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Mobile-platform based colorimeter for monitoring chlorine concentration in water

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ABSTRACT

Cost-effective monitoring concentration of residue chlorine in water can be simply accomplished via colorimetry where the selected indicating chemical material reacts with the chlorine in water to change its color. To suppress errors from reading the color level by naked eyes and from fluctuation of environmental illumination, this paper proposes a mobile-platform based colorimeter embedded with a self-referencing analysis for converting the color level of water to its corresponding chlorine concentration. The key idea relies on a two-dimensional (2D) color analysis in a portable closed chamber. Specifically, our 2D color analysis with self referencing is performed via the arrangement of both the reference material and the glass bottle in such a way that they both fit in the field of view of the mobile-device's camera. In this way, one color image inherently contains two image regions, one from the reference material and another from the glass bottle. Consequently, a specific color ratio from these two image regions is used for specifically converting the water color inside the glass bottle into its corresponding chlorine concentration. By using a chemical reaction between *o*-tolidine solution and chlorine dissolved in water and a smart mobile phone, the demonstration shows a very promising result in determining 0.06–2.0 ppm chlorine concentration in water. Other key features include cost effectiveness, compactness, portability, and ease of implementation.

1. Introduction

Chlorination process is a widely used process for destroying organisms and removing some plant effluents in water for consumer uses and for storing in fishery tanks [1,2]. As the chlorine residue in water can greatly affect our health and aquatic baby animals such as baby shrimps and baby fishes, it is highly desirable to regularly monitor the concentration of chlorine in water. Nowadays, the most commonly used and cost-effective method in determining the amount of chlorine in water is colorimetry [3]. In this approach, several chemically indicating materials such as toluidine groups [4], *o*-tolidine [5], diethylparaphenylene diamine (DPD) [6], and potassium iodine (KI) solution and starch [7] are selected and dropped into the water whose interaction leads to the change in water color. Color comparison between the water and a set of standard colors via naked eyes links to the amount of chlorine concentration in water. A high accuracy in estimating the color level can be accomplished by using an optical colorimeter [8], either in a very-old point-like detection version [9] or a two-dimensional (2D) detection scheme [10,11]. In particular, light emitting diode (LED)-based colorimeters are commercially available but with a price more than 500 USD [12,13]. Currently, the 2D colorimetry approach has been applied in several spectral analysis applications such as data non-intrusive credit card verification [14,15], Thai jasmine rice identification [16], light source analysis [17], and blood stain detection [18].

The advancement of electronics and information technology industry has led to the transformation of personal computers to smart mobile devices. The number of these devices packaged in a phone or a table style has been grown very rapidly [19]. As the smart mobile device is equipped with a digital color camera, its functionality has been extended for telemedicine [20,21], illumination analysis [22], microscopy [23–26], and fluorescent imaging [27]. Its colorful display is also used for spectroscopic analysis of foods and beverages [28] and for exciting the Rhodamine 123 doped within a mesostructured silica sphere [29]. For a colorimetry point of view, smartphone-based colorimetric detection and analysis has been proposed and demonstrated [30–32]. Some free mobile applications such as Colorimeter, Catch Color, and Color Detector are

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also available for roughly evaluating the color of the object [33]. Recently, we have proposed and showed for the first time how such a smart mobile device can be functioned as a 2D colorimeter for spatially classifying a banana into three different ripeness levels [34]. Nevertheless, in these approaches, the color of a reference object needs to be determined first and then the investigation of the object color is performed. This implies that variations in the object-detection distance and environmental illumination level can lead to system malfunction.

Realizing that the color information of the object at any spatial points can be simultaneously analyzed under the 2D detection plane, we have recently demonstrated that the color of rice leaf and its associated amount of nitrogen fertilizer can be estimated by using a smart phone [35]. The same principle has been also extended for assessing the chlorine concentration in water [36]. Nevertheless, its performance in the analysis of the chlorine concentration in water is greatly degraded under high illumination levels and a swing of the working distance, thus suitable only for indoor use with a controlled working distance. To overcome these two limiting issues, we propose a mobile platform-based colorimeter for monitoring the chlorine concentration in water. Our proposed mobile platform composes of two main elements. The first part is a portable module or a closed chamber that mainly provides a fixed illumination level, an object holder, and a reference scene positioned at a fixed distance from the 2D detection plane. It is also equipped with an opaque bottle cover for preventing the unwanted light from the surrounding environment. The second part is a smart mobile device embedded with our color analysis algorithm. As the reference material and the small glass bottle are already in the field of view of the mobile device's camera, we can simultaneously extract the image data from these two objects, leading to a self-referencing analysis. After that, a specific color ratio from these two image regions is used for specifically converting the water color inside the small glass bottle into its corresponding chlorine concentration. Additional key features include cost effectiveness, compactness, portability, and ease of implementation.

