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색상 양자화 기반의 팔레트를 사용한 비주얼-MIMO 시스템의 성능 향상

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Performance Improvement of Color-Independent Visual-MIMO System Using Color Quantization Based Palette

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요 약

색 공간 기반 변조 기법을 사용하는 색상 독립적인 비주얼 MIMO 시스템에서 카메라로 수신한 심볼의 색상을 판단하는 것은 쉽지 않다. 본 논문에서는 수신단에서 색 양자화를 적용하여 잡음의 영향을 최소화 시킨다. 또한 채널 환경을 고려하여 생성 된 팔레트를 이용하여 심볼 결정의 정확성을 높이는 방법을 제안한다. 마지막으로, 제안 된 방법은 전송 된 심볼의 위치를 색 공간에서 수신 된 심볼의 위치와 비교함으로써 수신 성능을 검증한다.

Key Words : Visual-MIMO, LED Array, Camera, K-means Algorithm, Color Quantization, Color Palette

ABSTRACT

In a color-independent visual-MIMO system using color-space-based modulation techniques, it is not easy to determine the color of a symbol captured by a camera. In this paper, the effect of noise can be minimized by applying the color quantization in the receiving end. Also, we propose a method to improve the accuracy of symbol decision using palette generated by considering channel environment. Finally, the proposed method is verified by comparing the position of a transmitted symbol with the position of a received symbol in the color space.

Ⅰ. Introduction

As interest and demand for visible light communication systems have increased, researches on visual-MIMO (multiple input multiple output (MIMO), communication between LED array and camera, have been actively conducted[1]. Furthermore, recently, a color-independent visual-MIMO system has been introduced that can communicate regardless of changes in color and brightness of LED light[2,3]. The modifier 'color-independent' indicates the independence of the variations in the light color and light intensity. Thus, we may achieve a visual-MIMO scheme that

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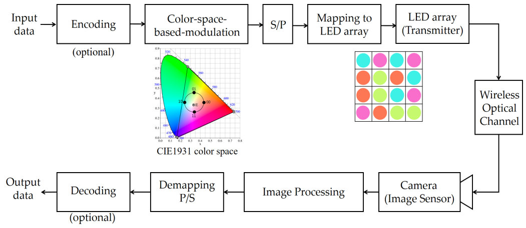


그림 1. 색에 독립적인 비주얼-MIMO 시스템의 송수신 과정 블록 다이어그램
Fig. 1. Block diagram of the transceiving process of a color-independent visual-MIMO system.

can maintain the original color and brightness while performing seamless communication. Fig. 1 shows the transceiving process of a color-independent visual-MIMO system[2].

A color-independent visual-MIMO system, using color space based modulation[4], demodulates the transmission data by determining the color of LED light received by the image sensor over a wireless channel[2]. However, it is still not easy to recognize the color of LED light at the receiver side due to channel noise, dynamic range limitation of camera, distance etc. These are the main factors that deteriorate the communication performance of the whole visual-MIMO system. T.-H. Kwon et al. detect LED color by averaging the intensity of 10×10 pixels around the center of an LED[5].

In this paper, we propose a method to improve the symbol error rate (SER) performance of a color-independent visual-MIMO system by using a color quantization-based palette generated by considering a channel environment.

Ⅱ. Proposed Algorithm

We need to get the correct data by extracting the correct color from the received symbols. The symbols are assumed to be carrying the correct colors but, they are affected by the noisy channel (environment). In this paper, we present a color quantization based algorithm which generates the color palette that can help us to get the correct symbol from each received color[6,7].

A palette is simply a set of colors extracted from an image of a symbol. In order to obtain a palette form the image, we first reduce the distinct colors in that image. We can limit the colors depending on criteria such as region of interest (ROI) or filtering method[6]. There are many techniques for color quantization such as k-means and median cut algorithms[8]. Then we simply scan over the image and store the value of each color. Fig 2 shows the process and color palette of symbol 1 as one of the received symbols.

