Development of a dual-modality, dual-view smartphone-based imaging system for oral cancer detection

Ross D. Uthoff, Bofan Song, Praveen Birur, Moni Abraham Kuriakose, Sumsum Sunny, et al.
Development of a dual-modality, dual-view smartphone-based imaging system for oral cancer detection

Ross D. Uthoff\textsuperscript{a}, Bofan Song\textsuperscript{a}, Praveen Birur\textsuperscript{b}, Moni Abraham Kuriakose\textsuperscript{c,d}, Sumsum Sunny\textsuperscript{c,d}, Amritha Suresh\textsuperscript{c,d}, Sanjana Patrick\textsuperscript{e}, Afarin Anbarani\textsuperscript{f}, Oliver Spires\textsuperscript{a}, Petra Wilder-Smith\textsuperscript{f}, and Rongguang Liang\textsuperscript{a}

\textsuperscript{a}College of Optical Sciences, The University of Arizona, Tucson, Arizona, United States

\textsuperscript{b}KLE Society’s Institute of Dental Sciences, Bangalore, India

\textsuperscript{c}Mazumdar Shaw Medical Centre, Bangalore, India

\textsuperscript{d}Mazumdar Shaw Medical Foundation, Bangalore, India

\textsuperscript{e}Biocon Foundation, Bangalore, India

\textsuperscript{f}Beckman Laser Institute, University of California, Irvine, Irvine, California, United States

ABSTRACT

Oral cancer is a rising health issue in many low and middle income countries (LMIC). Proposed is an implementation of autofluorescence imaging (AFI) and white light imaging (WLI) on a smartphone platform providing inexpensive early detection of cancerous conditions in the oral cavity. Interchangeable modules allow both whole mouth imaging for an overview of the patients’ oral health and an intraoral imaging probe for localized information. Custom electronics synchronize image capture and external LED operation for the excitation of tissue fluorescence. A custom Android application captures images and an image processing algorithm provides likelihood estimates of cancerous conditions. Finally, all data can be uploaded to a cloud server where a convolutional neural network classifies the images and a remote specialist can provide diagnosis and triage instructions.

Keywords: autofluorescence imaging, mobile health, oral cancer, low-resource settings, biomedical engineering, optical engineering

1. INTRODUCTION

Oral cancer is a rising cause of death in a number of countries, particularly in low-resource communities.\textsuperscript{1–3} Tobacco\textsuperscript{4} and alcohol\textsuperscript{5} use along with areca nut chewing in South and Southeast Asia increase the likelihood of oral cancer and oral submucous fibrosis.\textsuperscript{6–12} In the case of areca nut, euphoric and antidepressant properties make lifestyle change difficult despite the risk.\textsuperscript{7,13} Early, non-invasive detection of precancerous lesions with timely diagnosis by specialists can prevent cancer progression through proper treatment and reduce morbidity and mortality.

Smartphone-based medical devices can provide extensive data collection and transfer capabilities in a compact, easy-to-use format for point-of-care imaging. These tools are easily deployable in low and middle income countries that lack extensive healthcare infrastructure but have broad cellular network coverage.\textsuperscript{14}

2. METHODS

This device combines white light imaging (WLI) with autofluorescence imaging (AFI) to detect pre-cancerous and cancerous conditions in the oral cavity. Autofluorescence excitation wavelengths of 400 nm to 410 nm have been shown to be effective\textsuperscript{15–17} with increasing dysplasia resulting in decreased fluorescence spectral exitance.\textsuperscript{18–22} The biological effects of carcinogenesis\textsuperscript{23} include a breakdown of collagen and elastin cross-linking and changes in mitochondrial metabolism affecting flavin adenine nucleotide (FAD), both resulting in decreased fluorescence. Additionally, greater absorption of excitation and emission wavelengths stems from higher hemoglobin content.

Further author information:
Ross D. Uthoff: email: rossuthoff@email.arizona.edu
Rongguang Liang: email: rliang@optics.arizona.edu


Proc. of SPIE Vol. 10486 104860V-1
from increased microvascularization. Finally, a 635 nm emission peak occurs due to increased porphyrin take-up in cancerous cells making the red signal to green signal ratio an additional indicator of cancerous conditions.24–27

The smartphone platform transforms previous autofluorescence systems targeting oral cancer28–31 into a standalone system specifically targeted for low-resource applications. The intraoral probe and endoscope attachments extend capability compared to previous smartphone-based systems,32 reaching to the base of the tongue and cheek pockets in some patients, areas of increased cancer risk.3

A hygienic sleeve (TIDI Products, Neenah, WI) is used with the intraoral imaging modules for infection prevention.

3. SYSTEM OVERVIEW

This device augments a commercially available LG G4 (LG Corporation, Seoul, South Korea) Android smartphone, providing portable imaging, computation, and data transmission capabilities, along with a touchscreen interface for simple control (Figure 1). The dual-view system includes a probe for intraoral imaging and a whole mouth imaging module (Figure 1). The phone mount and imaging modules are 3D printed of VeroBlack-Plus RGD875 plastic (Stratasys, Eden Prairie, MN). The foundational structure (Figure 2) provides a universal mount for the interchangeable imaging modules and mounting for the electronics.

The system utilizes six Luxeon UV U1 LEDs (Lumileds, Amsterdam, Netherlands) to enable the autofluorescence image (AFI) and four 4000 K Luxeon Z ES LEDs (Lumileds) for WLI and general scanning. The LEDs are placed in a symmetrical pattern on two sides of the optical axis to provide uniform illumination. Both imaging channels include an excitation filter (Asahi Spectra, Tokyo, Japan).

