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Detection of an Object in a Phantom Tissue Using a Spatial Filter

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ABSTRACT

We report the detection of an object inside a phantom tissue using a spatial filter and a 5 mW He-Ne Laser. The phantom tissue is composed of 8% scattering Polystyrene spheres (particle size 579 nm) and is diluted to different concentrations in water. The solution is placed inside of a cuvette of length 5 cm and width 5 cm. The spatial filter, composed of a 4 cm plano-convex lens and a 10 μm pinhole, is able to extract ballistic and quasi-ballistic photons from the transmitted light. A photomultiplier tube is used for detection, and a lock-in amplifier is used to reduce the amount of noise in the signal. We are able to detect the object in a phantom tissue of 20 mean free paths [mfp] (concentration .016%) with a contrast of 99.0%. The contrast in a tissue with 30 mfp (concentration .024%) is 22.7%.

1. INTRODUCTION

1.1. Current cancer detection techniques

X-rays, Ultrasonography, and Nuclear Magnetic Resonance are methods that are used today for the detection of cancerous tissue. The X-ray technique requires the use of extremely high amounts of energy (on the order of MeV). As a result, the X-rays can ionize (remove electrons) from tissues in the body and therefore be harmful to the patient. Despite the energy used, X-rays can fail to produce a sufficient amount of contrast thereby blurring the image. X-rays may also cause discomfort, as well as require a period of rest for the patient.

Ultrasonography is a technique that enables the visualization of objects in the body by recording the reflections of mechanical waves directed at the tissue.¹ Since ultrasonography uses mechanical waves, it requires a density difference between tissues to produce a good image. This creates a problem because some cancerous tissues may have a density approximately equal to the surrounding tissue.

The third technique used today is Nuclear Magnetic Resonance Imaging (NMRI). This technique subjects an odd number of protons to a magnetic field and measures the deflections as a means of producing the image.¹ NMRI is an asset in providing images of the heart as well as soft tissues. However, it is costly and requires the patient to remain immobile for a lengthy period.

1.2. Purpose and significance of project

The purpose of this research project is to develop an alternate efficient optical method for the detection of cancerous tissues in the body. Although there are other techniques (X-rays, Ultrasound, NMRI) that are currently used, this technique has the potential to be more effective because it is potentially safer, does not require a difference in density, and is more cost efficient. It is a non-ionizing approach which subjects the body to less possibility of injury to the surrounding tissue without sacrificing the contrast of the image. This method uses light as a means of detection which enables the differentiation between tissues solely by their optical properties. Finally, this method of spatial filtering will be more cost efficient because its components are relatively inexpensive.

The significance of this research is that it could lead to significant improvements of cancer detection. One such improvement could be the aid in the search for an efficient method of determining whether a cancerous tissue is malignant or benign by using optical properties. With the application of this method, the safety of the cancer patient would increase during treatment while the cost of health care decreases.

1.3. Project basis

The basis of this technique hinges on the use of a spatial frequency filter. A spatial frequency filter restricts light that encounters it at certain angles. A simple filter is composed of a lens and a pinhole. The light that is parallel to the optical axis is focused onto the pinhole where it enters. However, the light that enters the lens at any other angle is focused at a different point and since the pinhole is very small (10 μm) the light does not get through. When light is incident upon tissue, a very small amount travels straight through without scattering, ballistic light. However, the majority of the light, diffuse light, is

randomly scattered. As a result, light leaves the tissue at various angles. Since the spatial frequency filter rejects light that enters the lens at wrong angles, the diffuse light which distorts the image is rejected allowing the creation of an image with little distortion (see Figure 1).

