An Algorithm to correct 2D Near-Infrared Fluorescence signals using 3D Intravascular Ultrasound Architectural Information

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Abstract

Intravascular Near-Infrared Fluorescence (NIRF) imaging is a promising imaging modality to image vessel biology and high-risk plaques in vivo. We have developed a NIRF fiber optic catheter and have presented the ability to image atherosclerotic plaques in vivo, using appropriate NIR fluorescent probes. Our catheter consists of a 100/140 μm core/clad diameter housed in polyethylene tubing, emitting NIR laser light at a 90 degree angle compared to the fiber's axis. The system utilizes a rotational and a translational motor for true 2D imaging and operates in conjunction with a coaxial intravascular ultrasound (IVUS) device. IVUS datasets provide 3D images of the internal structure of arteries and are used in our system for anatomical mapping. Using the IVUS images, we are building an accurate hybrid fluorescence-IVUS data inversion scheme that takes into account photon propagation through the blood filled lumen. This hybrid imaging approach can then correct for the non-linear dependence of light intensity on the distance of the fluorescence region from the fiber tip, leading to quantitative imaging. The experimental and algorithmic developments will be presented and the effectiveness of the algorithm showcased with experimental results in both saline and blood-like preparations. The combined structural and molecular information obtained from these two imaging modalities are positioned to enable the accurate diagnosis of biologically high-risk atherosclerotic plaques in the coronary arteries that are responsible for heart attacks.

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1. Introduction

Fluorescence molecular imaging is a powerful biological imaging modality. In particular, in vivo near-infrared fluorescence (NIRF) imaging appears attractive for molecular imaging of atherosclerosis in vivo [1]. A previous study from our group has displayed sensing of atheroma inflammation in vivo with a 1D system in small diameter (1.5-2.0mm) arteries, through blood and without the need for flushing, which is clinically advantageous [2]. Recently, we developed a NIRF intravascular imaging system and we have displayed its ability to image appropriate fluorescent probes [3]. One challenge for intravascular fluorescence imaging is that quantification of signal reception in reflectance mode is hindered due to nonlinear signal attenuation by blood. In other words, the strength of the fluorescence signal depends on both the volume of the fluorescence source and the distance between the source and the detector. In this paper, we will present an intravascular NIRF imaging system and a preliminary approach on how to acquire quantitative NIRF data.

2. The NIRF System

Our system (Figure 1) uses a narrow-band laser centered at 750nm. The laser is connected to a cube which hosts transmission and receiver filters, a beamsplitter and a dichroic mirror. The beamsplitter is used to transmit laser light to an intrinsic PMT, which can be used to correct for laser fluctuations. The dichroic mirror is used for the separation of the laser light and the fluorescence light. The transmission filter is a bandpass filter used to attenuate laser light side lobes and the receiver filter is used to eliminate laser light that might be coupled with the fluorescence signal and it directs the fluorescence signal to the fluorescence PMT. The two PMTs are connected to a computer through a National Instruments DAQ card and the interface between the computer and the system has been programmed in Labview (National Instruments). The two motors (translational and rotational) are used for automatic pullbacks of the fiber, which is housed into a 3F custom-made polyethelene catheter (PE-50).

As the motors translate and rotate the fiber, data samples are collected and an image of each pullback is formed using Matlab. Before forming the image, the data are digitally filtered [4] with an appropriate finite impulse response (FIR) low pass filter in order to remove the high frequency electronic noise and then with an FIR high pass filter in order to remove the low frequency laser fluctuations.

3. Phantom Experiments

In order to characterize the system, appropriate phantom experiments have been performed. The main experiment presented here is also the one used for the correction of the NIRF signal. As it is displayed in Figure 2 (a), a tube filled with fluorescent solution is put in an angle with the fiber, in a tank filled with a blood-mimicking solution. The angle between the catheter and the fiber is 7 degrees and using this information we have calculated the distance between the fiber and the tube for each pullback position and in this way characterized experimentally how the signal attenuates with distance (Figure 2 (b)). This information is used to correct the NIRF signal for attenuation due to distance. In order to calculate the distance between the detector and the fluorescence source in an unknown geometry, an Intravascular Ultrasound (IVUS) imaging system is used in conjunction with our NIRF system.

