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Research review paper

Medical diagnostics with mobile devices: Comparison of intrinsic and extrinsic sensing

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ABSTRACT

We review the recent development of mobile detection instruments used for medical diagnostics, and consider the relative advantages of approaches that utilize the internal sensing capabilities of commercially available mobile communication devices (such as smartphones and tablet computers) compared to those that utilize a custom external sensor module. In this review, we focus specifically upon mobile medical diagnostic platforms that are being developed to serve the need in global health, personalized medicine, and point-of-care diagnostics.

Contents

1. Introduction

Since the first successful commercial introduction of smartphones in 2004, it is estimated that 6 billion mobile phones are in use worldwide (Laksanasopin et al., 2015), with nearly 1.2 billion smartphones sold in 2014 alone (Lunden, 2015). Their combination of technologies that

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Table 1
Summary technologies and applications for intrinsic and extrinsic sensing approaches for smartphone-based medical diagnostics.

Intrinsic methods

Label	SYTO16	SYTO16	Alexa488	Cy3	None	None	None	None
Analyte	Microparticle, white blood cell, pathogenic protozoan parasite	Red and white blood cell, hemoglobin	Nanoparticle, human cytomegalovirus	microRNA-21	Eggs of soil-transmitted helminth	Porcine immunoglobulin G	β_2 microglobulin	Hepatitis B, HIV
Source	LED array ($\lambda = 470$ nm)	LEDs (λ = white, 430, 470 nm)	Laser diode ($\lambda = 450$ nm)	Laser pointer ($\lambda = 532$ nm)	Incandescent flashlight	Incandescent light bulb	Smartphone screen	Smartphone flash
Assay format	Capillary tube, Slide glasses	Plastic cuvette, cytometric chamber	coverslips	Plastic cuvette	Kato–Katz thick smear slides	Photonic crystal sensor	Fluidic device	Plastic cuvette
Readout method	Fluorescence microscopy	Fluorescence/bright field microscopy, absorption	Fluorescence microscopy	Fluorescence spectroscopy	Bright field microscopy	Resonance transmission spectroscopy	Reflection dip of angle-resolved SPR	Reflected light intensity
Authors	Zhu et al.	Zhu et al.	Wei et al.	Yu et al.	Bogoch et al.	Gallegos et al.	Preechaburana et al.	Giavazzi et al.

Sample type	Solid phase									Liquid phase		
Analyte	Thrombin	*Salmonella*	Cholesterol, total bile acid	*Salmonella*, TSH	pH for urinalysis	Urinalysis (multiple analytes)	Urinalysis (multiple analytes)	Malaria, tuberculosis, HIV	Blood type	PSA		Mumps, Measles, HSV
Source	LED ($\lambda = 470$ nm)	LED ($\lambda = 475$ nm)	Biochemilu-minescence	Smartphone flash	Ambient light	Ambient light	Ambient light	LED array ($\lambda = 565$ nm)	Ambient light	LED ($\lambda = 450$ nm)	UV lamp ($\lambda = 340 \sim 400$ nm	LED array ($\lambda = 464$ nm)
Assay format	Paper in glass/ PDMS wells	Paper microfluidic	Paper microfluidic	Paper microfluidic	Paper test strip	Paper test strip	Paper test strip	Lateral flow-based RDT strip	Paper microfluidic	Microcapillary strip		96-well plate
Readout method	Fluorescent light intensity	Fluorescent light Intensity	Biochemilu-minescence light intensity	Mie- Scattered light intensity	Color change	Color change	Color change	Spatial distance	Spatial distance	Absorption	Fluorescent light intensity	Fluorescent light intensity
Authors	Petryayeva et al.	Fronczek et al.	Roda et al.	Park et al.	Shen et al.	Hong et al.	Yetisen et al.	Mudanyali et al.	Guan et al.	Barbosa et al.		Berg et al.

Extrinsic methods

Connection	USB			Audio jack	Bluetooth	WiFi
Analyte	*pf*HRP2 antigen	DNA from *Bacillus cereus*	DNA from Kaposi's sarcoma herpesvirus	HIV, syphilis protein antigens	Horseradish peroxidase	DNA from *Escherichia coli* and *Staphylococcus aureus*
Source	Powered by smartphone	Powered by smartphone	LED ($\lambda = 520$ nm)	Powered by smartphone	Powered by external Li-ion battery (3.7 V)	Addressable green LEDs
Assay format	Microfluidic chip	Microfluidic chip	Microfluidic cartridge	Disposable cassette	Electrochemical cells cartridge	Microfluidic chip
Readout method	Electrical signal	Electrical signal	Optical density	Quantitative optical density	Electrical signal	Fluorescent light intensity
Authors	Lillehoj et al.	Velusamy et al.	Mancuso et al.	Laksanasopin et al.	Salomón et al.	Stedtfeld et al.