

New Imaging Technique Gets under the Skin . . . Deep

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New Imaging Technique Gets under the Skin . . . Deep

USING a combination of simple optical techniques, plain old white light, and image processing, two Lawrence Livermore researchers and a colleague from the City College of New York (CCNY) have developed a technique for imaging tissue structures—tendons, veins, tumors—deep beneath the skin. The ultimate goal of this research is to dramatically improve the ability to perform minimally invasive cancer detection.

“With a technique called spectral polarization difference imaging [SPDI], we use different wavelengths of light to reach different depths. We also use the polarization properties of the light to help us select the light that penetrates into the tissue and is reflected back out of the tissue as opposed to the light that bounces off the tissue surface,” says Livermore physicist Harry Radousky, acting Director of University Relations. “We then image the tissue structures at the different depths, based on how these structures absorb, scatter, and depolarize light. This technique, combined with fiber optics, charge-coupled-device cameras, and image enhancement calculations, allows us to image up to 1.5 centimeters inside tissue, far deeper than the millimeter depths managed by other existing optical techniques.”

The basic research to develop this technique was funded by the Department of Energy through one of its centers of excellence in laser medicine—the DOE Center for Laser Imaging and Cancer Diagnostics directed by Robert Alfano, M.D., at CCNY. A branch of this center is hosted at the Laboratory within the Materials Research Institute.

Optical Trickery

The SPDI system developed by the Livermore–CCNY team depends on simple and inexpensive instrumentation, including a white light source, fiber optics, a filter, two polarizers, and a camera lens coupled to a charge-coupled device (CCD).

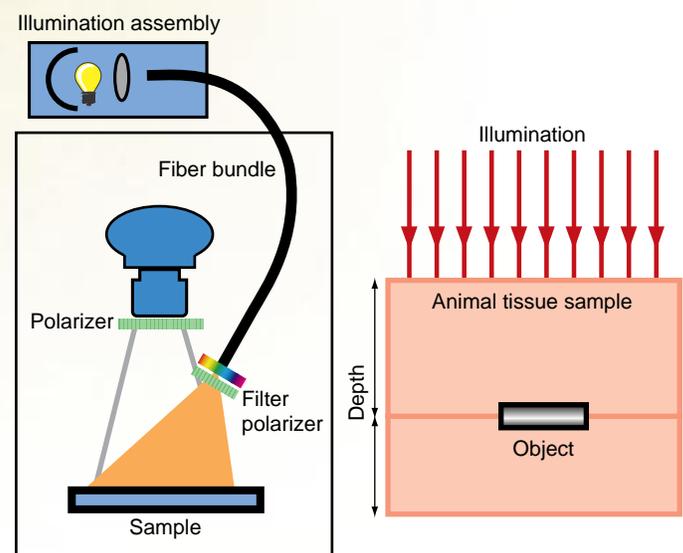
The low-power, white-light source is coupled to a fiber-optics bundle that delivers the light to a filter. This filter selects the desired wavelength of light. With this setup, the research team conducted experiments using different bandwidths at the visible to near-infrared portion of the white-light spectrum.

“Longer wavelengths penetrate tissue more effectively,” explains physicist Stavros Demos. “Think of what you see when you hold an ordinary white-light flashlight to your hand. The light that shines through your hand is red, which is at the longer wavelength end of the visible spectrum; the other

wavelengths in the visible spectrum are scattered and absorbed within the tissue. For even longer wavelengths—those in the near-infrared spectral region—scattering and absorption of the photons is even further reduced.”

The light that passes through the filter then passes through a polarizer. The light that finally hits the tissue sample is thus not only of a given wavelength but also of a selected polarization. As photons penetrate the tissue, they interact with various tissue structures that may have optical properties different from those of the host tissue. Finally, some of the injected photons emerge from the tissue in the backscattering direction. The intensity of the backscattered light depends on the optical characteristics of the tissue at the sample’s surface as well as below its surface at a particular location.

Light that reflects from the surface (known as a spectral reflection) is polarized and can be removed with a second polarizer set to reject this light. This phenomenon is similar to the way sunglasses work to remove the polarized glare from surfaces, such as the water surface in a swimming pool. The light that backscatters from somewhere below the surface of the tissue is depolarized and consequently can pass through this second polarizer. This remaining light passes through a 50-millimeter camera lens, which is coupled to a CCD detector that captures the image in an exposure of a few milliseconds.



