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Color calibration for multicolored barcodes using smartphones

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Abstract

The JAB Code, a 2D barcode standardized in ISO/IEC 23634:2022, offers improved reliability and data capacity over traditional barcodes, but its color recognition poses challenges. These issues stem from the suboptimal utilization of the RGB color space in printing and the non-bijective RGB-to-CMYK conversion, prompting the need to select colors that ensure distinct segregation in the transformed color space for enhanced detection robustness. We propose an approach for calibrating the colors of the JAB Code, involving the creation of a test pattern, quantization of the color space, and the calibration of colors using a calibration target. This method aims to ensure optimal color representation within the barcode and can be integrated into JAB Code generation tools or web apps, simplifying the process for users and ultimately improving color accuracy and fidelity within the barcode.

We conduct an experiment with different printers, utilizing a smartphone for image capture. The evaluation includes printing JAB Code test patterns, creating and calibrating standard and calibrated JAB Codes, and capturing images under various lighting conditions. We use the JAB Code detection algorithm to analyze color distances in the RGB space, revealing improvements in color distribution and lower error rates with printer color calibration, which can lead to faster reading processes and smaller JAB Code sizes with reduced area requirements. This work offers important insights that should be considered during the next revision of the ISO standard.

Introduction

JAB Code, a two-dimensional barcode, which has been developed by *Fraunhofer SIT* and standardized in *ISO/IEC 23634:2022*, provides increased reliability, security and data storage capacity compared to conventional monochrome barcode formats. Based on our widespread use of the JAB Code, we have noticed a few issues regarding the recognition of printed JAB Codes. It became apparent that by printing the barcode and reading it, e.g. with a cell phone camera, the sampled colors differ from those described in the standard. For the upcoming standard release, modifications to the JAB Code's color selection will be implemented to enhance its detection robustness.

The current status of JAB Code employs eight colors (black, white, red, green, blue, yellow, cyan and magenta) in a 3D coordinate system, representing a 3-bit RGB color space. However, printer and smartphone camera dynamics create limitations that result in suboptimal utilization of the theoretical RGB color space. Additionally, the lossy conversion from RGB to CMYK color spaces further affects JAB Code's fidelity because the conversion function is not bijective. An example is given in Figure 2 and Figure 1 where the former is a digital representation of the RGB color space and the latter is visualizing the same colors after printing and capturing with a smartphone camera. This clearly shows that the achievable color space is considerably smaller than the theoretical one.

To tackle these obstacles, it is crucial to discover a selection of colors which can be linked to the resultant subspace post-CMYK and RGB conversions. This guarantees distinct segregation of color spaces for the decoding algorithm, which examines each JAB Code module by mapping the sampled color into a predefined color palette. Enhancing this process involves detecting colors that maintain separability within the transformed color space while considering the restrictions inherent to printing and image capturing technologies.

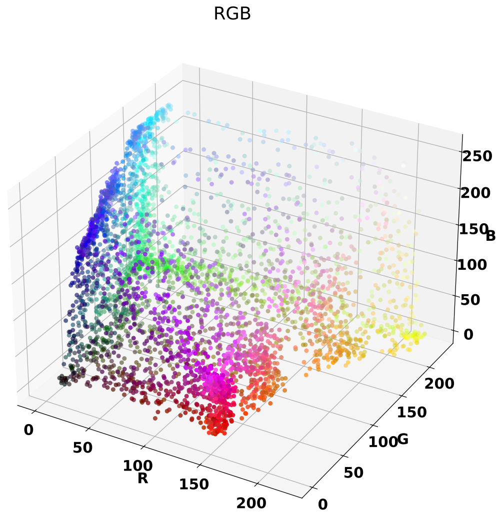

Figure 1: 3D representation of the test pattern colors in 3D space after printing and capturing with a smartphone.

