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Mobile phone as a fluorescence reader

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A new achievement of mobile phone application for fluorometry to identify cocaine concentration using samples made of tested person sweat implementing special designed software has been presented in this paper. Accessibility is one of most dominant features of this method since the main important part is a mobile phone which can be found and used vastly. Reliability of data collected using this technique is strong enough to compete with past time consuming and expensive devices and equipment. The results enable to have a close and precise observation about the amount of cocaine concentration, the same as reference device outputs.

Keywords: mobile phone, fluorescence detection, laser, CMOS, cocaine.

1. Introduction

Application of new mobile phones equipped with latest technologies of sensitive cameras, fast CPU(s), high resolution screens is rising up in different areas of sciences. As an example, many researches have been done to implement a mobile phone as an accessible and small analyzer which will be discussed briefly as follows. An application of a mobile phone as a test reader to sense the presence of a target analyte in a sample has been recently demonstrated by a few groups of researchers [1–8]. A personalized allergen testing platform running on a mobile phone that images and automatically analyses colorimetric assays toward sensitive and specific detection of allergens in food samples has been discussed [2]. The integration of imaging cytometry and fluorescent microscopy on a mobile phone equipped with a special designed optofluidic attachment which can be useful for rapid and sensitive imaging of bodily fluids for conducting various cell counts (*e.g.*, toward monitoring of HIV+ patients) or rare cell analysis as well as for screening of water quality in remote and resource-poor settings has been presented [3]. Other mobile phone applications have been discussed to determine the concentration of a target inside the sample as an *Escherichia coli* detection platform by quantifying the fluorescent light emission using an equipped mobile phone camera [4]. Another group demonstrated the wide-field fluorescent and darkfield imaging using a mobile phone which is able to detect the scattered light from the objects without the use of any filters [5]. Researchers at UCLA Electrical

Engineering Department demonstrated lens-free digital microscopy on a cell phone [6]. They demonstrated a device which does not utilize any lenses, lasers or other bulky optical components. A cheap LED which scatters light through the sample has been used as a light source. The interference of the light waves that passed through the cells with the unscattered LED light creates the hologram of each cell, which is detected using the CMOS detector array that is already installed in the phone camera. Moreover, another group of researchers at the universities of California Berkeley and San Francisco has presented a valuable usage of an equipped camera mobile phone for detection and analyzing images taken from malaria, sickle cell anemia and tuberculosis (TB) samples [7]. To convert a mobile phone camera into a microscope, special tools and parts have been attached to the phone for a better and precise imaging. They implement two ways of brightfield and fluorescence imaging to detect and capture a proper picture based on a sample. White LED for illumination in darker condition was used in brightfield imaging. Moreover, the illumination for fluorescent imaging has been provided by a high-power blue LED in the excitation range of the fluorescent Auramine O stain commonly used for detection of TB bacilli in the sample. Additionally, researchers at National Taipei University of Technology tried to use a mobile phone as a DNA detector. Conventional DNA detection is based on post-PCR (polymerase chain reaction) fluorescence detection which is an expensive method and only available at medical centers or clinic laboratories. Moreover, traditional PCR requires 30–40 process cycles with three discrete isothermal steps for DNA denaturation, primer annealing and elongation [8]. In their study, conventional PCR (cPCR) was employed to work with commercial mobile phones to achieve post-PCR DNA detection. After DNA amplification using cPCR, fluorescence images of the samples were captured to determine whether DNA fragments were contained in the test sample [8]. A constant-temperature heater consisting of a thin-film heater and a microprocessor was assembled on the fixture of the DNA sample tube. No control interface was required between the mobile phone and the heater. Immediately after completing the reaction, a signal generated by microprocessor was sent to inform the mobile phone to capture the fluorescence image [8].

As discussed before, a mobile phone can be used in different places and areas of science. A group of researchers from the faculty of Microsystems, Electronics and Photonics at Wrocław University of Technology has implemented a new method to detect cocaine concentration in a small amount of ng/ml using tested person sweat. They have used an OLED light source as an excitation light source, a sensitive CCD camera connected to the computer and specialized software as a detection unit and lab-on-paper as a sweat collector which is based on the immunochromatographic method with fluorescence detection [9]. An analyzing picture taken from excited fluorescent dyes inside the immunochromatographic strip impregnated with the sweat of a tested person by OLED light source will lead us to the amount of cocaine concentration inside the sample.

