Smartphone-based colorimetric readers for cost-effective in vitro diagnostics

A.G. Venkatesh[1*], Thomas van Oordt[2], Felix von Stetten[2,3], Roland Zengerle[2,3] and Sandeep Kumar Vashist[2,3]

[1] Department of Electrical and Computer Engineering, Jacobs School of Engineering, University of California San Diego, San Diego CA 92093, U.S.A
[2] Hahn-Schickard, Georges-Koehler-Allee 103, 79110 Freiburg, Germany
[3] Laboratory for MEMS Applications, IMTEK – Department of Microsystems Engineering, University of Freiburg, Georges-Koehler-Allee 103, 79110 Freiburg, Germany

[*]Corresponding author's e-mail: Felix.von.Stetten@Hahn-Schickard.de

Summary

We developed several smartphone-based colorimetric readers (SBCRs) [1, 2] for cost-effective in vitro diagnostics (IVD). The first type employs an optical platform that uses an array of light emitting diodes (LED) to provide uniform illumination to the bottom of 96-well microtiter plate (MTP). The second type employs the uniform bottom illumination of MTP by placing it at the designated screensaver regions on the gadgets (iPAD4, iPAD mini, iPhone 5s or Asus Nexus). The SBCR-based IVD assays had comparable analytical sensitivities as those performed using expensive MTP reader.

1 Material and Methods

The first type of SBCRs [1] employs an optical platform that uses an array of light emitting diodes (LED) to provide uniform illumination to the bottom of 96-well microtiter plate (MTP) (Fig. 1A). The LED-based SBCRs can provide white or any other light based on the type of LEDs used. They are highly robust and ideal for clinical, industrial and bioanalytical settings. The overall manufacturing cost based on the cost of components was about 70 euros, which is at least 100-fold cheaper than the commercially-available MTP readers being used for the readout of colorimetric IVD assays.

The colorimetric readout involves the placement of MTP containing colorimetric product onto the optical platform, covering the optical platform with a dark hood and then imaging the MTP by the smartphone's back camera (Samsung Galaxy SIII mini, 5 mega pixels resolution). A novel image processing algorithm was employed for the determination of composite pixel intensities based on the red, green and blue pixel values of the specific image sections corresponding to various MTP wells (Fig. 1B).

The developed SBCR was employed for the one-step kinetics-based human C-reactive protein (CRP) sandwich immunoassay, where the formation of sandwich immune complex was detected by the colorimetric product formed in 3,3′,5,5′-tetramethylbenzidine (TMB) substrate reaction (Fig. 1B). The versatility of SBCR is further demonstrated by altering the image processing algorithm to estimate protein concentration (e.g. bovine serum albumin) by bicinchoninic acid (BCA) protein estimation assay (Fig. 1B).

2 Results

The SBCR-based IVD assays had comparable analytical sensitivities as those performed using expensive MTP reader (€ 25,000) (Fig. 1B). This demonstrates cost-effectiveness of developed SBCRs, which can be employed for the detection of any colorimetric reaction-based IVD assays. Being highly affordable, they can form the integral part of all bioanalytical laboratories.