Related work

The work is based on the ISO standard ISO/IEC 23634 [1]. An open source implementation and an Android app are available in a GitHub repository[1], and a demo system is available on the product page[2]. We would like to point out that monochrome matrix codes (e. g. Data Matrix, QR Code, and Aztec Code) are well known and widely used as long as the payload is sufficiently small. For some security applications there is a larger physical area required as the monochrome barcodes provide. JAB Code has a higher data density and can store roughly three times more data on the same number of modules compared to the

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[1] https://github.com/jabcode/jabcode

[2] https://www.jabcode.org

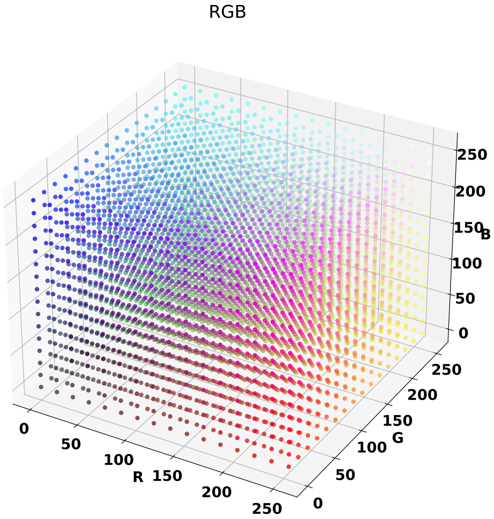

Figure 2: 3D representation of the test pattern colors in lossless digital color space.

monochrome barcodes because eight colors are used. The developer point out several advantages of JAB Code in [4]. There are several works based on JAB Code, especially in the IT-Security context. The authors of [3] propose an approach for digitally signing documents with the requirement that they can be verified after they have been printed. In [5] the authors provide a ready to use solution to digitally sign documents for a wide variety of ad hoc documents. The signing process is implemented as progressive web app with a high security and privacy standard. Both work state the challenges with the reliable readability of the JAB Code. This brought us to the research investigation that we present in this paper.

Proposed Approach

To enhance the color mapping and calibration process for JAB Code, we propose the following approach that includes analyzing and optimizing the color space, improving the color mapping and integrating calibration into the generation of JAB Codes.

1. Generation of a test pattern: Create a version of the JAB Code with version 15 by 15, consisting of 77 x 77 modules. Leave a margin in order to leave the functional finder patterns of the JAB Code, resulting in a total of 4096 modules within the code that can be overwritten. This way, the JAB Code detection algorithm can be utilized for alignment and color sampling. The test pattern serves as the calibration target. Figure 3 shows the generated test pattern with a standard JAB Code margin and 4096 color steps.
2. Quantization of the test color space: For each dimension red, green and blue, divide the space into 16 discrete steps from 0 to 255, resulting in $16 \times 16 \times 16 = 4096$ colors that can be placed on the calibration target code.
3. Print the calibration target: Utilize the specific printer that the calibration process aims to calibrate for, ensuring the test pattern is accurately printed. Although the JAB Code decoding will fail due to the invalid modules, the detection algorithm can still be leveraged to read the sampled color values.
4. Consider constraints: The functional finder patterns of the JAB Code standard use the colors black, yellow, and cyan, which should remain unchanged. The remaining five colors can be freely assigned. A color palette is embedded in the metadata of the JAB Code, allowing for correction of accidental color drifts or intentional remapping of colors.
5. Calibration method: For each of the five colors, determine the sampled color that is closest to its corresponding corner in the RGB color cube. Look up the source color in the color test pattern that resulted in this optimal printed color within the sampled space. Save this color in the calibration profile. This process establishes a mapping from five RGB colors to their calibrated counterparts that can be stored for repeated use.
6. Generating JAB Code: When generating a JAB Code, utilize the calibrated colors obtained from the calibration process for the modules. Remap each module's standard color to its corresponding color in the lookup table from the calibration profile. This ensures accurate color representation within the barcode.

The calibration process can be integrated into the JAB Code web app or generation tools, simplifying the process for users. This integration can guide users through the calibration process and save the calibration profile for future reuse. By implementing this proposed approach, JAB Code can achieve improved color mapping and calibration, resulting in enhanced accuracy and fidelity of color representation within the barcode.