Based on nowadays mobile phone abilities and its mentioned capabilities, the effort has been done to convert it into a portable drugmeter. It has been proposed to use

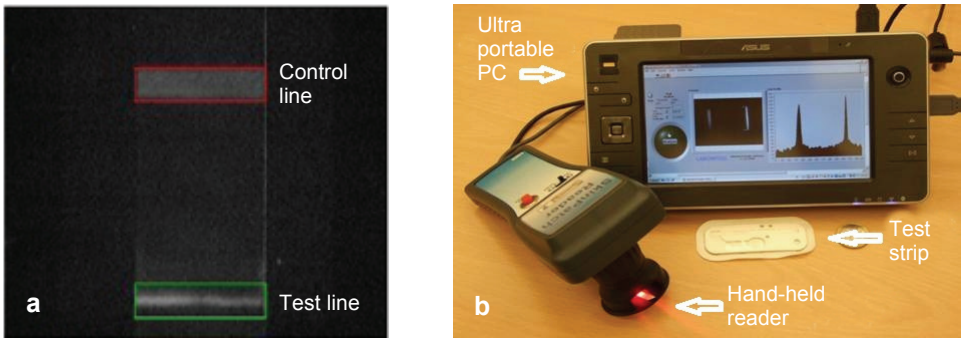

Fig. 1. View of the detection areas of the strips, as seen by CCD-based detection unit [9] (**a**) and computer--based device (**b**).

CMOS mobile phone camera and software possibilities of a mobile phone to read fluorescence signals. Most of the mobile phone cameras are equipped with CMOS sensor and that is the reason to choose CMOS instead of CCD sensor. Sensitivity is the main reason of CCD sensors usage in most of professional cameras. Since CMOS sensors are cheaper, it is more economical to use them in unprofessional devices like mobile phone cameras.

2. Methods and apparatus

Implementing and mixing different areas of optical detection in micro-scale helped us to use a method presented by a research group for detection of cocaine concentration even for the small amount in the sample. Using a special paper-based strip (developed by Biosensia Ltd., Dublin, Ireland), it is possible to collect tested person sweat, show the result by illuminating laser light into a placed control and then test lines on it using a detection tool. The comparison of fluorescence intensity of tested and control lines will lead us to the results. Figure 1 shows the device and the paper-based strip picture taken by a reference computer-based device using CCD sensor. This reference device contains a CCD camera, a 635 nm OLED, a 670 nm filter and a software designed using LABVIEW inside the computer. In this paper, the effort has been taken to present the ability of a mobile phone as a fluorescence detector implementing the above idea to identify cocaine concentration inside the sample. It has been proposed to use CMOS mobile phone camera and software possibilities of a mobile phone to read fluorescence signals.

2.1. Setup

The tested setup and its different parts which have been used for experiments are shown in Fig. 2. The mobile phone which has been used for this experiment is SAMSUNG GALAXY ACE (S5830) equipped with a 5 megapixel CMOS sensor camera. This phone is using ANDROID operating system (OS), one of famous and powerful OS(s)

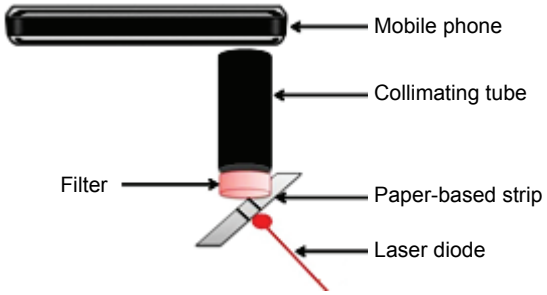

Fig. 2. Schematic of setup utilizing mobile phone and external optics for fluorescence detection.

which can work on different devices and smart phones. It is worth mentioning that the programs which have been written for this OS are based on JAVA language. Different capturing picture scene modes (scene, night, text, sunset and backlight modes) have been tested. The most useful, the one which gave the best results, was a night mode. Additionally, a text mode also provided some good pictures, but the procedure was not accurate and the results changed during different shots.

The strip is an immunochromatographic paper-based strip with cocaine capturing areas. The detection areas were deposited onto a nitrocellulose membrane. Test and control lines were deposited onto the strip with 5 mm spacing. The lines contained Dyelight 649 fluorochrome with the maximal excitation wavelength of 649 nm and emission at 670 nm [9]. The usage of such a filter is also necessary to omit those parts of light which are not essential in our picture to get better results in the output (blocking of fluorescence excitation light and passing fluorescence). The filter which has been used is an absorbance filter (Gottinger Farb Filter No. 104) which gives the best results in comparison with different interference filters of 650 nm long-pass and 660/670 nm band-pass. A laser diode with the wavelength of 635 nm and 5 mW power has been used as an excitation source. All pictures have been captured with voltage of 4.8 V and current of 0.04 A supplied by a power source for laser. Different angles of the strip illumination (from ~5° to ~60°) have been tested, however the angle of illumination is not important in such a method of spectroflourometry.

