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Paper Review

Paper: S. Sethuraman, S. R. Aglyamov, J. H. Amirian, R. W. Smalling and S. Y. Emelianov, "Development of a combined intravascular ultrasound and photoacoustic imaging system", Proc. SPIE 6086, 60860F (2006); doi:10.1117/12.646372

Summary

The authors of this paper have developed a combined intravascular ultrasound (IVUS) and photoacoustic imaging (IVPA) method to visualize coronary arteries and identify vulnerable plaques that may cause atherosclerosis in which plaques accumulate along the walls of arteries. The paper discusses why IVUS combined with IVPA imaging is advantageous over other conventionally-used techniques: MRI which can be used for characterizing plaques noninvasively has a limited resolution and a long imaging procedure, and electron-beam computed tomography can only characterize plaque calcium. The authors hypothesize that combining IVUS with IVPA is feasible and can be used to identify multiple plaque characteristics.

First, the paper addresses intravascular ultrasound (IVUS) imaging system. A guide wire and an access catheter make up an IVUS probe which can be advanced to the distal part of the artery. There are two types of IVUS probe: an IVUS catheter with a single element transducer and with an array of transducers. An IVUS catheter with an array of transducers has two main advantages over the one with a single element transducer. First, unlike the catheter with a single transducer, the catheter with an array of transducers does not require a mechanical motor to acquire a transverse cross-sectional image of the vessel in real-time. For the single transducer catheter, a motor is required to rotate it at 30 revolutions per second to obtain the cross-sectional image. In addition, the guide wire is placed in the center of the array for the catheter with an array of transducers. However, the single transducer catheter has the guide wire on the side of the ultrasound element, and therefore the wire can interfere with the ultrasound beam and produce noises (bright echoes) in an ultrasound image.

Then the paper describes photoacoustic (IVPA) imaging. Arteries contain several constituents including blood, collagen, plaques, and proteoglycans, and each component has its own optical absorption wavelength. Especially, the red blood cells absorb laser pulses the most in the 400 - 600 nm range. Therefore, by varying the wavelength of the laser pulses, it may be possible to identify different components of plaques and other functional information.

The design of the combined IVUS and IVPA imaging system is covered in the next section. The IVUS catheter probe is placed inside a blood vessel phantom or a sample which is optically excited by laser pulses. The authors used a catheter with a single transducer, and therefore, they also had to use a stepper motor to rotate the catheter in order to obtain a cross-sectional image of the sample. An Nd:YAG laser system that can emit laser pulses with either 532 nm or 1064 nm wavelength was used to excite the sample. In order to reduce the energy from the laser, a ground glass optical diffuser was used to diffuse the pulses to provide about 1 mJ/cm^2 energy.

The paper then describes the image acquisition scheme. Since the laser system was fixed (stationary), the sample had to be mechanically rotated to acquire a cross-sectional image of the sample. Hence, the IVPA system was initiated first, then the IVUS and the motor were initiated after a certain time delay. The IVPA signal was followed by the IVUS signal. After the signal acquisition, the authors applied several digital filters along with signal averaging to improve the signal-to-noise ratio (SNR). As a final step, the authors used scan conversion to convert the obtained signals to a spatially co-registered IVUS and IVPA images.

Finally, the paper finishes the method section with a description of phantoms that the authors used for this study. The phantoms were prepared to mimic an arterial wall and plaques. The artery vessel was modeled as a cylinder-shape phantom made with poly vinyl alcohol (PVA). Two optically absorbing inclusions embedded inside the phantom were used to mimic plaques inside the artery vessel. In order to demonstrate clinical feasibility of the combined IVUS and IVPA imaging system, the authors also performed experiments on an ex vivo sample of a rabbit artery.

The results section of the paper shows several images acquired from the combined system. It is clear from the figures that the combined IVUS and IVPA imaging system is indeed feasible to image blood vessels. The photoacoustic system was able to distinguish the inclusions from the phantom. The authors also showed that the combined system works on ex vivo samples of a rabbit artery. The discussion section addresses one major problem with the performed experiments. Due to the single transducer IVUS catheter and the stationary IVPA laser system, the sample and the IVUS catheter had to be rotated using a motor. The authors admit that this rotational motion creates certain motion artifacts, and the guide wire produces artifacts in the ultrasound image. They assert that this motion and guide wire artifacts problem can be solved by using the catheter with an array of transducers and an optic fiber that can deliver the laser to the interior of the vessel.

Critiques and Possible Improvements

In the introduction part, the authors mention how an IVUS catheter with an array of transducers is better than a catheter with a single transducer. However, they still decided to use the catheter with a single array for their experiments.

In the discussion section, the authors mention that a possible improvement would be to design an intravascular optic fiber that can transfer pulsed laser through the lumen and to the interior of the vessel wall. Therefore, both the single transducer catheter and the laser source will be placed inside the vessel and only the catheter will be rotated instead of rotating the entire system. However, this could still produce some motion artifacts. In my opinion, a better improvement will be to use a IVUS catheter with an array of transducers integrated with a laser fiber optic that can rotation around the catheter.

Another problem with the presented system is that it is not clinically feasible: a vessel from a patient cannot be rotated to acquire photoacoustic images. The IVPA optic fiber integrated with the IPUS catheter as mentioned in the previous paragraph could solve this problem, since only the catheter needs to be rotated in that system.

The last issue with this paper is that the authors did not show how their combined system performed on identifying different components of plaques. They mentioned in the introduction that the combined system's capability to identify different components of plaques is one of the main advantages over other imaging systems. However, in this paper, they only showed that the system can detect fiducials that were placed inside the phantom. It would have been better, if they did an experiment with fiducials or markers that are made of components that have different light absorption characteristics.

Relevance to Our Project & Motivation for Paper Choice

This specific paper was selected for review, because the work presented in the paper was similar to our work. They used photoacoustic imaging system combined with ultrasound system to image blood vessels. In our work, we have also developed an imaging system that combines photoacoustic and ultrasound systems. The general experimental setup was also similar: the only difference was that they used an intravascular ultrasound transducer and the motor to rotate the sample.

The main difference between their work and our work is the application of the combined system. The authors of this paper developed the system to image blood vessels, while we have developed the system to image an organ (in particular kidney) and to track the region of interest on the organ in real time without any EM markers or fiducials.