LENSFREE TELEMEDICINE MICROSCOPY ON A WIRELESS PHONE

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ABSTRACT

We present a lensfree digital microscopy platform implemented on a cell-phone. It operates based on digital in-line holography and provides a compact and light-weight alternative to conventional microscopes, such that the cell-phone is modified with an inexpensive attachment weighing only ~38 grams. This lensfree cell-phone microscope captures holographic images of the objects which are then rapidly processed by a custom-developed reconstruction algorithm to provide microscopic images of the sample. This mechanically-robust cellphone microscope achieves a numerical aperture of ~0.1-0.2 over an imaging field-of-view (FOV) of ~24 mm^2 and may provide a cost-effective and field-portable diagnostics tool for telemedicine applications.

KEYWORDS: Cell-phone Microscope, Telemedicine Microscope, Lensfree Imaging, On-chip imaging, LUCAS, Telemedicine, Wireless Health, Holography

INTRODUCTION

Remote healthcare through telemedicine has reached a vital significance by massive penetration of wireless communication devices into our daily lives. Cell-phones are the at the center of this opportunity as they are already equipped with advanced digital imaging and sensing platforms which can be utilized for addressing various global health challenges. In addition to this, the majority of the existing cell-phone subscribers (constituting > 4 billion) live in developing parts of the world where the medical facilities and infrastructure are extremely limited [1-2]. Therefore, this current state-of-the-art of the cell-phone technology creates a timely opportunity to be utilized towards remote diagnostics and offers numerous possibilities to improve healthcare especially in the developing world [3].

To provide a potential solution for such telemedicine applications, here we present an alternative digital microscopy platform running on a cell-phone [4]. This lensfree cell-phone microscope, which is based on digital inline holography [4-5], provides a cost-effective, compact and light-weight alternative to conventional microscopes, such that the cell-phone hardware is modified with a simple attachment weighing only ~38 grams (see Fig. 1). Considering the importance of microscopy in general for surveillance of various epidemics, this cellphone microscope can be used for high-throughput monitoring of bodily fluids including whole blood samples, sputum, saliva, urine, semen etc, as well as for screening of water resources even in field settings.

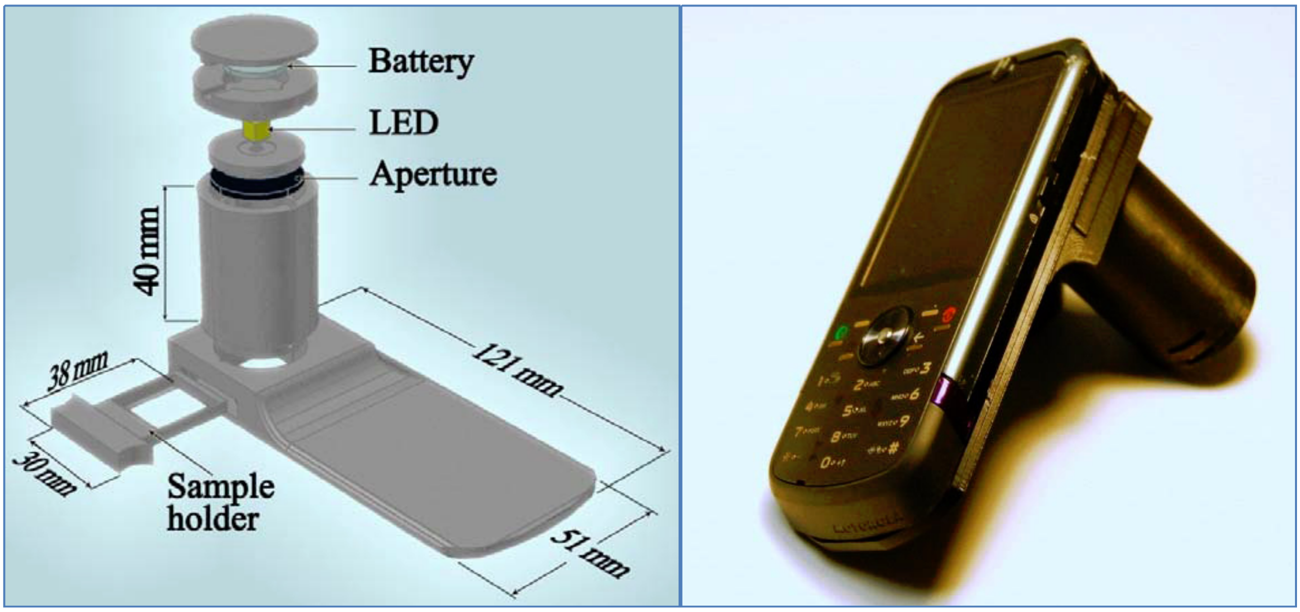

Figure 1: A schematic diagram of the microscope attachment (on the left) and the lensfree cell-phone microscope used in this study (on the right)

THEORY

To radically simplify the imaging platform, we use incoherent sources through large apertures (with a diameter of >100λ-200λ, see Fig. 1), which increases the light throughput by orders of magnitude, eliminates speckle noise and related artifacts; and at the same time makes the imaging platform much simpler, cost-effective, and easier to align.

Using Wave Theory we have investigated the impact of a large incoherent aperture on lensfree cell holography and on-chip microscopy [5]; and here we summarize our findings and conclusions. Based on this theoretical analysis [5], by bringing the cell plane much closer to the sensor surface, incoherent illumination through a large aperture can be made equivalent to coherent illumination of each cell individually. Furthermore, we also proved that, the spatial resolution at the cell plane will not be affected by the large incoherent aperture, which permits recording of the coherent hologram of each cell *individually* with an imaging field-of-view that is equivalent to the sensor area. In this theoretical analysis, we have also shown that through the use of a large incoherent aperture the undesired interference among different cells can be significantly avoided, which is especially an advantage for imaging of a dense cell solution such as whole blood samples. These are rather important conclusions that significantly separate the proposed approach from existing lensfree imaging techniques.