In the proposed method, we receive a random symbol. Then we generate a palette from the symbol[7]. Next we compare all colors of the generated palette with the original transmitted color (symbol) by Euclidean distance in color space. We then find the best match for each original transmitted color. Finally, we determine the random symbol as the closest color among the colors in a palette.

We used k-means to quantize the image and reduce the colors in order to get a palette from that image. Also, we used Euclidean distance as a metric for measuring the degree of symbol error. In the first step of k-means algorithm, we choose initial cluster centers in the color space and a fixed number of clusters. The idea is to keep updating the locations of cluster centers so long as the sum of distances between all points of clusters and their cluster centers will be minimal[6,8,9]. During these modifications, all points are allocated to closest cluster centers using a predefined metric. After each

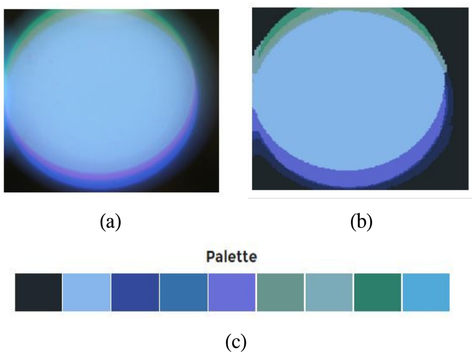


그림 2. 심벌 1에 대한 팔레트 생성 (a) 원본 이미지 (b) 색상 양자화 된 이미지 (c) 스캔 한 색상으로 생성된 팔레트
Fig. 2. Making a palette for symbol 1. (a) Original image (b) Color quantized image (c) Palette generated from the scanned colors.

allocation, new positions of cluster centers are computed as arithmetical means of cluster points. When the difference between new and old positions of cluster centers is too small we stop. Results will be evaluated using the equation in (1).

$$RMSE=\sqrt{\frac{\sum_{j=1}^{M}\sum_{i=1}^{N}(R_{ij}-R^*_{ij})^2+(G_{ij}-G^*_{ij})^2+(B_{ij}-B^*_{ij})^2}{MN}} \quad (1)$$

where R_{ij}, G_{ij}, B_{ij} are color components in original image and $R^*_{ij}, G^*_{ij}, B^*_{ij}$ are color components in quantized image[9]. In (1), M and N denote the total number of pixels in the row and column direction, respectively. Also, i and j represent i_{th} row and j_{th} column, respectively. K-means is an efficient algorithm that allows us to reduce the colors into distinct colors which is the most important step to generate a palette. Here, K-means algorithm is chosen because it is simple to implement and efficient to find out the dominant colors of an image.

Ⅲ. Experimental Results

In our experiment, the number of symbols (constellation points) is four. The constellation point corresponding to each symbol can be represented on CIE 1931 chromaticity color space. Fig 3 shows a color-space-based constellation of the generalized color modulation (GCM) method[5] used in our experiment. GCM constructs a constellation diagram in a light color space to represent data symbols. Each constellation point in a color space represents a corresponding color. The target color, i.e., the color perceivable to human eyes after modulation, is the average of all appropriate constellation points. A simple example of a constellation generation for a target color is illustrated in Fig. 3[3,5].

After receiving the symbol (color), we may extract the RGB value from middle area of each symbol in the received image. And the RGB values should be converted back to CIE 1931 chromaticity color space coordinate (x, y). Fig. 4 shows the received image obtained by a camera.

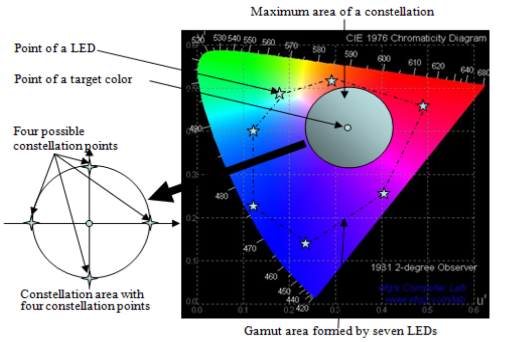


그림 3. CIELUV 색 공간에서 목표 색상에 대한 성좌도의 생성 예 (7 개의 LED 및 2 비트 데이터 심벌 사용)
Fig. 3. Generation example of a constellation diagram for a target color in CIELUV color space (example uses seven LEDs and two bit data symbols).