2.2. Algorithm

The algorithm, which a mobile phone program uses to analyze and process the images taken by a camera or those stored in mobile phone memory, is presented in Fig. 3. Choosing or taking a picture will lead us to the analyzing step which will run in the background. This step is responsible for converting the RGB information into the grayscale.

Arrays of pixels represent a digital color image where each of those pixels contains information of standard primary colors (red, blue and green (RGB)). To have better

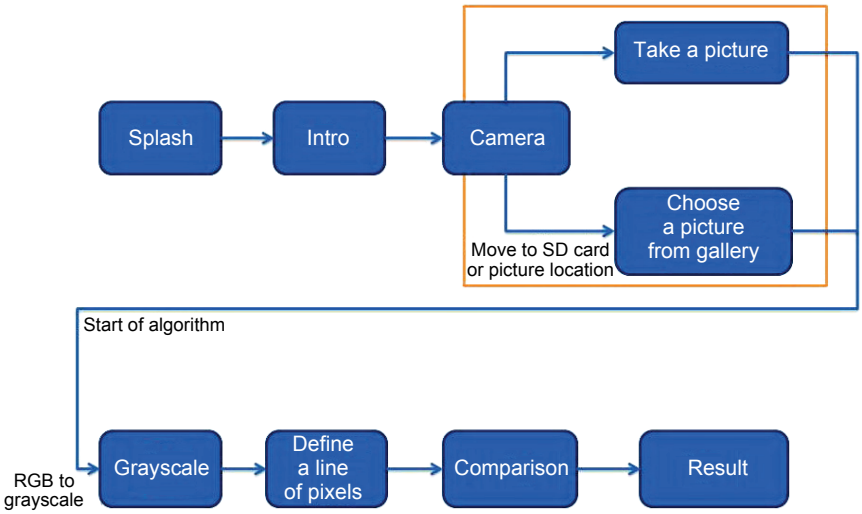

Fig. 3. Algorithm of the program analyzing the captured/loaded pictures.

results, it is more preferable to convert RGB information of each pixel into the grayscale and have a comparison of all those data on the next page. The formula that has been used to convert RGB to grayscale information of each pixel is as below:

Grayscale = (30% Red) + (59% Green) + (11% Blue)

Two lines of pixels in the middle of both vertical and horizontal axes must be chosen by the program to extract and compare the details of pixels RGB, print the results and draw the graph. Comparing two main peaks of this graph will lead us to cocaine concentration inside the sample [9].

3. Results

Different samples with different amounts of cocaine have been tested by the use of described here mobile phone-based instruments, and the results have been compared with the reference computer-based devices. Figure 4 shows graphs made by both computer-based and mobile phone-based software. Axis *X* is the number of pixels in the picture and axis *Y* is the fluorescence intensity based on RGB information converted to the grayscale.

The results obtained by mobile phone software are close to the expected ones used to be processed by computer-based software. As it can be observed clearly, the results obtained by both devices are close enough, especially for 1.5, 4.5 and 10.5 ng/ml. This means that the mobile phone setup can be a good alternative for a computer-based device. Comparing the picks' ratios in a percentage scale is the most recommended