The illumination LEDs are driven by a switching boost voltage regulator (Linear Technology, Milpitas, CA) powered by two 3.7 V Li-ion batteries (Orbtronic, St. Petersburg, FL). The Android application synchronizes image capture with the LEDs through a Bluetooth connected microcontroller unit (MCU) (SparkFun Electronics, Niwot, CO) where the MCU switches between the LED strings using signal voltages applied to MOSFETs.

A custom Android application provides a user interface for creating a unique patient ID and entering basic patient data, including relevant information such as a history of tobacco or paan chewing. The application’s main menu (Figure 3a) guides the user to image collection (Figure 3b) or viewing modes. The application provides for rapid on-phone image processing of AFI images based on the red-to-green signal ratio (Figure 3c).17,33 Additionally, patient data, images, and location data can be uploaded to a remote server. Convolutional neural networks (CNN) have been shown to be useful in biological image classification34 and on the remote server a virtual machine runs a pre-trained CNN, classifying the images for likelihood of cancerous or precancerous lesions. A web portal allows access to the uploaded and processed data for review by remote specialists where they are able to provide further triage instructions to the patient.
Algorithm Diagnosis for fluorescence image: Suspicious.

Warning for Reference ONLY! This is not a DOCTOR diagnosis!

(a) Main menu of the Android application
(b) Interface for image capture of both WLI and AFI
(c) On-phone image processing of AFI image

Figure 2: System foundation with mounting for circuit boards, batteries, phone, and the interchangeable imaging modules

Figure 3: Screenshots of the custom Android application
4. INTRAORAL PROBE

The intraoral probe’s custom optical system extends the entrance pupil away from the smartphone camera aperture and allows for close-focus, high-resolution imaging of the oral tissues. Smartphone cameras are well-designed to capture a wide field of view (FOV) at low numerical aperture (NA) from a relatively long distance away. With the custom optical system, the FOV is decreased to 20 mm, the entrance pupil (EP) is extended closer to the object plane and the diameter enlarged, increasing the NA. Additionally, the chief ray angle (CRA) incident on the smartphone camera ensures the entire image sensor is utilized. Finally, the optical design must yield a final packaged design that fits comfortably in the oral cavity and allows access to the base of the tongue and cheek pockets. During the design process, the lenses of the smartphone camera were modeled as a single paraxial surface due to the proprietary nature of the designs and to ensure compatibility with any smartphone camera.

A layout of the optical system is shown in Figure 4 and modeled performance in Figure 5. The aspheric lenses were designed using poly(methyl methacrylate) (PMMA) and OKP4HT (Osaka Gas Chemicals, Osaka, Japan) and were manufacturing using a single point diamond turning (SPDT) machine (Moore Nanotechnology Systems, Swanzey, NH). In the future, molded lenses could reduce cost and fabrication time.

5. WHOLE MOUTH IMAGING MODULE

The whole mouth module uses unmodified smartphone camera optics to image a larger area of the oral cavity. The camera is set to a fixed focus a short distance from the entrance to the oral cavity. The small NA of the smartphone results in a long depth of field, useful to image many features of the oral cavity at once. The whole
6. ENDOSCOPE PROBE

Initial testing of the intraoral probe revealed the need for a smaller packaged design, a longer working distance, and a larger FOV. An endoscope-type system was designed to address these findings. This design increases the FOV to 60 mm and decreases the overall system diameter to 16 mm. Additionally, the mirror folds the system at $70^\circ$ instead of $90^\circ$ to better reach the cheek pockets and base of the tongue. The design is a mix of diamond-turned aspheres made of PMMA and commercially available achromatic doublets (Edmund Optics, Barrington, NJ). Autofluorescence and white light illumination are accomplished using three LEDs of each type evenly spaced in an annulus around the last optical element. A freeform lens helps to uniformly spread the

mouth module uses the same LED illumination as the intraoral probe and utilizes an excitation filter in front of the smartphone camera for AFI.
radiation across the FOV. After assembly and testing of the new endoscope probe module, updated systems will be sent to collaborators in India for additional data collection.

7. FIELD TESTING

Preliminary data has been collected by our collaborators in India with the intraoral probe (Figure 6) and whole mouth (Figure 7) imaging modules. The combination of WLI and AFI provides the healthcare specialist with a more complete status of the patient’s oral health. The data is currently being analyzed and used to improve the efficacy of the image processing algorithms.

8. CONCLUSION

Described is the design and implementation of a smartphone-based dual-modality, dual-view imaging system for oral cancer detection in LMIC. The devices will continue to be improved and tested in clinical and field settings. Enabling oral cancer detection in low-resource communities with simple tools will lead to earlier detection and diagnosis, hopefully minimizing disease progression and ultimately, a reduction in oral cancer death rates.

ACKNOWLEDGMENTS

Thank you to Pier Morgan and the Center for Gamma-ray Imaging (CGRI) for use and operation of the rapid prototype printer and to Ken Almonte for assistance with the LED driver design. TIDI Products (Neenah, WI) generously provided custom sheaths for our device.

We are grateful for our funding sources. This research is supported by the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health award UH2EB022623 and the National Institutes of Health Biomedical Imaging and Spectroscopy Training Grant T32EB000809.

REFERENCES