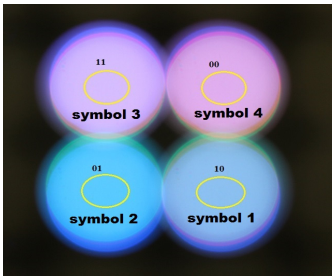
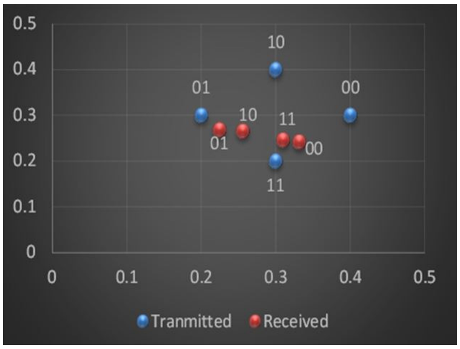


그림 4. 카메라로 얻은 수신 이미지
Fig. 4. Received image obtained by a camera.

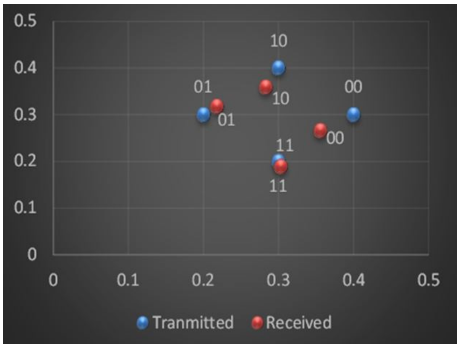
In Fig. 5(a), we can see the transmitted symbols (blue) and received symbols (red) in CIE 1931 chromaticity color space. Clearly, it is easy to know that an error has occurred. On the other hand, after applying the proposed method, error probability of each symbol can be significantly reduced as shown in Fig. 5(b). As shown in table 1, the proposed method gives significant improvement in symbols detection.

표 1. 성능비교 실험결과
Table 1. Experimental results for performance comparison.

	Transmitted points	Received points	Error	Received points after applying proposed method	Error
Symbol 1	(0.3, 0.4)	(0.256, 0.265)	0.142	(0.283, 0.359)	0.044
Symbol 2	(0.2, 0.3)	(0.224, 0.268)	0.040	(0.218, 0.318)	0.025
Symbol 3	(0.3, 0.2)	(0.310, 0.246)	0.047	(0.303, 0.188)	0.012
Symbol 4	(0.4, 0.3)	(0.332, 0.242)	0.090	(0.356, 0.266)	0.056



(a)



(b)

그림 5. CIE 1931 색 공간에서 전송 및 수신 된 심벌 (a) 각 심벌의 중간 영역 사용 (b) 제안된 방법을 사용
Fig. 5. The transmitted and received symbols in CIE 1931 color space. (a) using middle area of each symbol (b) using proposed method.

Ⅳ. Case Study

The case study bas been done in the lab and the final results were shown already in Fig. 5. In this scenario, the receiver knows which colors could be sent and what symbol (information) each color represents, but does not know what will actually be sent. So, the goal for the receiver is to determine what colors it is actually receiving. In other words, the transmitted colors should be pre-defined either specifically or among a set of colors (constellation points), That is, we may specify a ceratin region on the CIE 1931 chromaticity color space where the constellation points can be constructed. Because in the receiver end we need to know all possible colors that could be transmitted. Actually, the larger the number of symbols (more colors) the longer the detection processing time. We used four LEDs and one of four colors can be transmitted through each

표 2. 실험 구성 요소
Table 2. Experimental components.

