Optical detection of small objects offers x-ray alternative

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An optical technique detects small objects buried in turbid media with high lateral resolution and without the damaging effects of ionizing radiation that x-ray can cause.

Detecting objects of less than 2mm buried in turbid media is a difficult task, especially if we need to know the size of an object, its lateral position, and depth. Generally we use x-ray for this purpose because of its high penetration, but the technology has limitations when, for instance, we need to detect tumors in soft tissue. X-ray mammography commonly misses tumors of less than 5mm and may return false positive diagnoses. Additionally, x-rays are highly ionizing. When used in early breast cancer detection, for example, they can damage the soft tissue under examination.1

Non-ionizing techniques, such as pure optical tomography, are preferable. However, as light is highly scattered in tissue, it becomes difficult to obtain good resolutions at depths of greater than 5mm. Techniques have evolved that combine optical and acoustic transducers, such as photo-acoustic (PA) and ultrasound modulated optical tomography (UOT).5 PA techniques require specially designed piezoelectric devices (where electric charge results from stress), but have limited spatial resolution.6 It is possible to replace the piezoelectric systems with optical sensors, but these are based on interferometers that are highly sensitive to vibration.6,7 UOT involves the focus of an ultrasonic wave and a laser beam at the same spatial spot inside the test sample, and it is complicated by diffraction effects and light dispersion inside the sample.4

To overcome these limitations, we exploited two basic properties of a Gaussian laser beam. The first is the beam’s small spatial dimensions, which result in a very low divergence under propagation (typically less than 5μ radians). At small distances—less than 2mm, for instance—the beam remains approximately the same size: less than 1mm in diameter. The second property of the beam that we considered is the existence of ballistic and quasi-ballistic photons when the laser is dispersed by a turbid media.

We directed a laser beam by means of a mirror to a photodiode with a sensitive area larger than the laser beam spot (see Figure 1). We interposed a knife edge to cover approximately half the beam spot size. Then, by mounting the mirror on a motorized stage, we induced a small periodic motion of the beam in a plane perpendicular to its incident direction. Due to the vibration and the presence of the knife edge, the photodiode detected power changes. These changes converted to an electrical AC signal at the output of the photodiode, and they were displayed and recorded on an oscilloscope. A decoupling capacitor eliminated the DC component, and the periodic signal exhibited a positive peak followed by a negative one. The period of the signal corresponded to the frequency of the mirror’s vibration.

Figure 1. A mirror directs a helium-neon (He-Ne) laser beam, interposed by a knife edge, toward a photodiode. The arrows on the left indicate the vibration of the mirror as it induces a small motion in the laser beam, enabling the diode to detect power changes.
With the optical system aligned, we placed a sample containing a turbid medium between the laser and the detector (see Figure 2). The light dispersed, causing the photodiode to collect fewer photons and resulting in a drastic decrease in the AC signal. The collected photons arrived from several locations in the dispersive sample. To avoid detection of photons coming from random angles, we placed a circular aperture, roughly the size of the laser beam, in front of the knife edge. This allowed us to detect power changes caused only by ballistic and quasi-ballistic photons. Since the photodiode collected far less light, we increased the amplifier’s gain to obtain a clear signal on the oscilloscope.

Next, we scanned the sample in a plane normal to the direction of the incoming laser. As in Figure 3, if an object buried in the sample interposes the ballistic photons, it causes additional dispersion, which in turn causes a decrease in the signal. The closer to the front face the buried object is located, the more it will disperse the ballistic photons. Consequently, the closer the buried object is to the front face, the smaller the detected signal.

In future work, we could use the method described to estimate the depths of several objects buried in the same sample. Its suitability for use in soft tissue makes the technique viable as a means to detect breast cancer at an early stage.8

Figure 2. A He-Ne beam directed through a turbid sample and a circular aperture. Power changes in ballistic and quasi-ballistic photons collected by the photodiode create the output signal.

Figure 3. An object buried in the turbid sample causes additional absorption and dispersion of the ballistic and quasi-ballistic photons, causing a decrease in the output signal.

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References


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