Figure 1

SPATIAL FREQUENCY FILTER

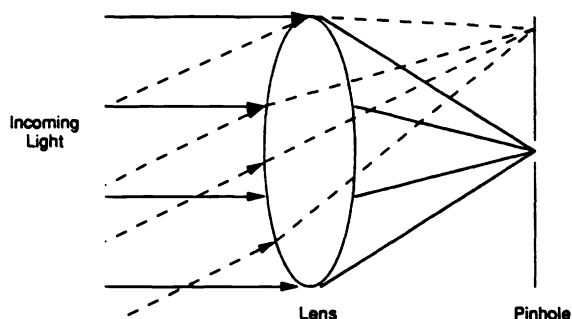


Figure 1: An illustration of the properties of a spatial filter

1.4. Project objectives

There are three major objectives in this research project. The first is to determine the maximum number of mean free paths that are attainable with this technique. When light encounters tissue, it undergoes a series of scatterings while some of it is absorbed. The average length between these interactions is called the mean free path (mfp). In the body, the length is typically on the order of one hundredth of a centimeter. Imaging capability of an approximately 5 cm thick tissue is desired. This corresponds to 500 mean free paths (mfp).

The second major objective is to optimize the spatial frequency filter in order to achieve the best possible resolution of the image. The optimization is performed by using the same concentration of phantom tissue and measuring the image of an object with various sizes of the pinhole.

The use of this technique in actual tissue is the final objective. Although phantom tissue (essentially a milk solution) is initially used for a preliminary study, an object will be buried in a chicken breast and scanned to determine if detection in tissue is possible.

A mean free path is the average length between which light is either scattered or absorbed. A continuous wave (cw) laser is one in which the light is continuously emitted at some specified

wavelength. Ballistic light is light that travels straight through the tissue without being scattered or absorbed. Quasi-Ballistic light is light that is scattered but stays in a defined neighborhood of the ballistic path. Diffuse light is light that is just randomly scattered inside the tissue.

1.5. Current Optical Techniques

Time gating, Ultrasound Tagging of Light, and Electronic Holography are three major optical techniques that are being researched as possible optical methods for cancer detection.

The time gating technique makes use of the fact that ballistic light contains the information about the image of an object and arrives to a detector earlier than the diffuse light. This technique uses a very short pulsed laser to illuminate the tissue. After the light emerges from the tissue, it encounters a cross correlated time gate which accepts only the ballistic light.²

Ultrasound Tagging of Light, or UTL, is another procedure that is being studied as a possible means of detecting cancer. This technique sends both a light wave and an ultrasound wave into the tissue. The pulsed ultrasound wave is focused to a small volume, and induces a frequency shift of the optical wave. The amount of light with the shifted frequency is related to the optical properties of the small volume. By scanning the focal point of the ultrasound while monitoring the light with the shifted frequency, one can detect an object with different optical properties from the surrounding tissue.³

The third optical technique that is being researched as a means of imaging is electronic holography. This procedure also takes advantage of the fact that the ballistic light contains the image information by having the object beam, the beam that enters the tissue and has in it the ballistic light, combine constructively (as to produce interference) with the reference beam. A Charge Coupled Device (CCD) camera is used as a detector so that an image is formed.⁴

2. EXPERIMENTAL SETUP

In the experimental setup, there are eleven key components. They are: Helium Neon laser, chopper with controller, two mirrors, adjustable aperture, lens pinhole, Photo Multiplier Tube, Lock In Amplifier, an Oscilloscope. A detailed schematic of the experimental setup is shown in Figure 2.

The light emerged from the 5 mW custom laser at a height of 16 cm and encountered a chopper which modulated the light at a 325 Hz which ensured that only light of the that frequency would be detected. After the light was reflected from the first mirror, it

Figure 2
EXPERIMENTAL SETUP

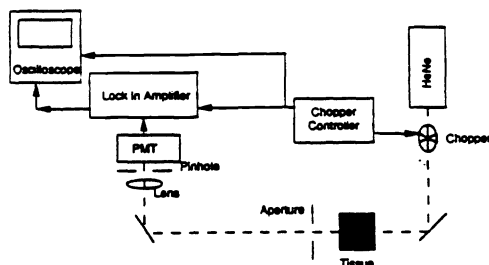


Figure 2: A schematic diagram illustrating the major components of the experimental setup

entered the tissue. The length of the cuvette is 5.5 cm. It is mounted on a translation stage and positioned so the beam enters the cuvette at approximately one centimeter from the edge when the translation stage is on zero. The cuvette is enclosed in a house of cardboard to prevent scattered light from entering the detector.