Component	Model
RGB LED	53N RGB 262C-9001
Hardware module	Atmega 128
Camera	Canon EOS 600D, Lens EF 50mm
Software Environment	Visual Studio 2015

LED and we captured them using a camera. Table 2 represents the experimental components. Although, phone camera could give good results[10], but we try to minimize errors resulting from transmission channel. The distance between camera and the transmitter was set as 40cm as shown in Fig. 6.

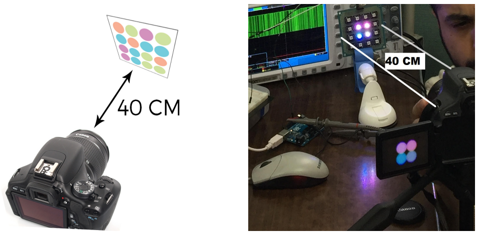


그림 6. 카메라와 LEA 사이를 40cm로 설정한 실험
Fig. 6. Experimental setup with 40cm distance between Camera and LEA.

4.1 Generating palettes

Once we receive the symbols as in Fig. 4, we can generate a palette for each symbol as shown in Fig. 7[6]. The number of colors in each palette is nine. Every time we noticed nine distinct colors while generating palette for every symbol. Experimently, we found that if the number of colors is less than nine then we may neglect some important information (color) and if it exceeds nine colors we will get the same colors repeated which is meaningless and costs more processing time. So we generated nine colors in each palette as it is the optimal number of colors set.

In the generated palettes, RGB values are converted into (x, y) coordinates based on CIE color space. The following table 3 ~ table 6 show the coordinates of each color in each palette.

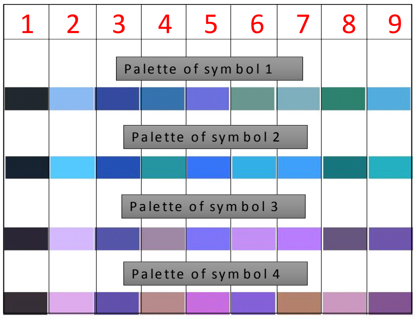


그림 7. 각 수신 심벌에서 생성 된 팔레트
Fig. 7. Palettes generated from each received symbol.

표 3. 팔레트 1의 각 색상 좌표
Table 3. Coordinates of each color in Palette 1.

	Coordinates and respective RGB color
Color 1	(0.275362 , 0.279495) RGB: 32,39,47
Color 2	(0.254929 , 0.256090) RGB: 135,182,236
Color 3	(0.204450 , 0.121528) RGB: 51,73,156
Color 4	(0.212462 , 0.204672) RGB: 53,112,170
Color 5	(0.232575 , 0.143114) RGB: 105,109,216
Color 6	(0.282972 , 0.358943) RGB: 103,148,141
Color 7	(0.272495 , 0.315925) RGB: 123,171,185
Color 8	(0.245125 , 0.414122) RGB: 44,127,107
Color 9	(0.225612 , 0.258882) RGB: 81,169,217

표 4. 팔레트 2의 각 색상 좌표
Table 4. Coordinates of each color in Palette 2.

	Coordinates and respective RGB color
Color 1	(0.236273 , 0.231251) RGB: 23,35,49
Color 2	(0.304827 , 0.652062) RGB: 82,195,48
Color 3	(0.187073 , 0.105541) RGB: 32,80,182
Color 4	(0.220909 , 0.321288) RGB: 37,145,157
Color 5	(0.192955 , 0.121349) RGB: 54,115,242
Color 6	(0.213218 , 0.278197) RGB: 44,176,214
Color 7	(0.205542 , 0.195056) RGB: 62,165,244
Color 8	(0.218917 , 0.326484) RGB: 23,116,124
Color 9	(0.218003 , 0.317956) RGB: 36,172,188

표 5. 팔레트 3의 각 색상 좌표
Table 5. Coordinates of each color in Palette 3.