EXPERIMENTAL

In our lensfree imaging architecture, we utilize an inexpensive light-emitting-diode (LED) instead of a coherent light source to illuminate the samples which can be mechanically loaded into the cell-phone from the side as illustrated in Fig. 1(a). This incoherent light, after being filtered by an aperture of ~0.1mm diameter, propagates in air over a distance of ~4cm to pick-up partial spatial coherence. As a result of this partial coherence, each cell is effectively illuminated by a coherent field to create their lensless in-line holograms on a digital sensor-array that is already installed as part of the cellphone. This holographic image captured by the cellphone then permits rapid reconstruction [4-5] of the microscopic images of the sample using a PC located e.g., at a remote location such as a central hospital or clinic.

RESULTS

To demonstrate the performance of our lensfree cellphone microscope, we imaged several micro-particles such as polystyrene beads (3 and 7 µm diameter), as well as platelets, red and white blood cells, and a waterborne parasite, namely Giardia Lamblia as illustrated in Fig. 2. For comparison purposes the same figure also shows the images of the same objects obtained using a standard 10X objective-lens, providing a decent match to our reconstruction results. It should be noted that these images of individual cells and parasites were digitally cropped from a much larger imaging FOV of ~24 mm^2.

In addition, we also investigated the compressibility of the raw holographic images to optimize the amount of raw data to be transmitted via the cell-phone without any distinctive loss of image resolution. Based on this study, we found that using a lossless compression format such as portable network graphics (png), for 1 mm^2 of object field-of-view we only need to transmit <0.1 Mbytes of raw data to a remote PC station for digital reconstruction of the microscopic images [4].

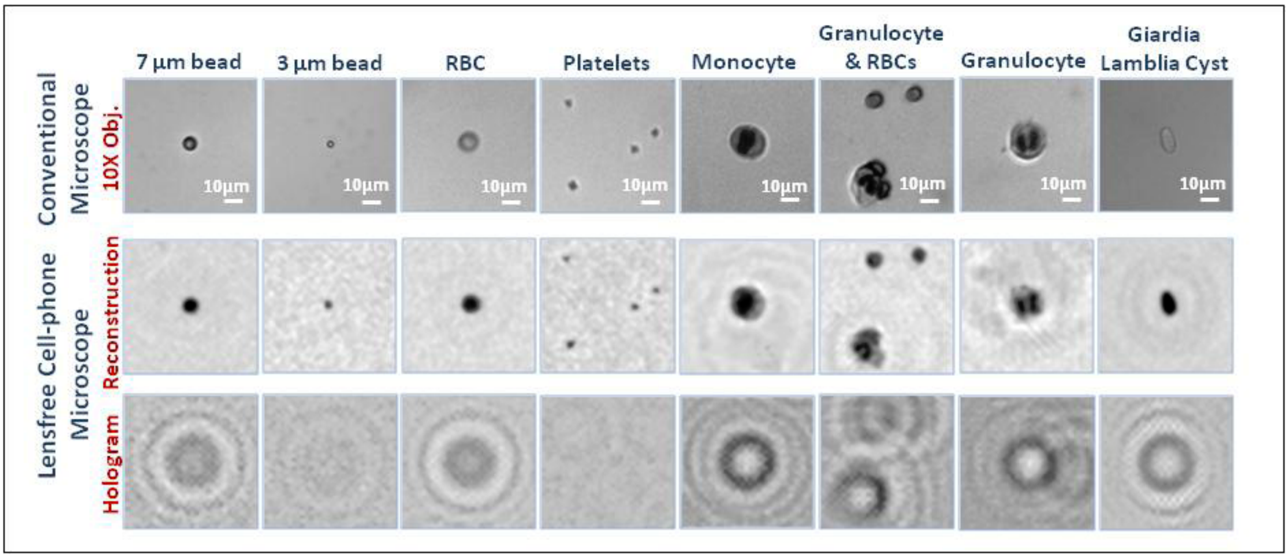

Figure 2: Various objects imaged to illustrate the performance of the cell-phone microscope shown in Fig. 1

DISCUSSION

To assure uninterrupted and rapid evaluation of microscopic test results is a crucial concern for telemedicine applications. For this end, in our cellphone microscopy platform to further reduce the hardware and software burden at the user-end, digital reconstruction of the acquired lensfree holograms can be done at a remote PC station located in a hospital or clinic where the microscopic images can be transmitted back and forth over wireless communication links. As a matter of fact, raw holographic image of ~1 mm^2 FOV requires transmission of only <0.1 Mb compressed data, making this a quite feasible model.

As shown in Fig.2, this mobile microscope achieves subcellular resolution over a wide FOV that is sufficient to differentiate blood cells or parasites within heterogeneous samples and therefore presents a cost-effective as well as field-portable alternative to conventional microscopes. Moreover, the current performance of this lensfree microscopy technology will further improve as next generation camera phones become available in the market with smaller pixel size as well as better digital signal to noise ratios.

CONCLUSION

In conclusion, we have demonstrated the proof of concept of a lensfree microscopy platform running on a cell-phone that achieves a numerical aperture of ~0.1-0.2 over a wide FOV of ~24 mm^2 that is more than an order of magnitude larger than imaging area of a typical 10X objective-lens. In order to demonstrate the performance of this cell-phone microscope, we imaged various objects including microbeads, red and white blood cells, platelets as well as waterborne parasites. We believe that the presented lensfree cell-phone microscope provides an important telemedicine tool which may bring improved healthcare delivery to resource poor environments and may significantly benefit our fight against various global health challenges that we are facing today.

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