CMOS Image Sensor for Rapid Chemical Detection

Jasmine P. Devadhasan and Mingwei Shao
Department of Bionanotechnology, Gachon University, Sungnam, 461-701, Republic of Korea.

Sanghyo Kim
Gachon Medical Research Institute, Gil Medical Center, Incheon, 405-760, Republic of Korea.
Email: jasminepramila.d@gmail.com, samkim@gachon.ac.kr

Abstract—**Toxic chemicals are one of the major global issues due to their adverse effect to human health and bio-systems. This present study demonstrated a CMOS image sensor based highly sensitive colorimetric sensing system for the detection various pH ranges (pH1 to 13). For the reaction, pH indicator blended with polyvinyl alcohol (PVA) and titanium (TiO_2) nanoparticle; and developed the thin hydrogel films, which was suitable chip to carry out the chemical interaction and detection by CMOS image sensor. Various pH solutions were applied on the hydrogel films, and the chemicals were reacted with pH indicator, and reactions produced the color changes based on their pH range within 30 seconds. Each film produced different color (red to blue) based on their pH range, which is useful to identify the pH range as qualitatively and the color development was quantitatively analyzed by the CMOS image sensor. The CMOS image sensor absorbed the color and displayed the red, green, and blue (RGB) color value as a digital number with the aid of an analog-to-digital converter. The sensor produced the highly sensitive results for each individual pH range based on color developed in the film. This novel method of pH detection will produce an excellent chemical sensor with rapid, cheaper, selective and user-friendly for smart on-site toxic detection.**

Index Terms—**CMOS image sensor, RGB color, PH change, Hydrogel film**

I. Introduction

Toxic chemicals are the most dangerous to living organisms and biosystems [1]. Some highly adhesive and volatile compounds are colorless, tasteless and inodorous, which is hard to sense the toxic level. Traditional methods of gas chromatography [2], mass spectroscopy [3] is considered as the most reliable method for toxic detection and required a trained person, expensive device, big portable size and heavy weight are limitations of the detection system. In addition, number of sensors such as electronic noses [4], [5], fluorescence [6], carbon-nano-tubes [7], microcantilever [8], liquid crystals [9] and array based sensing [10], [11] technologies have proven in toxic chemical detection with limited ability. Besides, the compact size, rapid, reliable and equipment free sensing are highly desirable. Since, the expensive and big size instrument cannot bring for onsite environmental toxic detection.

Recently array based calorimetric chemical detection is identified as powerful method which produces the color based on the dye applied over the array. Varieties of indicators and dyes such as metal ions (e.g. metalloporphyrins), acid indicators, base indicators, vapochromic, solvatochromic dyes and metal salts are used to develop the array [11]. This kind of array could be apply for the detection of toxic industrial chemicals [10], and volatile organic compounds [11] that produced the color red, green, and blue (RGB) at the array and the color monitored by the Chemometric analysis and absolute RGB value calculated by statistical analysis [10]. Generally, most of the array based chemical sensing working principles are same as aforementioned. In addition, some array based sensor could analyse the toxic gas sensing which is highly desirable in industries, laboratories etc. However, requirement of special array reader and absolute RGB calculation are weakness to reach for practical and use friendly application.

In that respect, the present group developed CMOS sensor based pH detection. Normally hydrogen fluoride (pH 2.1 in 0.1 M), hydrogen sulphide (pH 4.1), hydrochloric acid (pH 1.1 in 0.1M) and ammonia (pH 11.1 in 0.1 M) [9] are known as some toxic industrial chemical and each chemical carried their own pH range. Nowadays, PH meter and litmus paper are utilizing to find the pH range at laboratory; limited applicability could not apply meter for toxic chemical detection. Thus, we have developed a hydrogel based pH chip to analyse the various pH ranges as the preliminary level. Subsequently, the sensing system is aimed to try for various toxic chemicals. In order to achieve the PH sensing, the group developed a hydrogel based pH chip. A simple hydrogel film developed with alzarin red. Applied the various pH solutions (pH 1 to 13) on the chip and produced the color based on the pH range. The chip was analyzed by CMOS image sensor and produced the red, green and blue (RGB) value. Little amount of PH changes was hard to identify by pH paper and the CMOS sensor based PH sensing produce the results as quantitatively even minute differences. As a results hydrogel based pH monitoring is most useful system to apply for highly toxic chemical detection based on the pH change.

