A CMOS image sensor for surgical guidance and diagnostics

Abstract:

In the past 20 years mobile phone cameras have transformed how we record our lives. The demand for higher resolution in mobile phones cameras has made CMOS Image Sensor (CIS) the fastest growing segment of the semiconductor market. It has also brought about a dramatic reduction in CMOS Image Sensor (CIS) pixel sizes. This project will utilise the huge advances in CIS to build micro-cameras that can be used in stent operations. Stents have been used to treat coronary artery disease for more than a decade. It is now common practice to insert a stent to hold a coronary artery open and to maintain blood flow after an angioplasty. More than 2 million people get a stent each year. Presently surgeons can't see what type of plaque causes artery blockages. Applying a micro-camera to the guidewires used to insert the stent would help make stent operations safer and cheaper.

Introduction

The target area of research is to develop a micro-imager specifically designed for bio-photonics applications. Surgery is expensive and despite being carefully controlled there is still a risk of complications. Providing the surgeon with high quality, diagnostic images from deep within the body using micro-scale instrumentation such as arterial guidewires will lead to faster, safer procedures. Commercial micro-imagers are available but they are general imagers not specifically designed to address bio-photonics applications such surgical guidance based on fluorescence and reflectance biomarkers. The current state of the art commercial micro-imagers [1] , [2] are limited in sensitivity, dynamic range and spectral response which limits their use to simply imaging tissue. The power consumption of commercial imagers is high and in addition to requiring wired power supplies it also causes issues with electrical interference, self-heating of the imager causing increased imager noise and also heating the tissue in the patient's body.

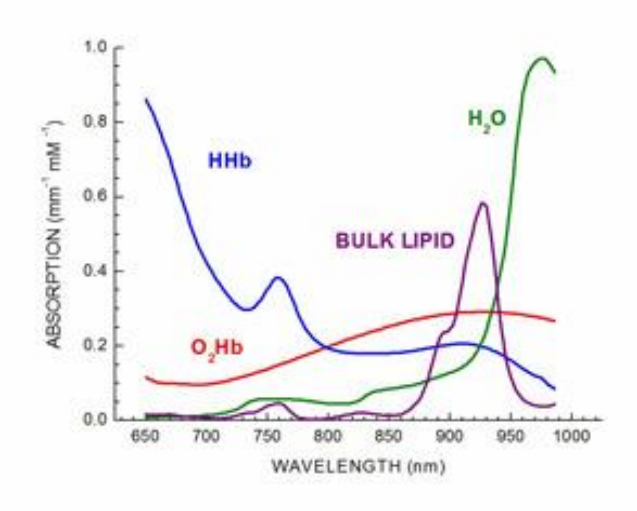

Figure 1: Bio-marker absorption at different wavelengths

Off the shelf micro-imagers cannot measure the oxygen content of flowing blood or allow quantification of tissue biomarkers as shown in

Figure 1 (lipid, water, collagen, oxygenated / deoxygenated haemoglobin).

The imager developed in this project will be used in a technology platform that will change and enhance many of the current clinical procedures by giving the clinician more guidance and diagnostic information to improve the quality of surgery. The platform research is fundamental research funded by Science foundation Ireland (SFI) through the IPIC Photonics research centre. The project is a Grand Challenge to research the 'World's smallest integrated imaging system for guided surgery' www.ipic.ie/biomedical. The use of a micro-imagers in the field of cardiology is already being explored by the Bio-photonics group in clinical studies.

This project consists of two main elements

1. CMOS Image Sensor (CIS) design
2. Characterisation of the Image Sensor and developing image correction algorithms

CMOS Image Sensor (CIS) Design

In Phase 1 it is proposed to work with a CMOS Imaging foundry to design an imager that uses smaller pixels, has higher Dynamic Range, better spectral properties at NIR frequencies and lower power consumption than commercially available micro-imagers. Figure 2 shows a rough floorplan of a CIS designed to fit on a catheter or guidewire with 1mm diameter, access to smaller pixels will allow an imager with reasonable resolution to be designed on this small footprint. The increased dynamic range will make the sensor sensitive to small changes in tissue oxygenation enabling the measurement of the oxygen content of the tissue. The improved spectral performance will enable multi-spectral imaging for bio-marker identification. The lower power consumption will reduce the need to provide as much power and also will cause less heating of the sensor and the surrounding tissue.