The phantom tissue is placed inside the cuvette. It is made by adding varying amounts of 8% Polystyrene spheres (particle size 579 nm \pm 21 nm) to 100 mL of deionized water. The maximum concentration of Polystyrene spheres is .027%. The object that is used is a nail placed vertically in the center of the cuvette. It is made of a metal and coated with an almost 100% absorber. This enables the nail to absorb most of the incoming laser light when the phantom tissue is being scanned.

After passing the adjustable aperture, the light encounters another mirror and then a plano-convex lens. The focal length of the lens is 4 cm and the light is positioned so that it goes through the center of the lens. This positioning reduces the amount of aberrations that occur. The 10 μ m pinhole is placed at the focal point of the lens. This optimal pinhole size is determined after comparison of the images from a 200 μ m, 100 μ m, and 50 μ m pinhole.

After passing the pinhole, the light entered the Oriel 7070 Photomultiplier Tube (PMT) where the light signal is converted to an electric signal and then is amplified. The PMT is connected to a Stanford Research System 510 Lock In Amplifier. The amplifier filters out any additional noise that has entered the PMT by comparing the signals that it receives from the chopper and PMT. This output is sent to a Tektronix 2440 Digital Oscilloscope. The oscilloscope is then adjusted so that it uses the output to calculate what the input signal is from the PMT.

3. PROCEDURE

There are six basic procedures used in performing this experiment. They are: measurement of phantom's optical properties, aligning the cuvette, construction of the phantom tissue, placement of the object, scanning of tissue, increase of phantom concentration, and removal of the phantom.

Measurement of the optical properties of the phantom tissue were made using a He-Ne laser and a Coherent power meter. The Polystyrene spheres were diluted to .08%. The power was measured as the amount of spheres increased over a range from 100 μ L to 1000 μ L. The outcome of these measurements are seen in Figure 3.

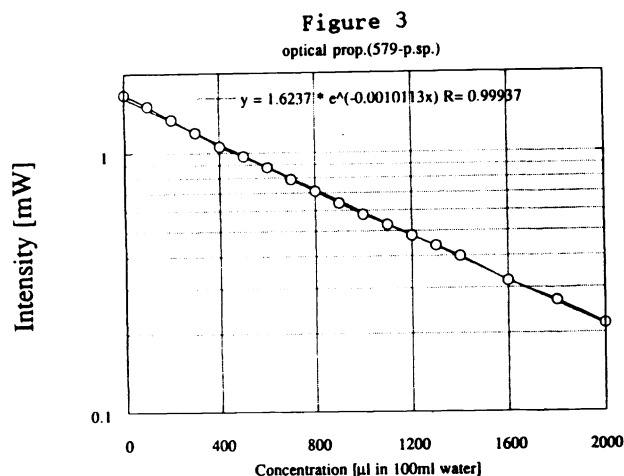


Figure 3: Illustration of the optical properties of the Polystyrene spheres

The empty cuvette is placed in the experimental setup and 100 mL of deionized water is placed inside. All of the optical components behind the cuvette (see Figure 2) are adjusted to the optimum position. It is placed such that the laser beam enters the tissue at 1 cm from its left end. The reflections from the cuvette are also aligned with the beam. The cuvette is mounted with double sided tape so that it is stationary.

The construction of the phantom tissue is made by adding a volume (between 100 μ L - 300 μ L) of 8% polystyrene spheres to the 100 mL of deionized water in the cuvette. The solution is then stirred until it is consistent throughout.

The next step is the placement of the object inside the phantom. The object is a metal object that is covered with an approximately 100% absorber. The object is positioned at approximately the center of the cuvette. The scan is performed by use of a translation stage. The tissue is generally scanned across 24 mm and the object is placed at 12 mm.

