Photoacoustic system characterization and four-dimensional imaging

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1. INTRODUCTION

Photoacoustic imaging is a hybrid imaging modality that combines the benefits of optical imaging (contrast) and ultrasound imaging (penetration depth and resolution). While photoacoustic imaging is a relatively new field, potential applications include the characterization of tumours surrounded by soft tissue, such as breast tissue, as well as imaging vasculature structure. Generally, optical imaging techniques are limited by the high scattering of light in tissue. Photoacoustic imaging circumvents a portion of this optical limitation by transporting the object's characteristic information via ultrasound waves. The method utilizes short laser pulses to diffusely illuminate the object. Provided the optical energy is deposited over a sufficiently short period of time, the absorbing structures undergo thermoelastic expansion and the energy is re-emitted as an outwardly propagating photoacoustic pressure wave with characteristics related to the size and depth of the optical absorber [1-2]. Back-projection of photoacoustic waves recorded at a number of perspectives provides a means to identify the location and size of the optical absorbers inside the object. This technique can accurately map the location and size of optically absorbing structures.

Our group has been developing a photoacoustic imaging method that utilizes a sparse array of acoustic detectors to collect signal from a limited number of perspectives. The system utilizes a staring, hemispherical array of detectors combined with parallel data acquisition and an iterative image reconstruction algorithm to produce three-dimensional photoacoustic images using only a single laser pulse [3]. An iterative reconstruction algorithm, first proposed by Paltauf et. al. [4], was employed in combination with the sparse array to account for the limited number of viewing projections supplied by the acoustic transducers [5-7]. A calibration scan of the detector array was performed in order to accurately characterize the system response for each voxel-detector pair. For each voxel-detector pair, this includes the signal's time-of-flight, full-width-half-maximum, and amplitude. Beyond the characterization scan, images were constructed from a variety of optically absorbing objects surrounded by tissue-mimicking gel. This includes point sources, line sources (to emulate veins), and spherical gels of various sizes (to emulate tumours).

2. METHODS

Two point sources were fabricated to characterize the system. The first from a fiber optic cable with one end polished into a hemispherical tip. The hemispherical end was coated in a black optically absorbing material, which served to absorb light from a pulsed laser transmitted through the fiber. This resulted in emission of spherical photoacoustic waves from the hemispherical tip. The second source employed the use of a liquid composed of Intralipid™, Methylene Blue, and water. The blend of Intralipid™ and Methylene Blue combined a high optical scattering liquid with a high optical absorber to distribute light in a spherical orientation while absorbing the light to create the photoacoustic wave emanating from a region defined by the characteristic length of the light.

Prior to calibrating the photoacoustic imaging system, measurements were conducted on the point source to characterize the uniformity of the emitted photoacoustic signal. This included signal change in both the azimuthal and zenith orientations. The hemispherical array of the imaging system was then characterized by raster scanning the photoacoustic point source through a 6x6x6 grid containing a total of 216 points, spaced by 5 mm in all directions. For each grid point, the source was moved to the appropriate grid position, the laser was triggered, and the photoacoustic pressure signal recorded on each detector simultaneously. At each scan point in the imaging volume, the width, amplitude, and temporal position of the photoacoustic signal emitted from the point source was recorded at each detector. All detectors in the array were sampled simultaneously. With the reconstruction algorithm utilizing information from the calibration scan, imaging of simple objects was completed. This included a translating point source and rotating line source embedded in tissue-mimicking gel.

3. RESULTS

The data collected for the fiber optic source (second-generation) was compared to the first-generation source used in a previous system [3]. The results are illustrated graphically in Fig. 1. In comparison to the maximum signal (at 22.5°), the second-generation source did provide a less directional signal. Data for the liquid-based source will be appended when analysis of the results is completed.