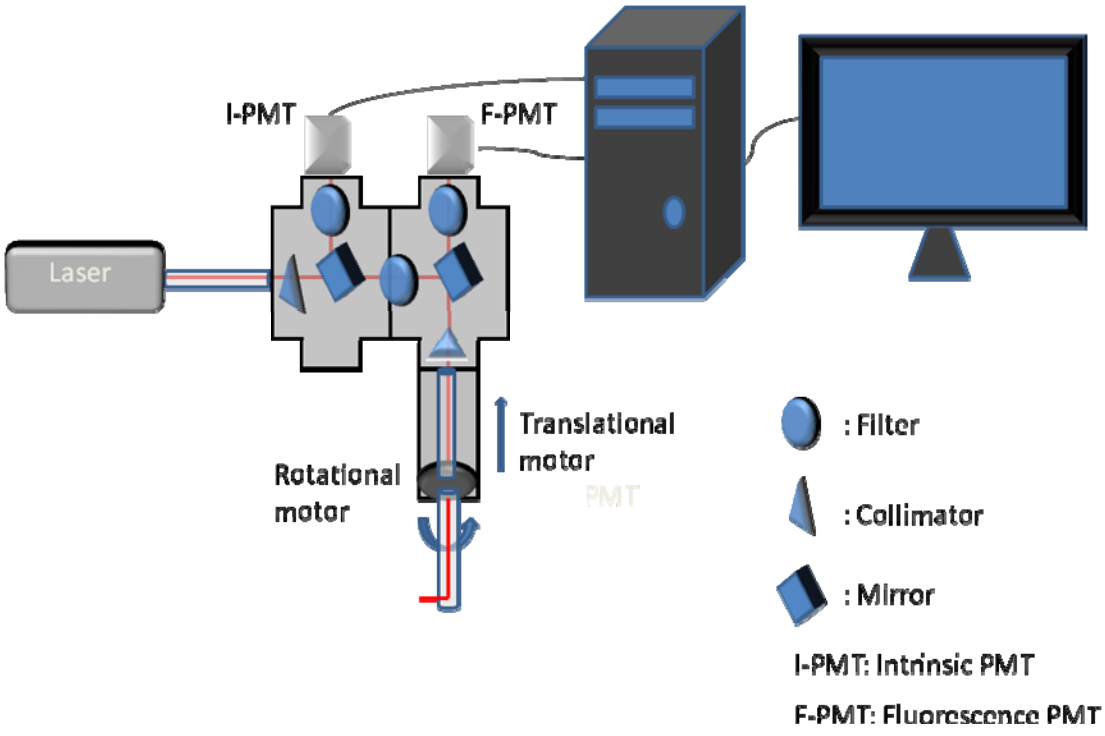

Figure 1: The NIRF system

4. Discussion

Intravascular NIRF imaging can detect high-risk of vulnerable atherosclerotic plaques by visualizing the underlying plaque's biology. However, raw NIRF data cannot be analyzed in a quantitative way, because absolute fluorescence signal strength is ambiguous, due to varying amounts of absorbing materials, e.g. blood. In this paper, we suggest a method to overcome this ambiguity by determining experimentally how fluorescence signal varies with the volume of blood-mimicking solution. In an in-vivo experiment with unknown geometry, an IVUS pullback can be used to determine the structural information of the vessel and then this information can be used for the correction of the NIRF signal. We are currently working on such experiments and we have developed an algorithm which uses IVUS information to correct the NIRF signal.

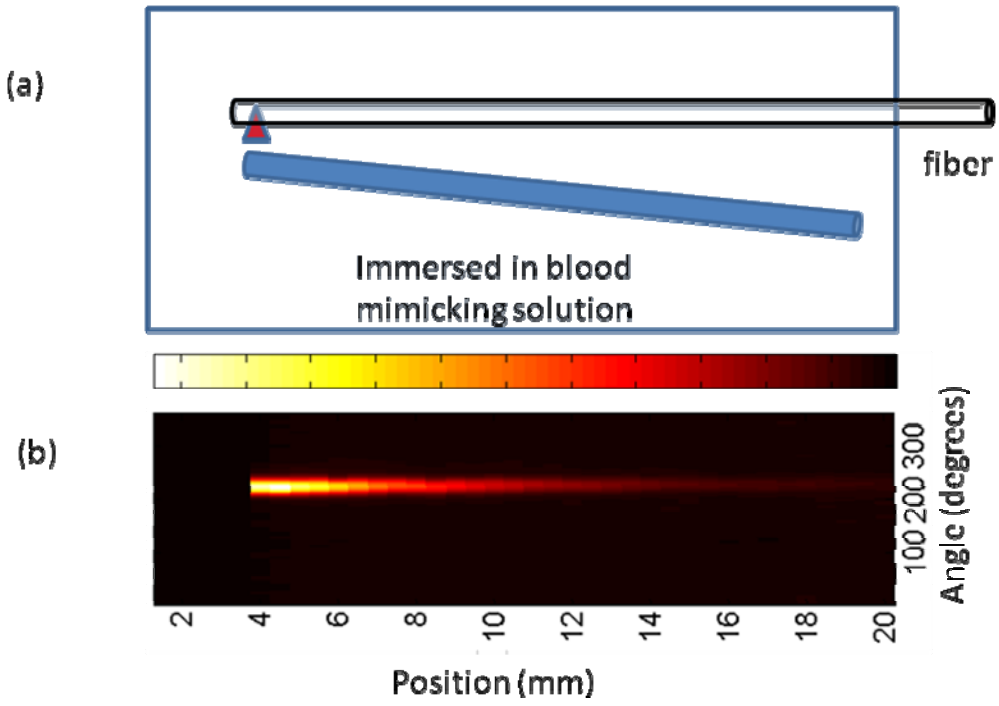

Figure 2: Phantom for characterization of the signal attenuation with distance; (a) Fiber housed in catheter in an angle with a tube filled with fluorescent solution; (b) uncorrected NIRF image of the phantom showing distance-based NIRF signal attenuation

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