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II. Materials and Methods

A. CMOS Image Sensor

A CMOS image sensor (Sponsored from Silicon File Technologies) is an electronic device that absorbs the color and converts the RGB value as digital numbers. In the present experiment, a NOON0PC30L, 110,000 active single chip polychromatic CMOS image sensor was used. The sensor contains 367x314 multi pixel photon arrays and is connected to a 10-bit analog to digital converter (ADC).

B. Preparation of Hydrogel for Chip Development

For chip development, polyvinyl alcohol (PVA) and water mixed as 1:10 ratio and kept it in the stirrer at 60-70°C till dissolved. Followed by, 500 µl of glutaraldyhyde added as a cross linking agent and mix thoroughly. Then, 0.3 gram of titanium oxide (TiO_2) nanoparticles with 100 nm size were added and sonicated for 20 min that created the opaque chip. Then Alzarin red dye (pH range 3.7 to 5.2) was added and mixed thoroughly. Now the hydrogel mixture applied over the cover glass and kept the slides into the hot air over under 40°C. After few hours, the hydrogel has dried like thin film.

C. pH Analysis with Hydrogel Film

The pH assay is very simple and rapid. For the experiment, small drops (10 µl-15 µl) of various pH solutions (pH 1-13) applied on 13 individual chips. The hydrogel chip absorbed the solutions immediately and produced the color within 15 seconds. Then, the chip analyzed by the CMOS image sensor qualitatively and quantitatively.

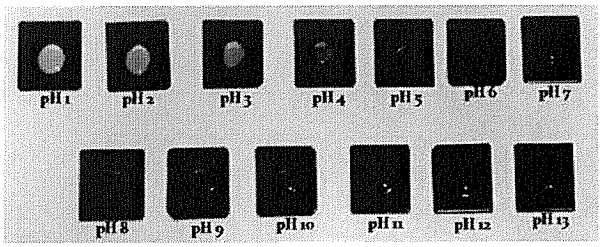


Figure 1. Color differences of various pH solutions (pH 1-13) on hydrogel chip. pH 1 shows sharp yellow color and turned to blue at pH 13.

III. Results and Discussions

A. Assay Detection on the Chip

Various pH solutions applied on the hydrogel chip produces different color within 15 seconds. The chip qualitatively checks the pH range; each chip produces the different color. The chip with various pH colors has showed in Fig. 1. Chip with pH 1 solutions shows the sharp yellow color and color has slightly faded and was stable in pH 6. It showed that the chip pH range is pH 6. Then the color turned to purple and finally reached to blue color at pH 13. Generally, group of chemicals such as methyl red, methyl orange, methyl violet, bromophenol blue, litmus, thymol blue, alzarin red and alzarin yellow etc., has been used as pH indicators. However, we have used a single dye of alzarin red with pH 3.7 to 5.2 for whole pH range analysis. Additionally, TiO_2 acts as a redox indicators which produce the deep color in the chip. This kind of approach has the capability for toxic chemical detection based on the pH range. Since, the applied pH solution has toxic chemical in acidic (HCL) and basic ranges which produces the various color accordingly. Subsequently, the chip quantitatively analyzed by the CMOS image sensor.

B. CMOS Sensor Based pH Analysis

Before analysis, fabrication of suitable chip was important task. CMOS sensor absorbs the color of the chip. Thus, the chip should not be highly transparent or glassy. Using the TiO2 nanoparticles produced the chip with opaque, non-transparent, controlled photons passage and act as redox indicators. After reaction, each chip was analyzed quantitatively by the CMOS image sensor. Each sensor contains a single photodiode; the sensor absorbs the photon color and produced RGB value based on the pH range of the chip. Interestingly, the CMOS Eye detection was different than the qualitative analysis. CMOS sensor color detection has given as Fig. 2. The chip color detection was different than detection with naked eyes. Here, pH 1 shows the greenish yellow color and the color turned to ash. The produced the purple color in the neutral pH range and turned to blue at pH 13. Based on the color RGB value has showed by the sensor.

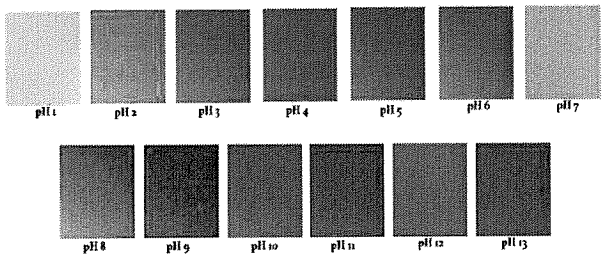


Figure 2. CMOS image sensor based pH analysis. The CMOS Eye monitored various pH solutions (pH 1-13) and shows the greenish yellow at pH1 and turned to blue at pH 13.