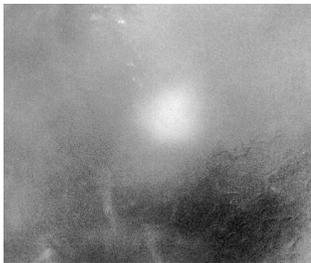
Schematic diagram of the spectral polarization difference imaging setup.

First Chicken, Then Beef

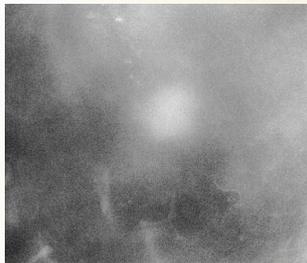
To prove their technique, the researchers attempted to image a small ceramic disc buried in a chicken breast (tissue) bought from a local supermarket. The disc—about the size of a small slice of pencil eraser (4 millimeters in diameter and 1 millimeter thick)—was placed on top of a 1-centimeter-thick slab of chicken breast and topped with an equally thick slab. This “chicken sandwich” was placed between two glass plates and slightly compressed to a uniform thickness.

Four images were recorded using light at 600, 690, 770, and 970 nanometers. The exposure time of the CCD camera was adjusted so the intensity of each image at an arbitrary point was about the same. The researchers took pairs of these digital images—one from a longer wavelength that reaches the disc, the other from a shorter wavelength—and digitally subtracted one from the other. By combining this subtraction technique with the elimination of specular reflections, researchers can remove the image information from the outer tissue layers. In the resulting images, structures deep within the tissue are more visible than they would be if the images were made with light at a single wavelength. “It’s like looking for stars in the daylight,” explains Radousky. “By ‘subtracting’ light from the sun, you’re able to see the stars.”

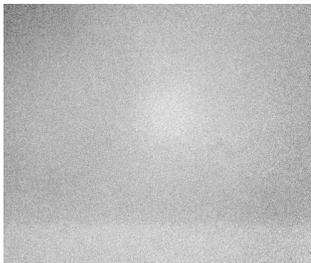
(a) 970 nm minus 600 nm



(b) 970 nm minus 770 nm



(c) 770 nm minus 690 nm



(d) 690 nm minus 600 nm



Four final images of an object 1 centimeter below the surface produced by the spectral polarization difference imaging technique. The images were produced by digitally subtracting images derived from photons at different illumination wavelengths (in nanometers, nm) that reach different depths within the tissue. Using the right combination of wavelengths of light is important to the clarity of the resulting image. The wavelength combinations in (a) and (b) allow the subsurface object to be seen with better contrast than in (c) and (d).

“Once we proved the basic technique,” adds Demos, “we imaged the tendons in bovine tissue as well as the veins in the arm of one of the researchers.”

More Details Coming

All in all, the researchers say, SPDI looks to be a promising technique that, once refined and developed into a system, could help the medical community in its fight against cancer.

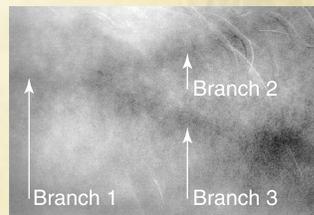
The next step in this DOE-sponsored project, notes Radousky, is to develop mathematical models that will reconstruct the object in more detail and also provide the object’s precise size, something that isn’t yet possible. “We’re going to work to enhance the images and get as much information out of them as possible. That, of course, is the goal of any cancer-detection system used in a clinical setting—to get as much information about the tumor to the clinicians as possible, in real-time.”

—Ann Parker

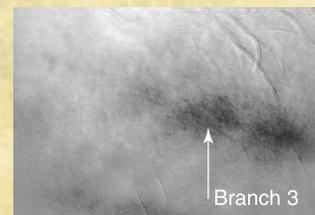
Key Words: cancer detection, Center for Laser Imaging and Cancer Diagnostics, Materials Research Institute, spectral polarization difference imaging (SPDI).

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(a) 850 nm minus 600 nm



(b) 690 nm minus 600 nm



(c) 850 nm minus 690 nm



(d) 690 nm minus 640 nm



Four subsurface views of the arm of a human male with well-developed muscle structure and deep veins. The different nanometer-wavelength combinations reveal different details of the subsurface. For example, (a) the image created by subtracting the 600-nanometer (nm) wavelength from the 850-nm wavelength reveals three vein branches, while (b) the 690-nm minus 600-nm subtraction shows only one vein branch, which is closer to the surface than the other two.