Design, fabrication and testing of a smartphone-based bimodal device for oral precancer diagnosis

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ABSTRACT

Oral cancer is among the top three types of cancers in India which accounts for about 30 percent of all types of cancer. We propose here a portable and cost-effective 3D printed smartphone based bimodal (spectroscopy and imaging) device for detection of oral cancer at an early stage. The device has the ability to perform fluorescence spectroscopy and imaging on a single platform using smartphone as an optical spectrometer and a CMOS camera respectively. A miniature 405 nm laser diode has been used as a source. Fluorescence spectra and images of some known fluorophores such as fluorescein, rhodamine, flavin adenine dinucleotide (FAD) and proto-porphyrin (PpIX) have been recorded using the proposed smartphone-based device for validation. The wavelength resolution of device for spectral measurements is 0.25 nm per pixel in the visible range and for imaging the total area captured at the detector is $1cm^2$. Preliminary studies have been performed on patients with oral precancer and cancer to evaluate the efficacy of the proposed system for in-vivo diagnosis of the disease at an early stage.

Keywords: Oral precancer, fluorescence spectroscopy, fluorescence imaging, smartphone based screening tool, clinical diagnosis

1. INTRODUCTION

Oral cancer is the most common cancer among men than women and it is also among the top three types of cancers in India with approximately 77000 new cases every year as per the Indian Council of Medical Research (ICMR) report in 2023.[1] According to International Agency for Research on Cancer (IARC), around 3.77 lakh new cases and 1.77 lakh deaths were reported in 2020 worldwide.[2] Conventional methods used for oral cavity screening are oral cytology, oral brush biopsy and staining with dyes. Histopathology of the biopsy samples is considered as the gold standard. However, this procedure is invasive in nature and time-consuming.[3] Optical techniques, especially fluorescence spectroscopy and imaging, on the other hand are rapid, minimally invasive and have the potential to detect biochemical and morphological changes occurring with disease progression which eventually help in early diagnosis. Many researchers have utilised fluorescence based optical systems for diagnosis of oral, cervix and breast cancers.[4–10] Both the fluorescence spectroscopy and imaging techniques have high sensitivity and specificity in discriminating various grades of oral cancer at an early stage. Our group has previously designed and tested two separate in-house developed fluorescence imaging and spectroscopy probes to detect the abnormal changes in the oral cavity and compared the efficacy of both the techniques. Fluorescence imaging is utilised to examine the oral cavity and scan the infected area. Spectroscopy can be used for multiple point measurements from the same area.[11,12] Combining both these probes can be really beneficial in early diagnosis and also in biopsy guidance for the doctors. However, optical systems generally suffer in clinical applications as they are not

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Biophotonics in Point-of-Care III, edited by Michael T. Canva, Ambra Giannetti,
Hatice Altug, Julien Moreau, Proc. of SPIE Vol. 13008, 1300805
 · doi: 10.1117/12.3026971

miniaturised and easy to use. In last several years, an increasing trend has been observed among researchers to develop smartphone based standalone and field portable optical systems for various research applications.[13–16] In this study, we have designed, fabricated and validated a 3D printed smartphone-based bimodal device for oral precancer diagnosis. The proposed device is able to record fluorescence images (FI) and fluorescence spectra (FS) on a mobile phone camera by utilising a simple and cost-effective optical geometry.

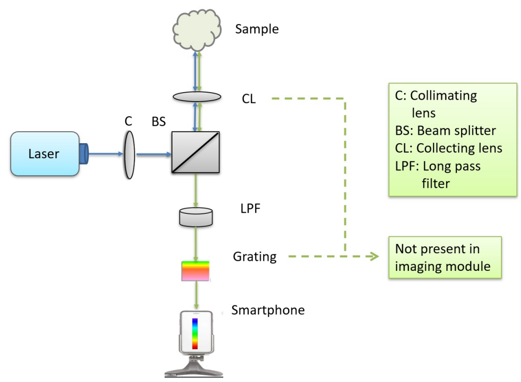

Figure 1. Block diagram of the smartphone-based bimodal device (SBBD) demonstrating various optical components present in the spectroscopy module (SM) and imaging module (IM)