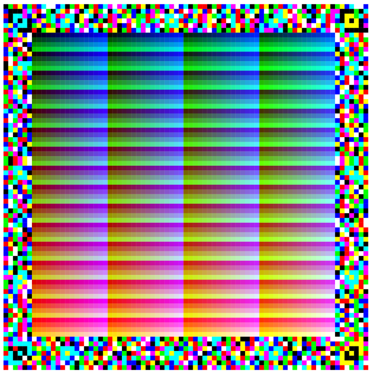

Figure 3: Generated test pattern with 4096 RGB samples using a step size 17 in each dimension.

Evaluation

In this section, the proposed approach is evaluated. First, we describe the test setup and the steps discuss the measured results. Then, the test results are evaluated and discussed.

Test setup

For our experiment setup, we employ an inkjet *Pixma iP4000* and a laser printer *Konica Minolta bizhub C458*. We capture images using a *Google Pixel 5* smartphone. To initiate the evaluation, we print the JAB Code test pattern, illustrated in Figure 3, using both printers and analyze the calibrated colors as described in the approach. Following this, we create a standard JAB

Code and calibrate it using the calculated lookup table to map each color to its calibrated counterpart. Then, we print both the standard JAB Code, ensuring the same size of $77 \times 77 = 5929$ modules, and the calibrated JAB Code with both printers. Pictures of the printed JAB Codes are then captured under three distinct lighting conditions (daylight, artificial warm, and artificial cold), as depicted in Figure 4 and Figure 5. The JAB Code detection algorithm is used to extract the sampled colors from the captured images to calculate the distances between the point clouds in the sampled RGB color space. As a measure of improvement, the euclidean distances are calculated for each pair of two colors, measuring the distance from each sample from color A to each sample from color B. To ensure reliability, we compute the mean of the 30 smallest distance values while accounting for a margin of error attributable to outliers. It is important to note that the JAB Code's error correction code (ECC) can rectify a large number of errors during the decoding process to a certain degree during the decoding process. The findings are presented in Table 1 and Table 2, and for better understanding, visualized in Figure 4 and 5.

Discussion

The results clearly show an improvement in the distribution of the eight colors in the RGB space on the *Canon PIXMA iP4000* inkjet used. It should also be mentioned that the saturation of the inkjet printer is not as high as that of the laser printer. Therefore, it is all the more important that the eight colors used are as far apart from each other as possible. The improvements come at the cost of some degradation in other color pairs, but it's crucial to note that these are color pairs that were and continue to be widely spaced anyway.

With the laser printer, the biggest problem was the spacing of the red and magenta colors. As a result, when the JAB Code was read under different lighting temperatures, it had a lot of reading errors that could not be corrected. With color calibration, the main problem is solved. Again, it is similar to the inkjet printer in that the improvements are at the expense of the other spacing, but none of this is a problem because the colors had and continue to have a large spacing anyway.

Table 2 and Figure 5 provide the insights. Together with Figure 6 we see that the red channel provides very good separation properties. The green and blue channels are challenging especially the blue color and the magenta color as can be derived from Figure 1. A saturation reduction in the green channel brings a reduction of the saturation in the blue channel when printing the colors.

With this printer color calibration, we achieve lower error rates when reading the colors and thus lower error correction effort. This leads to two advantages, namely an acceleration of the reading process and also the module size of the JAB Code can be selected smaller, which leads to a smaller overall size and thus smaller area requirements for JAB Codes.

Conclusion and future work

In this research, we address the limitation of printers and camera devices in achieving true color replication abilities, which often leads to suboptimal detection of the JAB Code. To overcome this challenge, we propose a novel approach that focuses on calibrating the process specifically for a given printer model.

Our approach relies on the assumption that the ideal color replication solution is located at the corners of the RGB color cube. By utilizing this assumption, we strive to enhance the precision of color detection and replication. Nevertheless, we acknowledge that alternative solutions may exist that could potentially yield better results if this assumption is not considered. Notably, such alternative solutions could result in significant deviations from the eight RGB colors.

