Talanta 178 (2018) 377–383

Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

# Optical molecular analysis using office flatbed photo scanner: New approaches and solutions

K.V. Oskolok*, E.V. Shults, O.V. Monogarova, A.A. Chaplenko

*Department of Chemistry, Analytical Chemistry Division, Lomonosov Moscow State University, 119991 Moscow, Russia*

ARTICLE INFO

*Keywords:*
Office flatbed scanner
Colorimetry
Photometry
Fluorimetry
Nephelometry
Analysis of drugs

ABSTRACT

The design and operations principles of a prototype of optical device based on an office flatbed photo scanner with a slide adapter are described in the paper. The developed device is intended for the analysis of liquid-phase samples by colorimetry, photometry, fluorimetry and nephelometry. Teflon cassettes designed for fixing cuvettes on glass plate of the scanner. Teflon wedge-shaped inserts for cuvettes have been developed to optimize the conditions of colorimetric analysis. These inserts allow varying the thickness of the absorbing layer of solutions. Multilayer absorption filters with a variable bandwidth are proposed for light monochromatization. Filters are obtained by the method of inkjet printing on polymer films. A violet laser pointer is used as a light source for fluorimetric and nephelometric analysis. The principal possibility of measuring the absorption and fluorescence spectra using photo scanner is shown. The analytical capabilities of the developed prototype of an optical molecular analyzer are demonstrated when determining riboflavin in an injection solution, acetylsalicylic acid and magnesium hydroxide in *Cardiomagnyl*® drug.

## 1. Introduction

In recent years, digital optical gadgets (smartphones, cameras and other devices completed by a light sensor) are increasingly used as measuring instruments for chemical analysis [1–5]. For example, they have been used for digital microscopy [6–9], cytometry [10,11], read-out of immunoassays [12,13] and lateral flow tests [14–17], electrochemical biosensing [18,19] and surface plasmon based biosensing [20], colorimetric detection [21] and healthcare monitoring [11,19] and among others [22]. Low cost, rapidity and the ability to document measurement results allow considering similar technical solutions as a reasonable alternative to the use of test tools in pharmaceutical [23,24] and cosmetology laboratories, in the food industry [25,26], as well as for environmental monitoring [27], bioanalytical sciences and medicine [22].

However mediocre metrological characteristics of measurement results (low sensitivity, reproducibility and selectivity, high error, narrow range of linearity of calibration dependence) using digital optical gadgets limit the possibilities of chemical analysis significantly. To solve these problems the developed devices and measurement techniques are being improved. In particular, complex systems consisting of a modified light source, a simple device for dispersion of light flux (for example, a holographic film transmission grating), sample holder, mobile camera and software package for digital processing of images is described in paper [28]. As a source of radiation in such systems incandescent lamps was used [12]. However large size, nonuniformity of light, high power consumption lead to an increase proportion of device, a decrease the reproducibility of the determination results. Therefore, recently as source of radiation light emitting (including ultraviolet) diodes are used [10,28]. To focus the light waveguides, lenses and camera apertures are applied [11]. To obtain an analytical signal from a small amount of a sample the use of on-chip microscope in combination with a smartphone is suggested [7].

Modern digital optical gadgets combine a photosensitive sensor (detector), three absorption filters (rudimentary polychromator), a microcontroller and, in some cases, a lighting system and a recording device. The described scheme is ideal for design of first level not recording photocolorimeter (three color channels only!). This device will allow detecting sufficiently intense fluxes of primary radiation interacting with the analyzed sample. Unfortunately, the use of cheap CCD array, the absence of a serious hardware signal amplification system, and the effective suppression of noise limit the ability to detect weak fluxes of secondary radiation emitted by the analyte. The situation is aggravated by the technical complexity of separating primary and secondary beams in space and wavelengths. The above mentioned reasons cause the predominant use of digital optical gadgets for colorimetric analysis [29–31]. In this case the most popular are smartphones, according to papers [32–35]. The advantages of smartphones

* Corresponding author.
*E-mail addresses:* k_oskolok@mail.ru, oskolok@analyt.chem.msu.ru (K.V. Oskolok).

http://dx.doi.org/10.1016/j.talanta.2017.09.049
Received 4 July 2017; Received in revised form 14 September 2017; Accepted 17 September 2017
Available online 20 September 2017
0039-9140/ 

are compactness, mobility and the possibility of obtaining a result without using a stationary computer or laptop. However, on the basis of a number of characteristics (proportions, form factor, possibility of selection of measurement conditions, ensuring the stability of these conditions, combination with additional auxiliary devices) an office flatbed photo scanner with a slide adapter is most convenient for use in chemical analysis [1]. Besides, it is simpler to overcome typical problems of application of smartphones for chemical analysis when using the flatbed photo scanner:

| Problem | Solution |
|---|---|
| Automatic selection of exposure time for image formation using a smartphone camera can prevent to correct analytical signal measurement. | The photo scanner has an exposure time setting zone on the glass desktop. We propose to regulate the exposure time by means of darkened semitransparent polymer films placed in this zone. |
| Automatic image correction using a smartphone camera can disturb the analytical signal measurement. | The scanner has a programmable postprocessing function. It can be switched off. |
| Narrow level range of the color channels when working with the *RGB*-model (0–255) limits the linearity range of calibration curve. | Many modern scanners work not only with 24-bit color (8-bit per channel), but also with 48-bit color (16-bit per channel). |
| As a rule smartphones use compressed lossy JPG-format for raster image saving. In some cases it can distort analytical signal. | Scanners can use uncompressed lossless TIF-format for raster image saving. |

