Linearized inverse scattering for three dimensional terahertz imaging

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Abstract: Two dimensional electro-optic sampling allows a target's scattered terahertz field to be measured. By obtaining multiple projection images we have performed the reconstruction of three dimensional targets with millimeter resolution.

There has been considerable recent interest in tomographic methods of THz imaging [1, 2, 3]. These methods extend the advantages of 2-dimensional T-ray imaging to applications involving 3-dimensional (3D) targets. Short pulses of broadband THz radiation (with typical frequency components ranging from 100 GHz to 3 THz), are used to illuminate the target. Coherent detection methods are used to allow the reflected or transmitted THz pulse profile to be measured. This provides spectral information over a broad range in the important far-infrared band.

THz pulses are generated using a regeneratively amplified femtosecond laser (SP Hurricane) and a wide aperture biased GaAs emitter. The pump and probe beams are expanded to a beam diameter of 2.5 cm using telescope lenses. The THz pulse is incident on the target and the scattered THz signal is measured using 2D electro-optic sampling [4] in a 4 mm thick, 2 cm diameter ZnTe electro-optic crystal. The sensor crystal is positioned close to the target (5 cm) to maximize the angular range ($\pm 11°$) over which the scattered radiation is collected. The modulated probe beam is detected using crossed polarizers and a CCD camera.

A motion stage is used to scan the THz temporal profile and the target is rotated to obtain images at multiple projection angles. The full data acquisition period for a CCD exposure time of 30 ms per frame and a projection step size of 10° can be under 4 minutes, however in these experiments additional averaging was used to improve the signal to noise ratio (SNR) and the acquisition time was several hours.

To reconstruct the target from the scattered field we have used the Rytov approximation and used the Fourier Diffraction theorem to solve the linearized Helmholtz equation. We perform the reconstruction at a single frequency, by Fourier transforming the received pulses and using the Fourier coefficients at a single frequency. The Fourier diffraction theorem states that the spatial Fourier transform of the scattered field along the receiver line, is proportional to the 2D spatial Fourier transform of the object function along a semi-circular arc. Bilinear interpolation is then used to estimate the values of the object function on a regular grid, and the inverse Fourier transform yields the object function in 2D space[5].

A test structure consisting of 3 rectangular polyethylene cylinders was imaged using this system. The reconstruction was performed using a frequency of 0.2 THz, which provided the maximum SNR for our antenna source. The scattered fields at each height were averaged to provide a high fidelity 2D reconstruction as shown in Fig. 1. Alternatively each slice may be reconstructed individually and combined to form a 3D image, as illustrated in Fig. 2.

This reconstruction algorithm is only applicable to weakly scattering objects. In the future non-linear iterative techniques will enable more general targets to be reconstructed. This technique may have important applications in the spectroscopic detection of biological materials such as anthrax and TNT for mail, package and luggage screening.

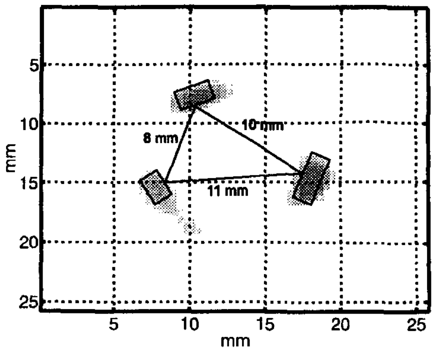

Fig. 1. Reconstructed cross-section of the polyethylene cylinders. The reconstructed image has been thresholded at 50% of the peak amplitude. The geometry of the test structure is overlaid with black rectangles. The rectangular cylinders have dimensions of 2.0×1.5, 3.5×1.5 and 2.5×1.5 mm (clockwise from top).

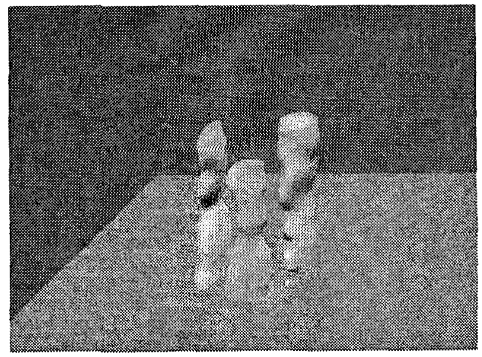

Fig. 2. Reconstructed 3D image of the polyethylene cylinders. Each horizontal slice was reconstructed independently and combined to form a 3D image. The visible ripples on the surface of the cylinders are caused by noise and the surface rendering method.

References

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