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Computational imaging, sensing and diagnostics for global health applications

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In this review, we summarize some of the recent work in emerging computational imaging, sensing and diagnostics techniques, along with some of the complementary non-computational modalities that can potentially transform the delivery of health care globally. As computational resources are becoming more and more powerful, while also getting cheaper and more widely available, traditional imaging, sensing and diagnostic tools will continue to experience a revolution through simplification of their designs, making them compact, light-weight, cost-effective, and yet quite powerful in terms of their performance when compared to their bench-top counterparts.

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Introduction

Consumer electronics industry has been experiencing a remarkable revolution, bringing high-performance computers and various tele-communication devices to users at low cost in very compact forms. This digital era has also facilitated various emerging opportunities for the development of advanced computational imaging and sensing platforms. Compared to traditional designs, these computational schemes can decrease the complexity of optical hardware, which can be compensated in the digital domain by use of novel theories and numerical algorithms. This reduction in complexity of components can also lead to light-weight and cost-effective biomedical imagers and sensors. Toward this end, there has been considerable effort to develop computational techniques in various research areas, including super resolution microscopy [1], holographic microscopy [2••,3••,4•], fluorescence microscopy [5,6•,7•,8•], optical coherence tomography [9], endoscopy [10], spectroscopy [11–13], integral imaging [14,15], time-coded imaging [16•], giga-pixel imaging [17••,18,19], as well as magnetic resonance imaging [20•].

In parallel to these advancements in computational imaging approaches, there has been growing interest in portable and cost-effective biomedical technologies to be used as point of care (POC) diagnostic devices that can potentially improve and reform healthcare delivery in both the developed and developing countries. For this ambitious goal, the development of affordable medical testing/measurement equipment is essential since patients might not have routine access to advanced medical laboratory infrastructure in low resource settings. In developed countries, however, even if such resources are readily available, overall cost of these medical tests and diagnostic tools might become an obstacle for some patients, especially in under-represented communities. Therefore, computational imaging and sensing technologies, with their simplified and cost-effective device architectures, hold promise as field-deployable diagnostic devices for both the developed and the developing parts of the world.

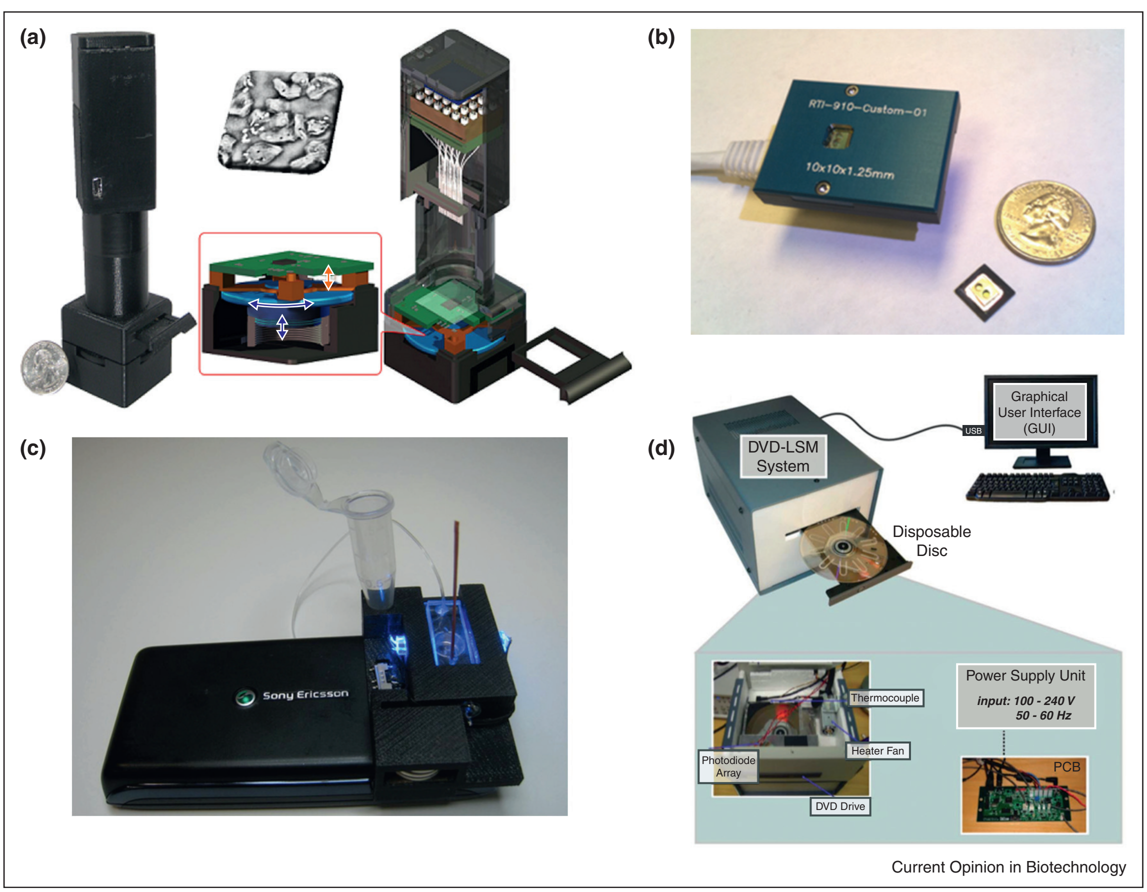
To provide an overview of global health related imaging, sensing and diagnostic tools, here we review various computational imaging and sensing platforms along with some of the complementary efforts that are based on non-computational, more traditional approaches tailored for field use and/or telemedicine applications. Starting with the next section, we will provide a summary of these emerging medical diagnosis and telepathology concepts that might fundamentally impact health care delivery across the globe by combining various analog and digital resources/tools.

