipping method is used as described before and the output after clipping is mapped linearly to the [0 255] interval for a grey scale image. In Fig. 7 the effect of various clipping levels is shown along with additive white Gaussian noise. As the clipping increases, the average power also increases due to fixed maximum power and lower PAPR. However this increased av- erage power is at the expense of a more distorted signal which translates into more BER. In this figure BER approaches 18% as clipping ratio decreases. Moreover, increasing noise level forces the BER approach 50%. It can also be observed that increased noise level requires a lower clipping threshold to obtain optimal error rate, but the induced distortion causes the benefit of in- creased average power to be limited and at some point BER actually starts to increase while average power is also increasing.

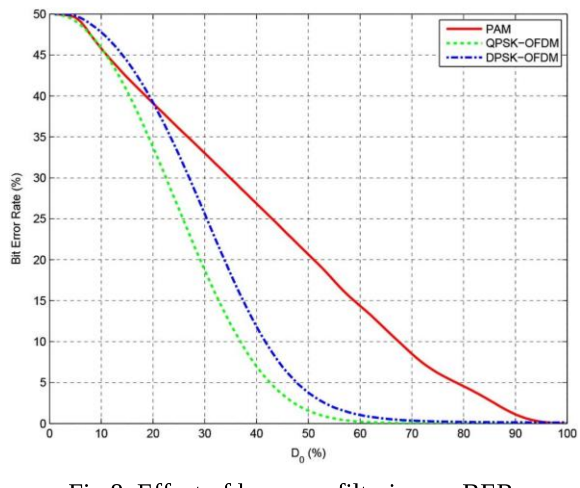

Fig.8. Effect of low pass filtering on BER performance. When cut off frequency is higher than 20%, OFDM based methods are superior to the PAM method.

Low Pass Filtering

Inter symbol interference and out of focus lens may be modeled by applying low pass filtering on the captured image

. To simulate this out of focus effect, the Butterworth low pass filter in the frequency domain is used with various cutoff frequencies and the resulting BER is measured. Equation (6) defines the applied filter.

$$L(u, v) = \overline{1 + (u^2 + v^2)^n / d_0^{2n}} \quad (6)$$

The resulting BER-based performance plots using different modulation methods are shown in Fig. 8. It can be observed in these plots that the BER increases with lower cutoff fre- quencies. Here D_0 = defines the cutoff frequency as a percentage of image width ( ). It can be seen that unless the cutoff frequency is less than 20%, frequency domain modula- tions have better error performance than the PAM method.

V. CONCLUSION AND FUTURE WORK

In this paper Differential Phase Shift Keying was combined with Orthogonal Frequency Division Multiplexing in order to modulate data stream into visual two dimensional barcodes. It was shown that QPSK-OFDM modulation has serious short- comings in the mitigation of camera LCD movements where the phase of each element changes continuously. On the other hand, addition of a differential phase modulator before OFDM to modulate the data stream into phase differences of adjacent elements (DPSK-OFDM) causes the motion effect to increasingly weaken because of its gradual change from element to element, contributing to a small deviation from the ideal phase in the received signal.

It was observed that under relative LCD-camera motions that generate error rates in excess of 30% in PAM and QPSK-OFDM, the proposed system of DPSK-OFDM will maintain an error rate less than 8% which is practically correctable using error correction coding. Future inquiries in a resolution to this problem have to address the best choice of differential pattern to optimize performance for various motion scenarios. Moreover, extension of the current two-bit per symbol constellations increases data transfer capacity, and its BER performance evaluation would be required. Nevertheless, a study on the effect of perspective correction errors on the BER performance of this algorithm compared to the other ones could augment our understanding of its applicability to real world scenarios.

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