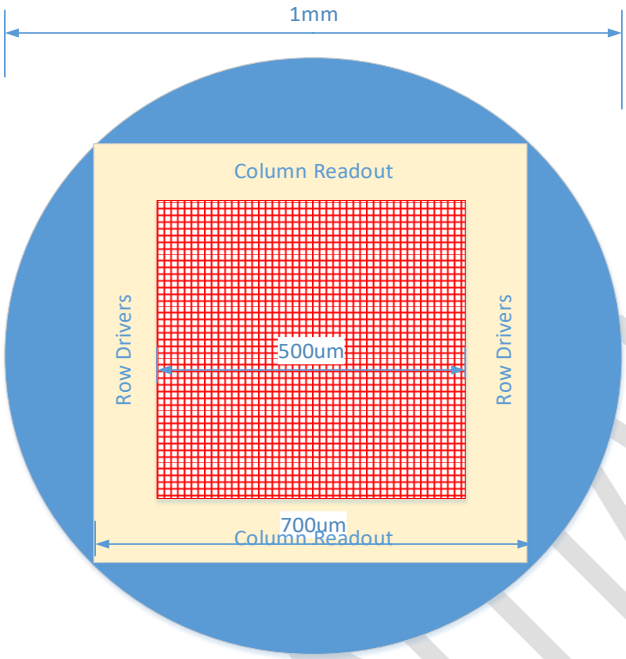

Figure 2: CMOS Image Sensor for a guidewire/catheter with 1mm diameter

To reduce the output pins for the imager it is planned to have ADCs on chip and use a two wire digital bi directional interface to programme the imager and transmit the data from the imager. ADCs can be a large power consumer in a CIS imager and matching their area to the pixel pitch is a challenge. Single slope ADCs are the most popular choice for CIS as they are the lowest area choice however they are not the most efficient from a power consumption perspective [3]. The power and area consumed by the ramp DAC which must produce an accurate ramp at fast rate is often not taken into account. Several recent imagers have used Delta-Sigma ADCs using oversampling to reduce the sampling capacitor area [4].

Unlike commercial imagers the bio-photonics imager will be designed with a programmable exposure time that can be synchronised with external light sources to enable multi-spectra imaging. It is also planned to have a frame rate of around 100 frames per second to enable fluorescence intensity measurements.

Figure 3: 3D drawing of guidewire system with camera at tip

Latest progress & Next steps

Hiring for the project is in progress, job offers to a PostDoc and a PhD student have been accepted and we plan that both candidates will start by the end of September. We have been having discussions with a leading CMOS imaging foundry to get access to a suitable technology for this work. We hope to conclude the legal agreements by the start of September.

Discussion with the Tyndall Photonics packaging group are ongoing Fig. 3 shows a 3D CAD diagram of the complete guidewire system with the camera that this project designs at the tip.

The next steps are to conclude the legal agreements and hiring and to create a draft specification table for the project by the end of August.

References:

[1] M. Wäny, S. Voltz, F. Gaspar, L. Chen, and A. L. M. Tecnopolo, "Ultrasmall digital image sensor for endoscopic applications," in *Proc. Int. Image Sensor Workshop*, 2009, pp. 1-3.
[2] "Omnivision OVM6948," 2021. [Online]. Available: https://www.ovt.com/sensors/OVM6948.
[3] M. Kwon and B. Murmann, "A New Figure of Merit Equation for Analog-to-Digital Converters in CMOS Image Sensors," in *2018 IEEE International Symposium on Circuits and Systems (ISCAS)*, 27-30 May 2018 2018, pp. 1-5, doi: 10.1109/ISCAS.2018.8351578.
[4] Y. Chae *et al.*, "A 2.1 M Pixels, 120 Frame/s CMOS Image Sensor With Column-Parallel $\Delta \Sigma$ ADC Architecture," *IEEE Journal of Solid-State Circuits,* vol. 46, no. 1, pp. 236-247, 2011, doi: 10.1109/JSSC.2010.2085910.