To expand of analytical capabilities of the scanner it is necessary to use additional, simple and affordable, but more efficient means of monochromatization of light. It is advisable to use inexpensive household sources of monochromatic radiation of the optical range with small angles of divergence of rays and high spatial localization of the released power. It should also be more effective to use the opportunities of light sensor. The CCD array is a huge set of micron-sized detectors (diodes) working simultaneously and capable of independently forming a signal of the same object. But since the size of the analyzed sample is incommensurably larger than the size of the individual diodes of the CCD, only a small part of this sample in a cuvette placed on the glass table of the scanner provides the signal of each of diodes. Therefore:

1) Focusing of light on a limited number of diodes of the CCD matrix, i.e., optical reduction of the image size of the analyzed sample can increase the signal-to-noise ratio and, accordingly, the detection sensitivity (geometrical signal amplification).
2) Mathematical processing of the data of a huge number of diodes of the CCD-matrix, forming an analytical signal under the same conditions, allows to substantially leveling the uncertainty of the measurement results.
3) The spatial variation of signal generation conditions within a wide range allows one to extract a large amount information in one measurement act and select the optimal mode for achieving the best metrological characteristics of the analysis results (for example, the required range of linearity of the calibration dependence).

Taking into account the above-mentioned paradigm of chemical analysis using photo scanner, a special practical interest is the possibility of detecting primary radiation that has not only passed through the sample but also is elastically scattered by it, as well as secondary radiation emitted by the analyte. The purpose of our work is the test of feasibility of chemical analysis using a scanner and development of a prototype of cost-effective optical device based on an office flatbed photo scanner with a slide adapter for analyzing liquid-phase samples by colorimetry, photometry, fluorimetry and nephelometry.

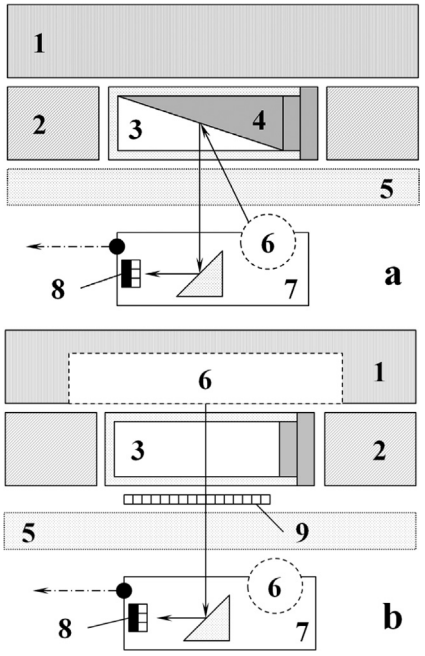


**Fig. 1.** Block diagram of the device for colorimetry (**a**) and photometry (**b**): 1 – flatbed scanner cover, 2 – Teflon cassette, 3 – cuvette for photometry, 4 – wedge-shaped insert, 5 – glass plate of scanner, 6 – lamp, 7 – scanner carriage, 8 – CCD array, 9 – LVF.

## 2. Materials and methods

### 2.1. Equipment

The special Teflon cassette for ***colorimetric analysis*** is created. This cassette is placed onto glass plate under the scanner cover and it allows measurements of light reflection using standard photometric cuvettes ($l$ = 10 mm) (Fig. 1a). Calibration and analyzed solutions, as well as a blank solution can be placed in a cassette simultaneously. Each cuvette is closed by a wedge-shaped Teflon insert, which allows one to determine and in one pass of the scanner carriage to measure the signal in the thickness range of the absorbing layer from 0 to 20 mm. The macros for the table processor MS Excel is written. It allows getting information about the lightness of all color channels in the form of a multidimensional array of data from a bitmap image of the cassette, saved in the format “bitmap 24-bit”. The choice of conditions for the analytical signal formation is carried out in an automatic (with use of macros) or manual mode when analyzing the obtained multidimensional data array. It is necessary for varying the sensitivity coefficient, position, and width of the working range of the analyte concentrations for calculation of regression coefficients for the calibration dependence. As an analytical signal, we used a parameter similar to the optical density calculated from the results of measuring the lightness of the selected color channel for the analyzed solution and the blank solution simultaneously. This allows linearizing the calibration dependences and suppressing the noise components associated with the fluctuations in the brightness of the scanner lamp.

The special Teflon cassette for ***photometric analysis*** is created. This cassette is placed under the cover of scanner with slide adapter and it allows measurements of light transmission (Fig. 1b). Two standard cuvettes ($l$ = 10 mm) with analyzed solution and a blank solution can be placed in a cassette simultaneously. The corresponding pairs of