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Free Chlorine Digitization Using Colorimetric Barcodes and Machine-Leaning Models

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Summary:

The introduction of colorimetric barcodes, this is a 2D barcode which embeds a color chart, has enabled the digitization of colorimetric chemical sensors using smartphones. We applied this concept to free chlorine monitoring in water using commercial BTB and DPD reagents.Color QR Codes acted as both localization and color correction references. Images were processed through geometric normalization and nonlinear color correction. Machine-learning models achieved high accuracy under real-world conditions. This approach enables low-cost, hardware-free chlorine monitoring for on-site applications.

Keywords: colorimetric sensing, QR Code, chlorine detection, computer vision, smartphone analysis

Introduction

Ensuring the safety of drinking or pool water requires regular monitoring of free chlorine (FC), a commonly used disinfectant. Traditional colorimetric tests like BTB strip and DPD powder methods —gold standard in the HORECA sector— are cost-effective but rely on subjective visual interpretation[1]. Recent advances in computer vision and mobile imaging have enabled the digitization of colorimetric indicators, by introducing machine-readable patterns like barcodes embedded with several color references[2]. Our work builds on this idea by integrating color reference patterns into QR Codes, creating compact, printable, and robust calibration charts for smartphone-based sensing, while improving accuracy and enabling traceability.

Methodology

We present a novel method for FC detection using 'colorimetric QR Codes'—barcodes that include embedded color references for calibration—. Each QR Code corresponds to a specific test type (BTB strip or DPD powder) and includes color patches aligned with the test's color response curve. These codes are placed next to the test during imaging, enabling geometric correction and color calibration using thin plate spline warping. Smartphone images are processed using OpenCV to detect the QR Code, extract the region of interest (ROI), correct for lighting conditions, and feed color features into machine-learning models trained for FC classification and regression. Fig. 1, shows these color QR Codes alongside each of the test.

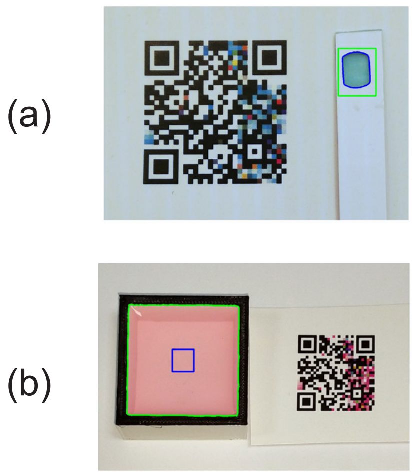

Fig. 1. (a) ROI detection on BTB strip test with adjacent colorimetric QR Code; (b) color extraction from DPD cuvette using contour-based segmentation. Both setups illustrate the use of QR Codes for geometric alignment and color correction under uncontrolled lighting.

Free chlorine solutions from 0.1 to 8.4 ppm were prepared by stepwise dilution of a 100 ppm sodium hypochlorite stock. Concentrations up to 2.2 ppm were measured directly using a Hach DR300 colorimeter (±0.02 ppm), while higher values were extrapolated from diluted samples. These tagged concentrations served as ground truth for evaluating both BTB and DPD tests.

Results

A supervised machine-learning pipeline was implemented to quantify free chlorine from smartphone-acquired images of colorimetric tests. For each sensor (BTB strip and DPD powder), mean RGB and HLS features were extracted from the region of interest after applying geometric normalization and thin plate spline color correction. A two-stage analysis was done: (1) a Support Vector Classifier (SVC) was trained to categorize free chlorine concentration into three regulatory classes—*low*, *middle*, and *high*; and (2) a regression model was applied only to the *middle* class to refine concentration estimates. Models were trained using data from a Huawei P20 and tested over an iPhone SE, a Morotorola G6 and a Xiaomi A2.

For the BTB test, all six color features (R, G, B, H, L, S) were used as input to the SVC after dimensionality reduction via Principal Component Analysis (PCA), which preserved over 97% of the variance in two components. Regression in the acceptable range used the logarithm of the corrected red channel, which exhibited the strongest monotonic decay.

Tab. 1: Evaluation results for BTB strip and DPD powder methods. All models were trained using the Fixed Setup and tested in Room Setup conditions. Classification accuracy and regression performance (R^2) are reported for each smartphone. For BTB, flash and no-flash conditions are compared; for DPD, only no-flash results are included due to reflection artifacts.

Smartphone	Flash	Method	Classification (Accuracy %)	Regression (R^2)
Huawei P20	No	BTB	88.1	0.88
	Yes	BTB	92.5	0.82
	No	DPD	88.1	0.94
iPhone SE	No	BTB	91.3	0.87
	Yes	BTB	95.8	0.79
Motorola G6	No	BTB	87.0	0.78
	Yes	BTB	96.6	0.80
	No	DPD	100.0	0.82
Xiaomi A2	No	BTB	100.0	0.96
	Yes	BTB	94.7	0.79
	No	DPD	90.0	0.91

For the DPD test, classification was performed using the green and blue channels as raw inputs, while regression employed a PCA-based projection of their logarithmic values. This hybrid approach improved both robustness and accuracy across lighting conditions and smartphone models. The best performance was achieved by the Xiaomi A2 in the BTB test without flash, reaching 100% classification accuracy and a regression R^2 of 0.96 against the actual concentration values (Tab. 1). An application was developed for a potential client named *Selfytest* (Fig. 2.).

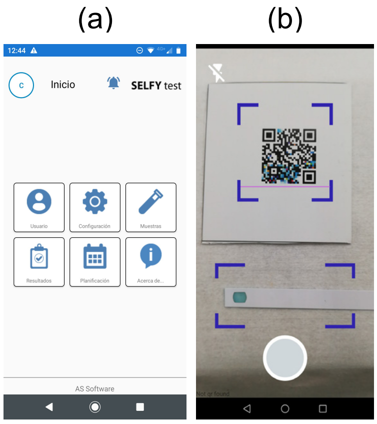

Fig. 2. Application for free chlorine measurements using colorimetric test and Color QR Codes as helper. (a) a view of the user data; (b) the scanner view.

References

[1] Shang J. et al., On Site Determination of Free Chlorine in Water Samples by a Smartphone Based Colorimetric Device, New J. Chem. 2019

[2] Benito Altamirano I. et al., Back Compatible Color QR Codes for Colorimetric Applications, Pattern Recognition 2023, doi:10.1016/j.patcog.2022.108981

[3] Benito Altamirano I. et al., Image Color Consis tency in Datasets: The Smooth TPS3D Method, arXiv:2409.05159

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