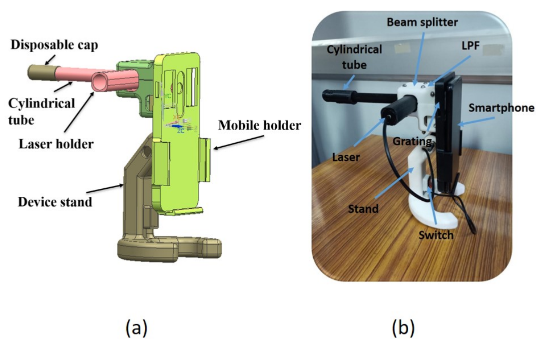

Figure 2. (a) A 3D-CAD model and (b) photograph of the smartphone-based bimodal device (SBBD)

2. MATERIALS AND METHODS

The smartphone based bimodal device (SBBD) is an upgraded combined version of previously in-house developed fluorescence spectroscopy and fluorescence imaging probes. The whole system can be divided into two modules: Imaging module (IM) and spectroscopy module (SM). A block diagram explaining optical assembly of the device has been shown in figure 1. A miniature 405 nm laser with collimating lens is used as an excitation source, beam splitter reflects the input signal towards sample through a cylindrical tube and transmits the resultant fluorescence images (FI) / fluorescence spectra (FS) towards the mobile phone camera, a 450 nm long pass filter after the beam splitter eliminates the source signal and at the end the image/spectrum is recorded on a Redmi K20 mobile phone camera. SM consists of two additional optical components other than IM. A collecting lens (CL) at the tip of the cylindrical tube for focussed light to be incident on the sample and a visible transmission grating, parallel with the camera, to convert the emitted fluorescence signal into a spectral image and get recorded in the smartphone camera. An arrangement has also been made to flip the grating and camera at 45 degrees with the optical path i.e. to easily switch from IM to SM and vice-versa. Figure 2 (a) and (b) showcase a 3D-CAD model and photograph of the smartphone-based device respectively. The 3D-printed cradle of the device is made of a bio-compatible and non-fluorescent PLA material.

3. RESULTS AND DISCUSSION

The proposed portable SBBD is able to capture FI and FS sequentially on a single platform with minimum changes in the overall optical geometry. FI and FS of some known fluorophores such as Flavin Adenine Dinucleotide (FAD) and Proto-porphyrin (PpIX) have been captured on smartphone camera using a freely available android app 'Open Camera' in .dng extension. FS, shown in figure 3 (a) and (b), display the ability of the proposed device in collecting the raw response of fluorescent dyes with major peaks at 525 nm for FAD and at 630 nm and 670 nm for PpIX. Figure 4 (a) and (b) represent the original recorded FI of FAD and PpIX with their respective RGB bands respectively. These images confirm that major component of FAD lies in the green band while for PpIX the major intensity lies in the red band. SBBD has also been tested in-vivo on a few patients suffering with abnormalities in their oral cavity. Both the spectra, shown in figure 5 (a) and (b), have major peaks around 500 nm corresponding to the FAD fluorescence. An additional porphyrin peak around 635 nm is also seen in the case of cancer patients (figure 5 (b)). Similarly, fluorescence images also have green band (around 500 nm) intensity higher than the red band (around 635 nm) in the normal oral sites and a comparatively higher intensity in the red band for cancer sites as demonstrated in figure 6 (a) and (b) respectively. These preliminary in-vivo testing results suggest that a ratio ($I_{Porphyrin}/I_{FAD}$) based analysis can be performed in combination with AI/ML techniques to discriminate between normal and cancerous oral patients.

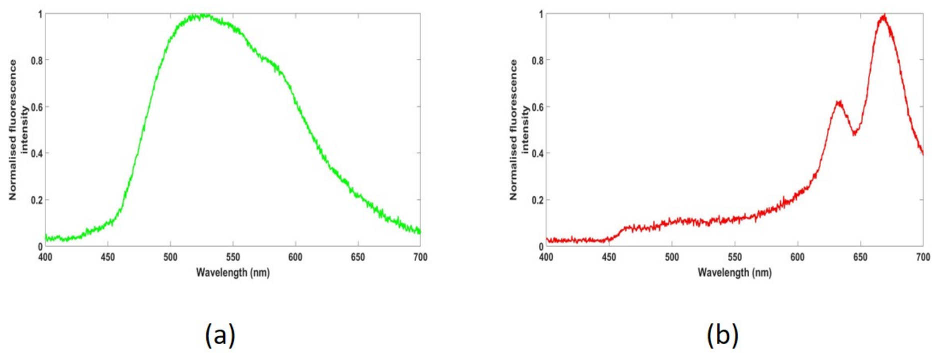

Figure 3. Normalised fluorescence spectra of (a) FAD and (b) PpIX recorded using the smartphone-based bimodal device (SBBD)