	Coordinates and respective RGB color
Color 1	(0.299740 , 0.236560) RGB: 42,38,53
Color 2	(0.307029 , 0.237092) RGB: 207,180,251
Color 3	(0.235347 , 0.144327) RGB: 83,84,166
Color 4	(0.334279 , 0.274265) RGB: 155,132,161
Color 5	(0.235651 , 0.130405) RGB: 123,114,243
Color 6	(0.302945 , 0.188424) RGB: 190,140,239
Color 7	(0.286541 , 0.150478) RGB: 181,122,250
Color 8	(0.305173 , 0.224281) RGB: 100,84,123
Color 9	(0.266607 , 0.149693) RGB: 108,84,168

표 6. 팔레트 4의 각 색상 좌표
Table 6. Coordinates of each color in Palette 4.

	Coordinates and respective RGB color
Color 1	(0.339888 , 0.290951) RGB: 54,47,54
Color 2	(0.334151 , 0.241962) RGB: 217,167,230
Color 3	(0.249235 , 0.135483) RGB: 95,79,167
Color 4	(0.396383 , 0.320676) RGB: 179,135,136
Color 5	(0.329833 , 0.161714) RGB: 195,107,219
Color 6	(0.259451, 0.129343) RGB: 129,94,210
Color 7	(0.435945 , 0.356383) RGB: 174,126,106
Color 8	(0.355686 , 0.266298) RGB: 197,149,187
Color 9	(0.327761 , 0.192394) RGB: 127,83,142

We also compare our proposed method for 68 random symbols with conventional method (average of all palette). Table 7 shows the comparison between conventional method and proposed method in CIE1931 color space. Proposed method achieves high accuracy than conventional method.

표 7. 기존 방법과 비교 (68개 임의의 심벌에 대해서)
Table 7. Comparison with Conventional Method (for 68 random symbols)

Distortion type	Name of the method	
	Conventional Method	Proposed Method
<15%	11	52
15%-50%	50	16
50%-70%	7	0
>70%	0	0
Accuracy (%)	72	85

4.2 Finding the best match

In this part, we applied the Euclidean distance[6] to find the minimum distance (error) between the transmitted coordinates in table 8 and the received coordinates generated from palettes in table 3 ~ table 6. We take every transmitted symbol coordinates and compare it with all colors generated from palette, that is 36 cases. In order to achieve our goal for improving the detection accuracy, every symbol should match to its own palette by finding the minimum distance (error). Table 9 shows the scanned results.

표 8. 전송된 좌표
Table 8. Transmitted coordinates.

	Transmitted points
Symbol 1	(0.3,0.4) RGB: 125,176,147
Symbol 2	(0.2,0.3) RGB: 54,47,54
Symbol 3	(0.3,0.2) RGB: 60,185,212
Symbol 4	(0.4,0.3) RGB: 219,154,168

표 9. 스캔한 결과
Table 9. Scanned results.

	Minimum distance found (error)
Symbol 1 over palette 1	0.04445
Symbol 1 over palette 2	0.11509
Symbol 2 over palette 2	0.02543
Symbol 2 over palette 1	0.04844
Symbol 3 over palette 3	0.01194
Symbol 3 over palette 4	0.02878
Symbol 4 over palette 4	0.05567
Symbol 4 over palette 3	0.11225

V. Conclusion

In this paper, we proposed a received symbol decision method to improve the SER performance of a visual-MIMO system using a color quantization-based palette. The noise effect was minimized by applying color quantization in the image processing at the receiving end and the palette generated by considering the wireless channel environment was used for improving the symbol decision accuracy. Experimentally, by comparing the position of the transmitted symbol with the position of the received symbol in the color space, it has been proved that the proposed method can improve the SER performance. Generating palette using color quantization method is promising for visual-MIMO communication and opens the door for the researcher.

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