To assess the merits of our suggested methodology, it is advisable to perform additional experiments with diverse optimization algorithms. Such experiments would enable us to explore and compare the performance of the calibration process under different conditions. By conducting a more extensive analysis, we aim to provide a comprehensive evaluation of our approach and its potential for improving color reproduction in printers and camera devices.

Acknowledgments

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			daylight		cold light		warm light	
	Color A	Color B	standard	calibrated	standard	calibrated	standard	calibrated
0	white	red	122.04	151.45	89.75	98.68	111.08	109.01
1	white	cyan	60.69	64.79	46.46	46.75	44.91	46.61
2	white	green	140.23	136.62	68.03	79.33	90.14	81.47
3	white	magenta	82.71	92.83	64.98	64.29	65.63	66.98
4	white	black	262.43	276.56	143.58	177.42	193.07	170.93
5	white	blue	146.19	163.08	89.07	97.38	97.33	95.26
6	white	yellow	104.42	103.90	87.94	85.34	83.28	99.71
7	red	cyan	195.83	195.40	198.68	201.20	173.87	205.40
8	red	green	114.16	190.19	84.97	92.75	86.15	93.08
9	red	magenta	197.09	303.06	196.24	208.74	171.84	205.60
10	red	black	125.71	123.84	59.52	62.62	87.09	74.17
11	red	blue	195.05	218.65	180.61	206.05	169.38	199.67
12	red	yellow	199.43	270.73	202.21	192.55	183.33	187.44
13	cyan	green	90.42	93.59	56.37	70.83	62.35	79.11
14	cyan	magenta	169.26	167.99	164.24	166.78	129.06	150.22
15	cyan	black	197.54	200.40	102.07	114.73	139.98	112.98
16	cyan	blue	67.37	73.37	36.49	33.60	33.17	25.41
17	cyan	yellow	219.87	281.96	227.30	223.04	222.20	229.87
18	green	magenta	204.50	205.26	224.95	230.04	216.97	237.50
19	green	black	82.15	91.83	32.46	42.31	42.31	38.56
20	green	blue	156.10	152.16	158.39	159.60	139.82	157.01
21	green	yellow	255.63	281.18	271.31	265.03	204.06	258.95
22	magenta	black	184.05	182.16	90.91	109.97	130.57	111.86
23	magenta	blue	110.28	109.36	86.67	83.95	90.98	98.30
24	magenta	yellow	196.99	192.67	203.26	202.75	184.30	206.38
25	black	blue	281.38	280.11	190.84	282.16	253.20	282.19
26	black	yellow	192.02	201.66	212.80	193.89	182.37	230.84
27	blue	yellow	149.21	155.47	163.04	166.18	123.49	169.84

Table 1: Minimum euclidean distances between sampled color cloud points for each pair of two colors A and B for an inkjet printer