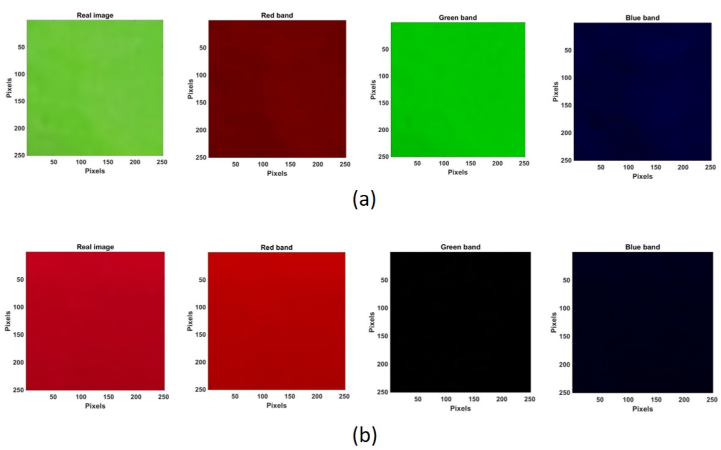

Figure 4. Fluorescence images of (a) FAD and (b) PpIX with their respective RGB bands captured through the smartphone-based bimodal device (SBBD)

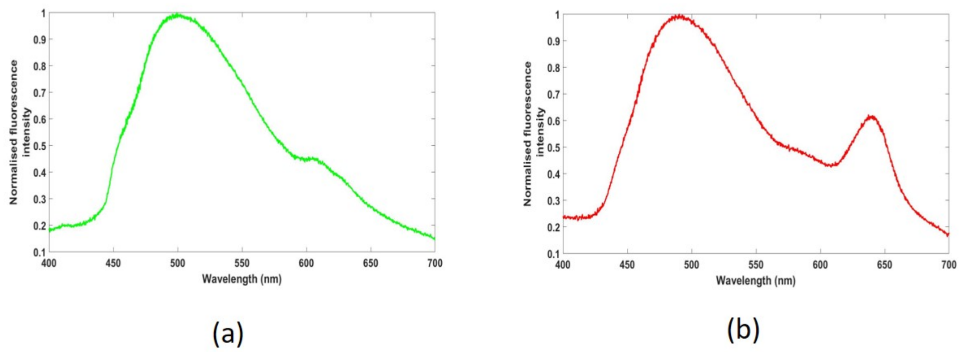

Figure 5. Normalised fluorescence spectra of (a) normal and (b) cancerous patient recorded using the smartphone-based bimodal device (SBBD)

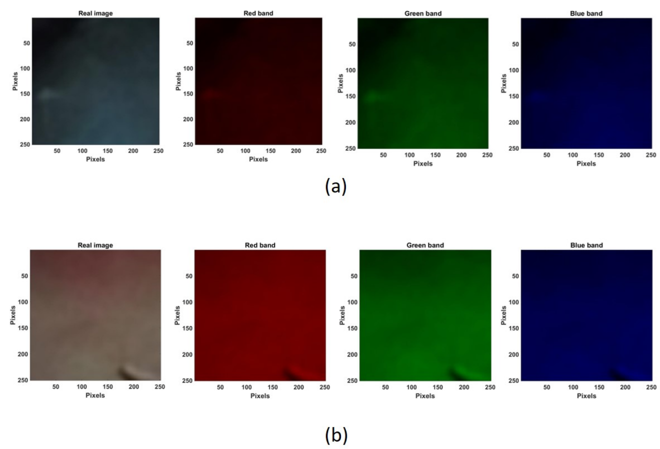

Figure 6. Fluorescence images of (a) normal and (b) cancerous patient with their respective RGB bands captured through the smartphone-based bimodal device (SBBD)

4. CONCLUSIONS

The proposed 3D-printed smartphone-based bimodal device (SBBD) has the potential to be used as a screening tool for capturing the unprocessed FS and FI in a RAW image format and analyse them further. The imaging module (IM) scans an area of $1cm^2$ and spectroscopy module (SM) can record multiple spectra of that area with a resolution of 0.25 nm/pixel which can be useful in the marginal biopsy guidance. The preliminary results on the known fluorescent dyes and in-vivo testing on a few patients in the hospital prove its applicability as a low cost and field portable device for oral precancer diagnosis.

ACKNOWLEDGMENTS

Authors would like to acknowledge Ms. Swati Dwarkaprasad Walde for designing the basic 3D-CAD model of the device.

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