Computational imaging for global health applications

Optical imaging has been serving as a well-established tool in biomedical research and clinical diagnostics for several decades. Particularly over the last two decades optical microscopy has experienced a fascinating renaissance, with various fundamental advances made in spatial resolution, depth of field (DOF), field of view (FOV), imaging speed as well as effective numerical aperture (NA) of optical microscopes. However, despite these rapid advances, the basic design of conventional microscopes that are used in clinical settings has not changed much, where they still heavily rely on bulky imaging optics and costly components, limiting their use to relatively advanced laboratory settings. Therefore, there is an unmet need for field deployable and cost-effective microscopic imagers, especially for telemedicine applications.

To provide solutions to this important need, there has been extensive research on the use of computational approaches to develop field-portable and cost-effective imaging tools. Along these lines, computational microscopy based on lensfree digital in-line holography [3,21] has become an emerging technique that can provide lightweight and compact imaging devices (see Figure 1a), making them ideal for field use. These lens-free microscopes can simplify the design of optical imaging by eliminating the need for bulky and costly components such as objective lenses. Instead, computational methods are used to compensate for the lack of complexity through the help of digital reconstruction algorithms. In the holographic on-chip microscope design shown in Figure 1a, the samples are placed directly on the top of an optoelectronic sensor array (e.g., a complementary metal–oxide–semiconductor (CMOS) chip) with an object to sensor distance of, for example, 1–5 mm, and are illuminated with a partially coherent light source, created by, for example, a simple light emitting diode (LED). This illumination is then scattered from the micro-objects to coherently interfere with the unperturbed background light, creating in-line holograms of the objects at the detector plane. Holographic reconstruction and pixel super resolution approaches are used to partially undo the effects of diffraction and spatial undersampling occurring due to the lensfree operation and unit magnification, which can then be used to reconstruct 3D microscopic images of the specimens. At the core of this reconstruction process lies an iterative phase-recovery algorithm [22], which is used to retrieve the 2D optical phase information that is lost during the intensity recording process at the detector plane. In addition to iterative phase-recovery, another important computational block

Figure 1



Computational imaging modalities for point of care applications. **(a)** Lensfree computational microscopy platform based on pixel super resolved digital in-line holography. **(b)** Lensless contact imaging device. **(c)** Computational fluorescent imaging and cytometry on a cellphone. **(d)** Digital microscopy on a computer drive.
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