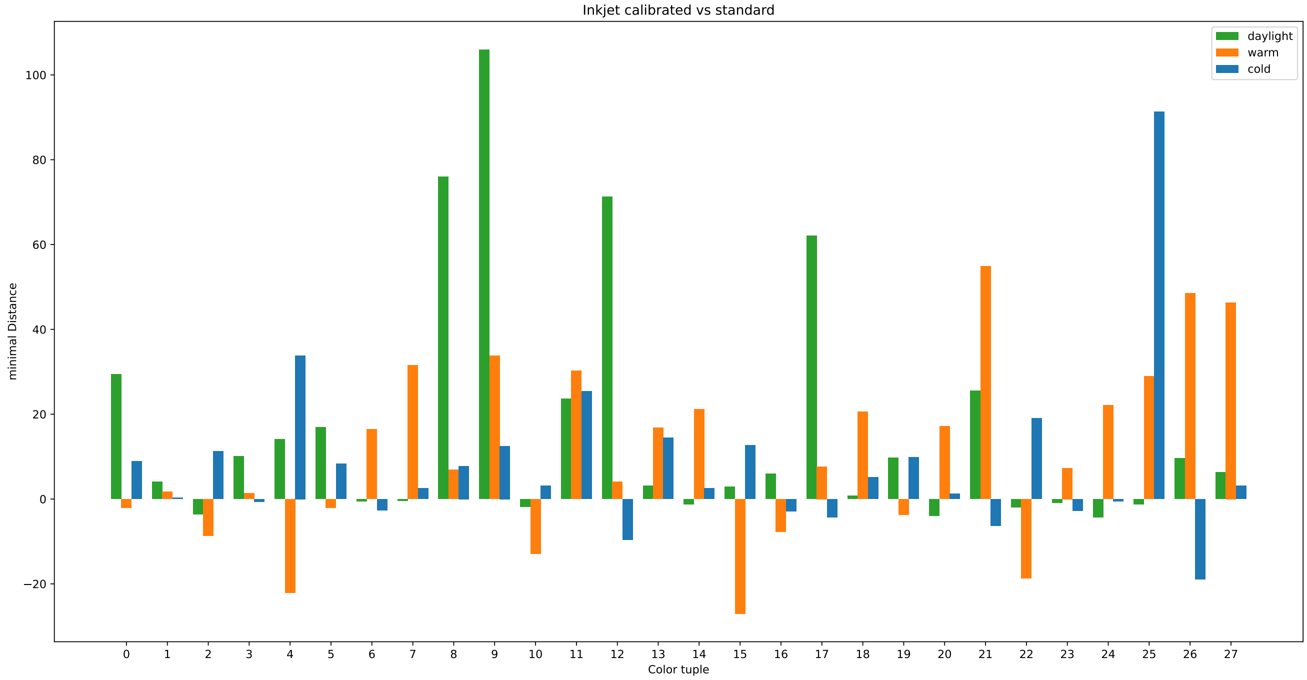

Figure 4: Difference between the standard and calibrated color cloud points for an inkjet printer

			daylight		cold light		warm light	
	Color A	Color B	standard	calibrated	standard	calibrated	standard	calibrated
0	white	red	182.51	144.36	129.63	130.64	138.37	133.62
1	white	cyan	152.81	141.98	140.06	126.61	154.09	149.35
2	white	green	184.43	147.03	111.58	93.63	111.57	95.10
3	white	magenta	153.37	84.70	114.14	71.49	111.51	73.14
4	white	black	264.51	200.55	162.09	149.23	152.02	160.32
5	white	blue	194.88	158.45	117.36	107.63	108.29	111.08
6	white	yellow	102.56	98.05	101.25	96.95	103.51	95.24
7	red	cyan	210.29	208.32	191.45	201.20	191.19	212.77
8	red	green	219.47	223.61	221.69	223.57	161.59	151.40
9	red	magenta	211.11	289.88	37.15	204.17	34.82	199.21
10	red	black	113.07	90.06	87.54	81.06	100.55	99.07
11	red	blue	240.65	225.52	216.75	208.17	213.03	203.95
12	red	yellow	293.92	156.01	147.46	157.82	147.19	153.89
13	cyan	green	106.75	107.67	113.46	115.27	110.20	109.92
14	cyan	magenta	135.89	88.71	109.96	103.52	96.18	93.76
15	cyan	black	163.51	152.27	157.26	142.69	160.32	153.86
16	cyan	blue	67.60	59.03	47.54	46.48	62.20	56.42
17	cyan	yellow	191.13	181.85	184.04	189.05	187.02	199.54
18	green	magenta	231.61	197.81	174.61	203.59	134.12	211.17
19	green	black	74.22	68.48	56.57	50.77	52.72	49.66
20	green	blue	183.22	177.25	157.36	159.46	175.77	167.51
21	green	yellow	215.71	220.91	216.89	230.34	187.92	190.45
22	magenta	black	123.31	116.11	93.68	85.31	98.44	102.63
23	magenta	blue	142.44	119.36	136.35	108.03	153.78	125.11
24	magenta	yellow	225.17	173.93	147.77	186.62	148.65	185.93
25	black	blue	262.43	214.41	183.53	188.18	184.05	183.75
26	black	yellow	185.96	185.76	199.85	206.98	185.69	178.93
27	blue	yellow	119.90	119.69	135.13	140.02	133.32	140.29