Also, the color detection was very simple and produced the RGB value in digital number for each pH chip. The RGB differences of each pH solutions have given as Fig. 3 (a). The figure shows sensitivity of the RGB variation; pH 1 RGB shows the high amount of G and R value and least amount of B value and turned oppositely in pH 13 as high amount of B value and least amount of R and G value respectively. The data proved the CMOS sensor based pH detection is the highly sensitive method and can utilize for the chemical sensing. To find the absolute ΔRGB value, Euclidean distance has given in Fig. 3 (b) which provides the difference between the reference and test value and their similarities. The value decreased from pH 1 to 6. Again the value was increased from pH 7-13. Additionally, the reference value of the chip value corresponded with pH 6 and Euclidean distance also proved the similarities and differences. Also, this data proved the assay sensitivity and capability to

apply for toxic chemical detection.

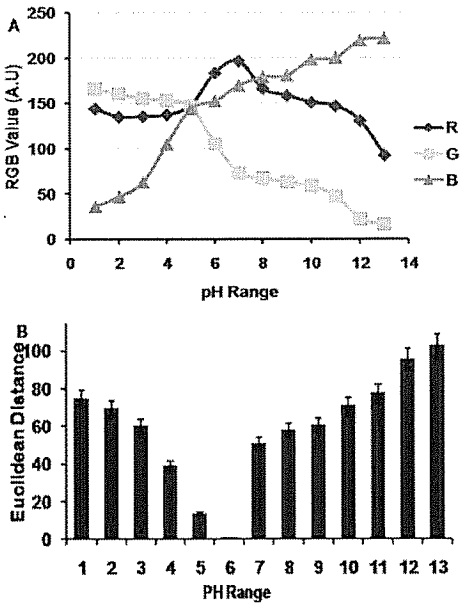


Figure 3. RGB values of various pH solutions (a) CMOS sensor based RGB value differences for various pH solutions. (b) Euclidean distance shows the absolute ΔRGB value for each pH range.

In recent days, varieties of toxic chemical detection are available due to requirement of on-site monitoring. However, the sensitive method of array based detection and other colorimetric toxic detection required a separate reader and statistical analysis. The CMOS sensor based detection not required any expensive or additional devices. CMOS sensor is available in the mobile phone camera; according to report, approximately 90% of the world populations are using the mobile phone. Thus, the sensor system does not require any additional handheld device and could monitor the chemical at any place and any time

IV. Conslusions

CMOS sensor based pH analysis represents a new kind of calorimetric based chemical sensing approach. The CMOS sensor-hydrogel chip based pH analysis well suitable for toxic chemical detection. The qualitative and quantitative data proved the sensitive of the detection system. Further, various kind toxic chemical and toxic gases or vapors sensing study is under progress and will be communicated soon. This kind of approach will help to produce a rapid, less expensive and user friendly smart on-site chemical sensor [12].

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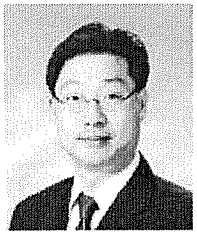
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Jasmine Pramila Devadhasan received her B.S degree in botany from Manomanium Sundaranar University, India in 2003. Her M.S and M.Phil degree in biotechnology from Bharathidasan University, India in 2005 and 2007, respectively. Her Ph.D degree in biomedical engineering from Gachon University, South Korea in 2013.
She is currently working as a post doctoral fellow at department of Bionanotechnology, Gachon University, South Korea. She teaches advanced bionanosensor and her main research in CMOS image sensor based biomolecular diagnostics and toxic chemical detection towards point-of-care monitoring.



Mingwei Shao received his B.S degree in bioengineering from Ludong University, China in 2013. He is current master student at department of Bionanotechnology, Gachon University, South Korea and doing his research in rapid toxic chemical detection.



Sanghyo Kim received his B.S degree in polymer engineering, Busan University, South Korea. His M.S and Ph.D degree in polymer engineering and BioMEMS and NEMS, respectively from Pohang University of Science and Technology, South korea Currently, he is an associate professor at department of bionanotechnology, Gachon University, South Korea. His research interests include biomaterials, tissue engineering, polymer engineering, molecular diagnostics, drug delivery and advance bioanalytical techniques. He has published more than hundred research papers, scientific reviews, and book chapters.