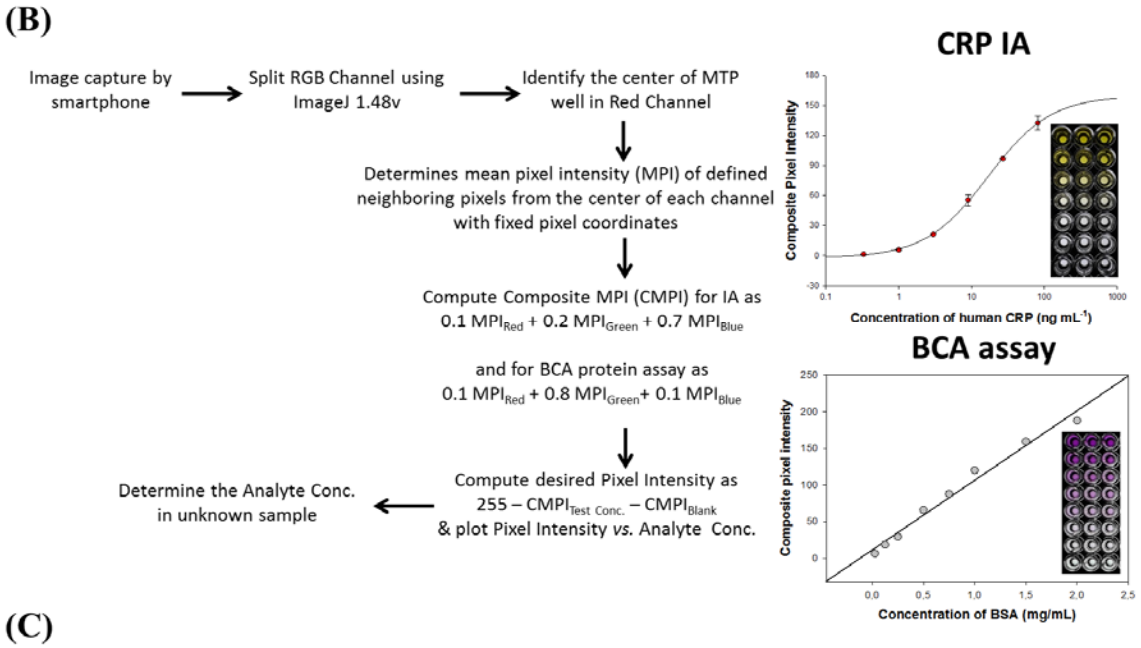
Similarly, we have developed second type of SBCRs that employ the uniform bottom illumination of MTP by placing it at the designated screensaver regions on the gadgets (iPAD4, iPAD mini, iPhone 5s or Asus Nexus) [2] (Fig. 1C). These SBCRs are intended for use in decentralized, remote and personalized home settings, where most of the persons have a gadget and a smartphone. The basic set up and smartphone imaging was exactly similar to the LED-based SBCRs, but it further requires an inexpensive base holder for the gadget in order to keep the gadget in a fixed position and to align the dark hood without scratching the gadget's screen. However, they can be used for the readout of colorimetric IVD assays in any transparent and flat diagnostic platform based on lab-on-a-chip or microfluidic technology.

3 Conclusions and Outlook

We foresee a large commercial potential and tremendous IVD applications of the developed SBCRs taking into account that most of the existing IVD market in healthcare and industry is based on colorimetric assays. Moreover, now-a-days almost everyone has a smartphone, i.e. about 7 billion cellphone users, the developed smartphone-

ISBN 978-3-8007-4100-7

based IVD technology would cater to the mobile healthcare need of the wider population. Smartphones will provide geotagged and personalized IVD data with time and date stamp apart from generating tremendous opportunities for telemedicine, text alerts, secure data management and cloud computing.



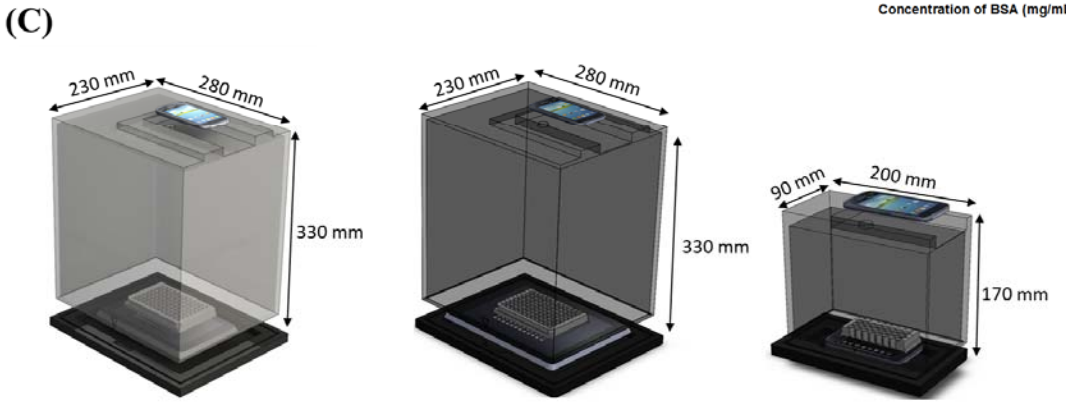


Figure 1. (A) SBCRs based on optical platform using LEDs-based illumination. (B) Left: Smartphone image analysis algorithm. Right: Smartphone-based human CRP IA and BCA protein assay for BSA. (C) SBCRs based on screensaver-based bottom illumination provided by gadgets.

ISBN 978-3-8007-4100-7

4 References

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ISBN 978-3-8007-4100-7