Table 2: Minimum euclidean distances between sampled color cloud points for each pair of two colors A and B for a laser printer

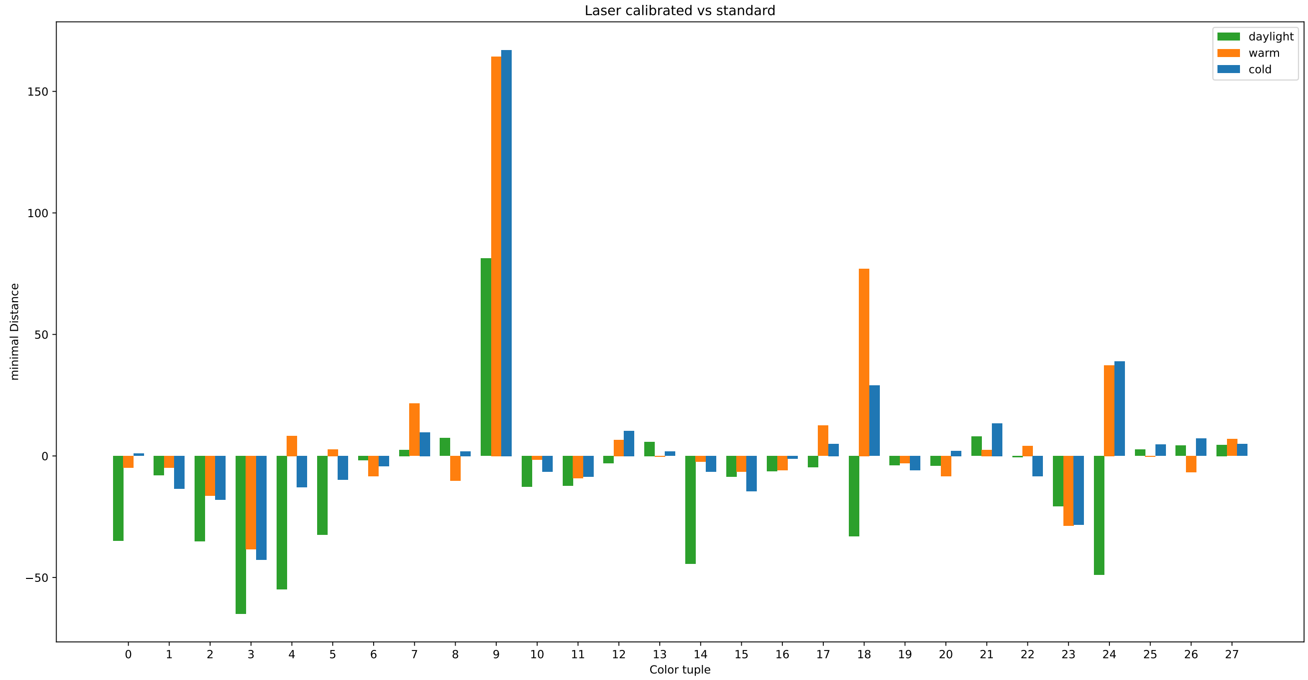

Figure 5: Difference between the standard and calibrated color cloud points for a laser printer

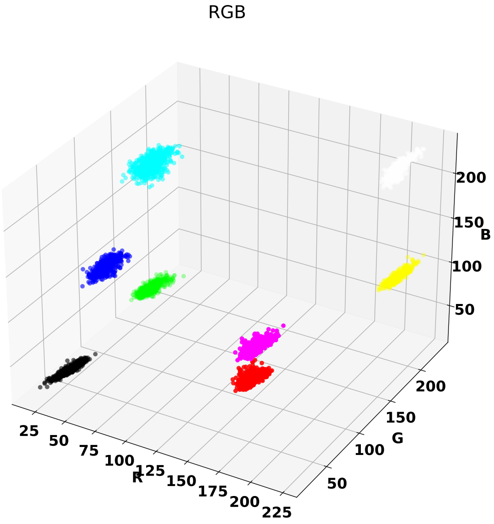

Figure 6: Example plot of the sampled JAB Code point cloud mapped to the RGB color cube.