The phantom is removed by using syringes. This prevents the

cuvette from moving from its optimum position. This also enables the walls of the cuvette to be cleaned without actually moving it. The data is analyzed using a software program entitled Kaleidagraph Version 2.0. It is published by Synergy Software and was developed by Abelbeck Software. It is a data analysis and graphic application for the Macintosh computer. This software package is used for normalizing the data so that different concentrations of tissues can be compared despite differences in the signal (see Figure 4).

Figure 4

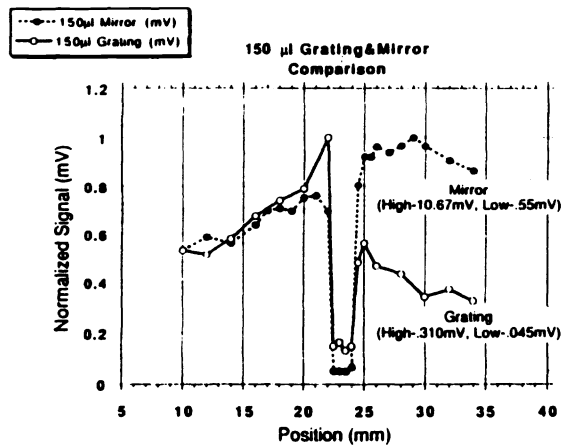


Figure 4: Illustration of the scaling properties of Kaleidagraph Data Analysis Software

4. FINDINGS

The first objective was to determine the maximum number of mean free paths attainable with this method. We were able to detect the object in a tissue of 20 mfp with a contrast of 99.0% and an object of 30 mfp with a contrast of 22.7% (see Figure 5). It had not yet been determined whether this is the maximum number possible. However, Figure 5 tended to imply because of the decrease in the depth of the drop that detection beyond this point

Figure 5

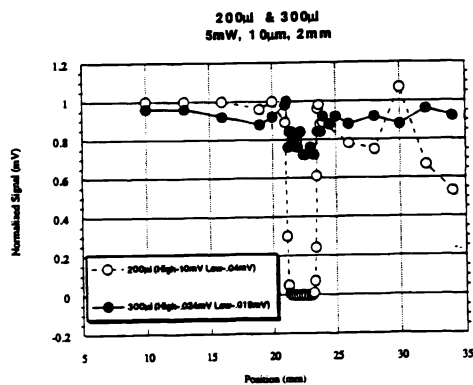


Figure 5: Illustration of the contrast of 200 mfp and 300 mfp phantom tissues

would be difficult.

The second objective was to optimize the spatial filter. This is achieved when the pinhole size is 10 μm . Due to unavailability, we are unable to try pinholes smaller than this size. Therefore, there may be some room for improvement, but we speculated only a little due to the decrease in signal.

The application of this technique to real tissue was the final objective. However, this experiment had not actually begun. A preliminary study was been done just to determine if the object would be able to be detected and it is simply too early to determine.

We also found that this setup was extremely sensitive. When it became misaligned it could take two weeks to realign so that a comparable amount of signal can be attained. However once aligned, the setup yielded repeatable results. A commercial spatial filter mounted in one piece would simplify the alignment task.

6. DISCUSSION

An efficient optical method for imaging of cancer inside tissue is desirable. This method is promising as a potentially new technique that will compliment other methods such as X-ray, Ultrasonography, and Nuclear Magnetic Resonance Imaging. This technique is made possible by the use of a spatial filter which allows vital information about the object to be created into an image by rejecting the diffusely scattered light. Detection is possible in tissues with 30 mfp thickness. A preliminary study has been performed which has determined that this is a plausible technique for cancer detection that should be considered in the future.

There are numerous possible approaches for further research on this technique. The use of a manufactured spatial filter should be investigated to determine the effects on resolution due to increased stability. It should be determined if the 10 μm pinhole is actually the optimal size. The mirror before the lens (see Figure 2) should be replaced with a grating to determine if the grating provides better resolution at higher concentrations. The Polystyrene spheres served as a scattering medium. Another possible approach is the addition of an absorber to the tissue to see how the resolution is affected. Finally, this technique could be used on chicken meat with an object inside of it to determine if detection is possible in actual tissue.

6. ACKNOWLEDGEMENTS

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