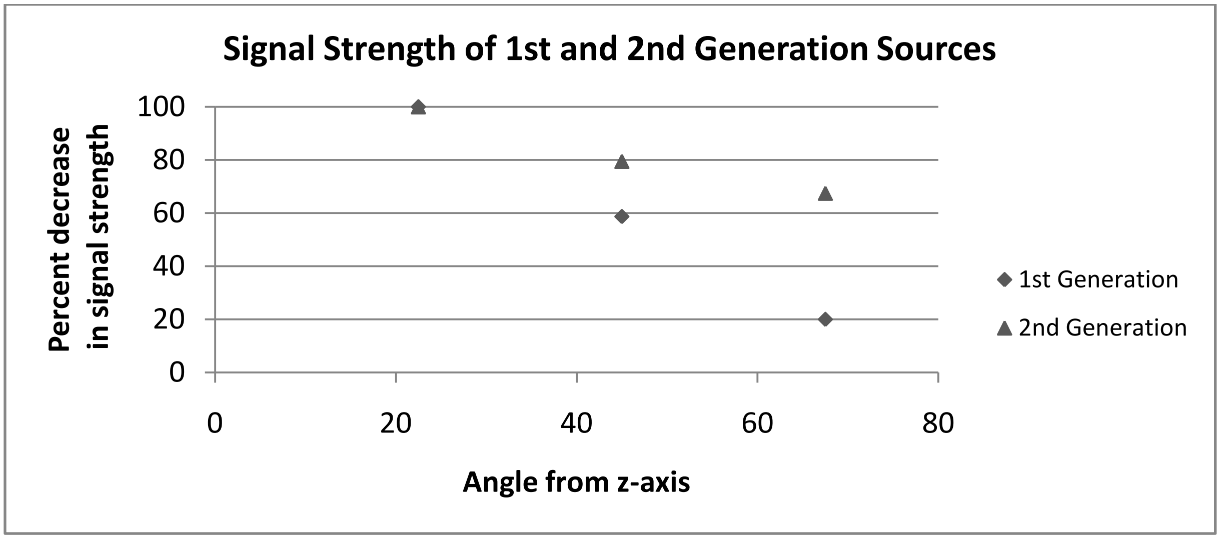

Figure 1: Relative signal amplitude of the first- Vs. second-generation photoacoustic point sources as a function of angle from the z-axis. The signal amplitude of the first-generation source decreased by approximately 80% while the amplitude measured with the second-generation source decreased by only 30%.

After the calibration scan was completed, reconstruction of a point source and line source were completed. Results of a translating point source (y-axis) and rotating line object (xy-plane) are shown below in Fig. 2.

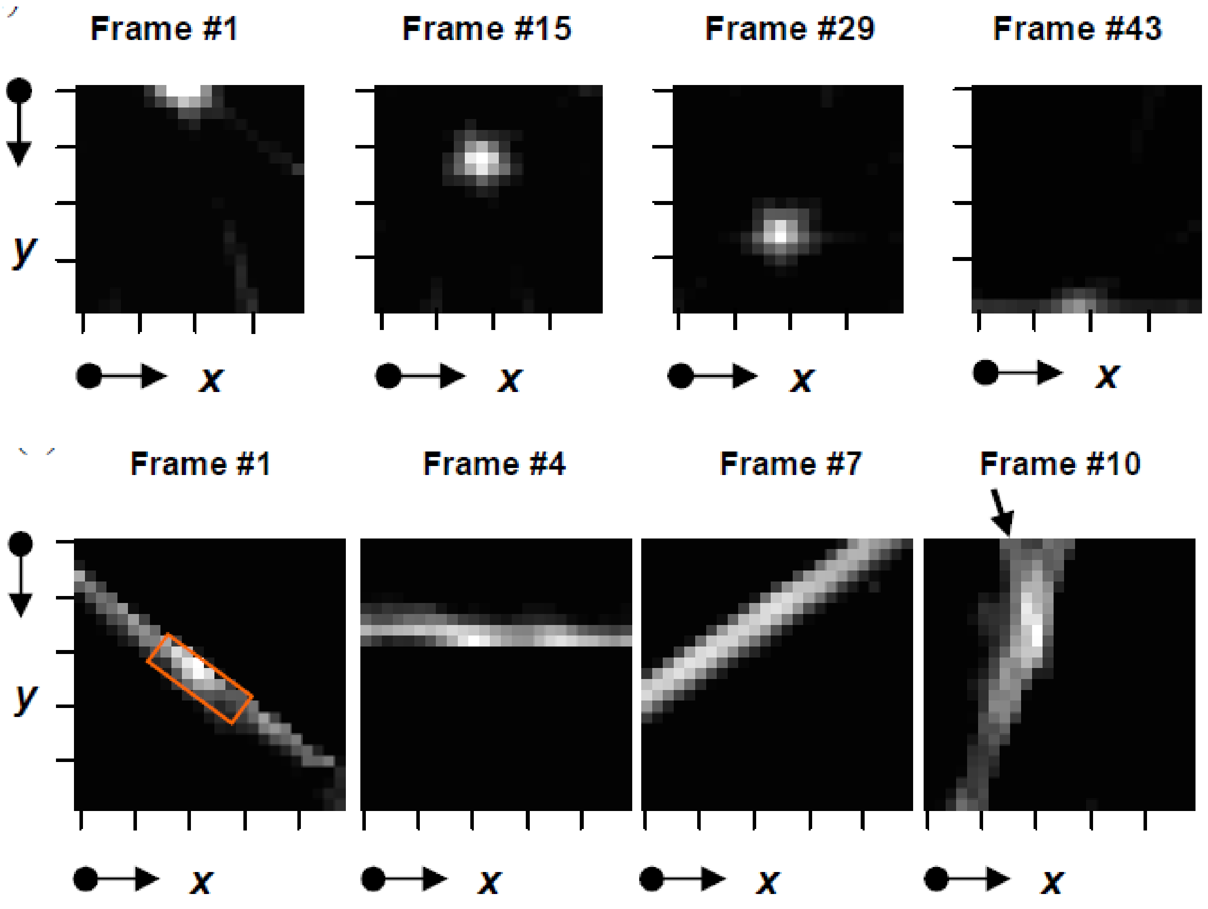

Figure 2: Reconstruction of point source (top row) and reconstruction of rotating line object (bottom row).

4. REFERENCES

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