2. Proposed mobile platform-based colorimeter structure for monitoring chlorine concentration in water

Fig. 1 illustrates the two main components of the proposed mobile platform for estimating the amount of chlorine in water. The first part is a portable closed chamber with an opaque bottle cover. It is simply designed in order to provide a fixed illumination, an object holder, and a reference scene at a fixed distance from the 2D detection plane. Due to the opaque bottle cover, this module inherently eliminates the unwanted effect from the variations in the environmental illumination. The second part is a smart mobile device, either a smart mobile phone or a tablet, embedded with our color analysis algorithm. Inside the first part of our mobile platform contains white light sources, a sheet of white diffuser, a flat reflective surface, an ON/OFF switch, and a set of batteries. On the top cover of the first part, there are an object holder and an observing window.

From Fig. 1, when a diffuser is illuminated by white light sources, it functions as a diffused light source that uniformly illuminates the object (e.g., a glass bottle) located near the center of the diffuser. In addition, two portions of the diffused light source located along the side of the glass bottle are considered as reference scenes. This means that we inherently have reference objects near the object under our investigation, leading to a self-referencing analysis. The flat reflective surface orientated at 45° folds the optical path to make the module more compact. The smart mobile device is orientated on the observing window such that both the glass bottle and the reference scenes can be clearly seen within the field of view of

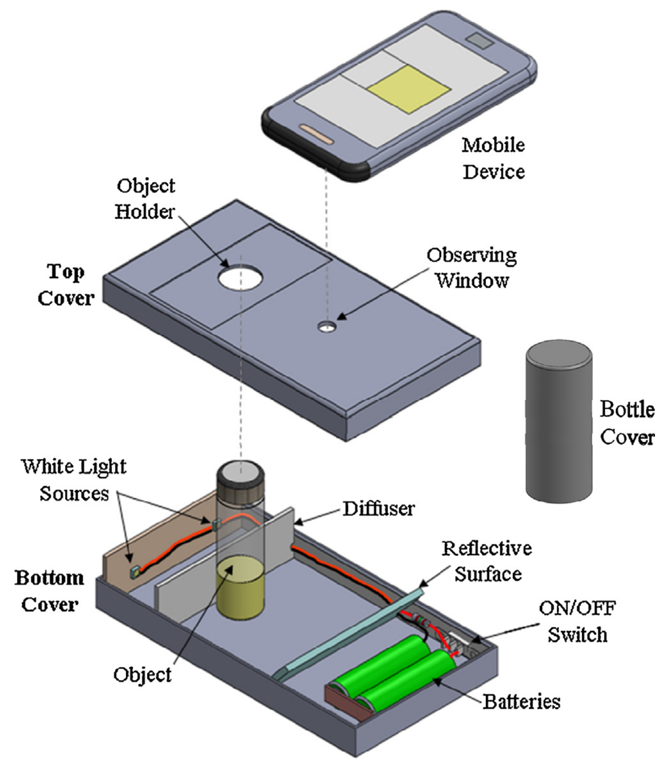

Fig. 1. Proposed mobile platform-based colorimeter with a self-referencing configuration for estimating the chlorine concentration in water.

its digital color camera. With our design simplicity of the portable closed chamber, it can support any smart mobile devices that have different sizes and appearances.

Based on a widely-used chemically indicating material such as DPD, toluidine, and KI-starch solution, the change in water color occurs only in one color tone either in red, yellow, or blue for ease of visual inspection, respectively. This means that we can analyze the red, green, and blue colors obtained directly from the smart mobile device rather than converting them into the hue parameter. For simplicity in the analysis, the color information obtained from the glass bottle and the reference scenes is calculated as a color ratio (CR) as described in our previous work [35,36]. As our analysis is performed under a fixed distance between the smart mobile device and the glass bottle, and a fixed uniform white light illumination, a good relationship between the measured CR and the chlorine concentration in water can be determined. It can also be noticed that our proposed mobile platform-based colorimeter can be applied to analyze the concentration of other chemical materials as long as they can react with the suitably indicating chemical materials that lead to the change in their colors.

3. Sample preparation

Samples of the chlorine solution are needed to test our proposed concept. In this case, we choose to dissolve calcium hypochlorite in water as it is typically used in the chlorination process for drinking water and swimming pools. A 5-ml chlorine solution is brought into a small glass bottle having 1 mm thick, 20 mm outer diameter, and 73 mm high. After that, 200–220 μl (e.g., 5 drops) of *o*-tolidine solution is dropped into 5 ml of the chlorine solution. Note that we select *o*-tolidine solution as the chemically indicating material because it is widely used in fishery farms in Thailand. Fig. 2 shows chlorine solutions with 14 concentration levels mixed with the *o*-tolidine solution for at least 30 s. It can be clearly observed