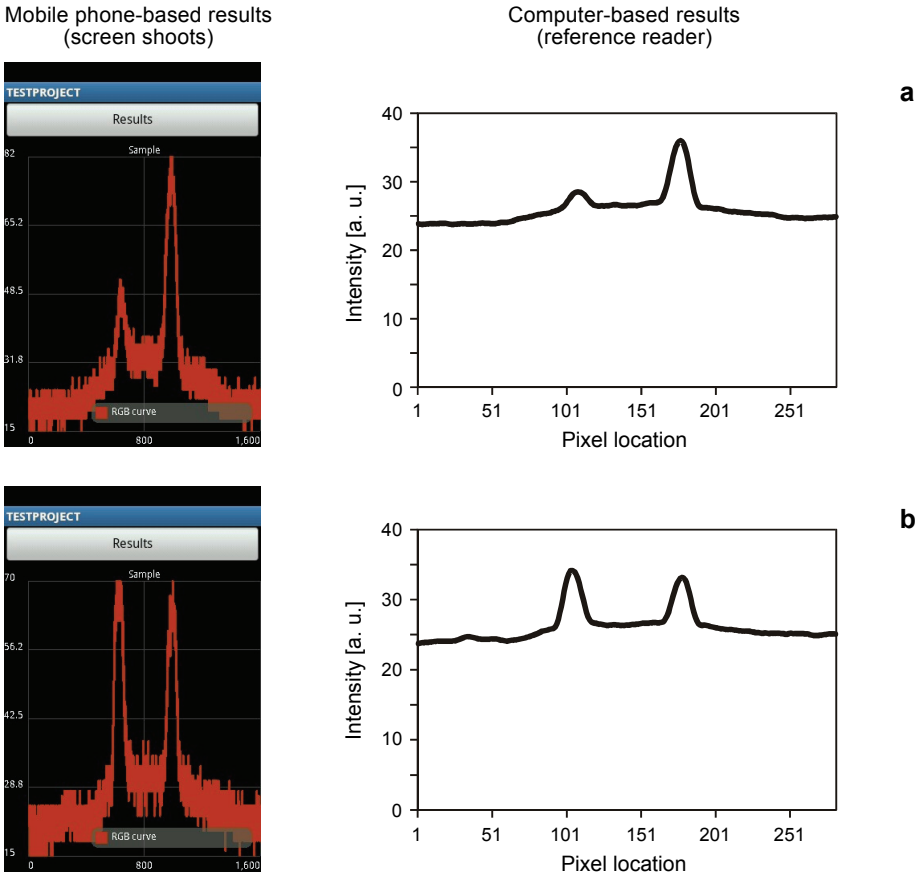

Fig. 4. The graphs show the profile of fluorescence intensity detected using computer-based and mobile phone-based software inside the sample with different amounts of cocaine of 100 ng/ml (**a**) and NEG: no cocaine (**b**).

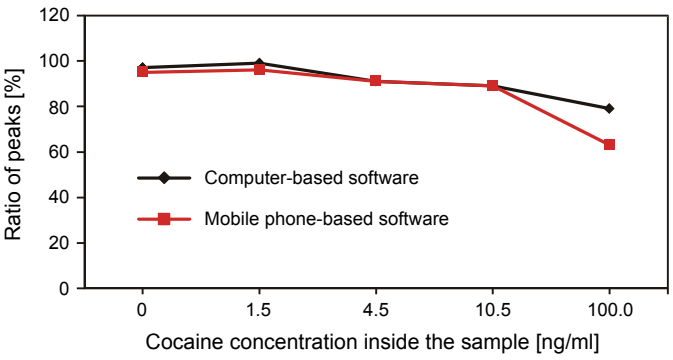

Fig. 5. Ratio of peaks (ratio of pixel brightness at both picks) calculated on the basis of computer-based and mobile phone-based instruments and software.

T a b l e 1. Cocaine concentration results based on data collected with both mobile phone and computer-based software and setups.

	NEG No cocaine	1.5 ng/ml	4.5 ng/ml	10.5 ng/ml	100 ng/ml
Computer-based	97%	99%	91%	89%	79%
Mobile phone-based	95%	96%	91%	89%	63%

method. It is more reliable since both lines in each measurement are excited with the same energy of laser and the control line can be enumerated as a reference line. Figure 5 reveals the differences in values obtained using both devices.

By analyzing the graph, it can be easily inferred that increasing the cocaine concentration inside the sample has an effect on the brightness of lines. The major difference is in the last value of 100 ng/ml when the brightness of the control line is significantly small. The results of the comparison made by both programs and devices for different concentrations of cocaine using pictures taken by a mobile phone camera are presented in Table 1.

4. Conclusions

A new achievement of mobile phone application making use of its camera as a fluorescence detector and specially designed internal software to identify the fluorescence signal informing about cocaine concentration inside a sample has been demonstrated in this paper.

The optical setup has been prepared co-working with a mobile phone, equipped with special mobile phone software and test strips with cocaine concentration from NEG to 100 ng/ml. It has been demonstrated that mobile phone fluorescence readouts are comparable to the reference device and proved that the mobile phone can be applied as a fluorescence reader.

The mobile phone-based device equipped with the software can be useful, especially when computer and laboratory facilities are not accessible. Moreover, mobile phone software outputs have been close enough to those made by computer-based reference software. In this edition of mobile phone software, all the analyses have been based on RGB information from the middle row of pixels in the picture. In the next version of this software, the effort will be focused on making this analysis for all pixels in the picture or at least for more than one line and a specified area for better outputs to improve a signal-to-noise ratio.

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