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Photothermal Coherence Tomography: Three-Dimensional Imaging Modality Based on Diffusion Localization

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Traditional diffusion-based imaging techniques such as thermography are limited by diffusive energy transport and can only produce depth-integrated two-dimensional images in general materials. In the field of thermal diffusion, periodic heating and cooling cycles give rise to so-called "thermal diffusion waves" (or simply "thermal waves") with key characteristic the ability to control the propagation depth by means of the diffusion length – a quantity that depends on the frequency of the periodic thermal disturbance and on the material thermal diffusivity. This talk will present *truncated correlation photothermal coherence tomography* (TC-PCT), a novel platform developed in the CADIPT for subsurface imaging of wide classes of materials and tissues. TC-PCT enables thermal waves to exhibit *energy localization* akin to non-diffusive waves like ultrasound, despite their diffusive nature. It uses laser-pulse-induced thermal excitation and performs pulse compression and matched filtering, two encoded waveform processes inspired by radar science. Time-windowed thermal diffusion transient signals are cross-correlated with the delay-shifted reference signal and used to reconstruct slice-by-slice depth distribution of optical and thermal sources in opaque and multi-absorber solids.

When used with a mid-infrared camera, this approach results in *depth-selective* imaging which not only improves axial and depth resolution despite the physics of spreading (diffusive) thermal transients, but also allows for deconvolution of individual superposed axially discrete sources, opening a new field of three-dimensional (3D) thermal imaging in a wide spectrum of applications from non-destructive testing of industrial materials and components to dental caries diagnosis, to non-invasive imaging of biotissues. Images are further processed with a unique spatial-gradient-gate adaptive filter in a scanned mode along the (x,y) coordinates of the camera pixel array. In optically inhomogeneous media such as biomaterials, this filter reveals optical absorber true spatial extent from laser generated diffusive thermal images and restores pre-diffusion lateral image boundaries thereby enhancing spatial resolution beyond the Rayleigh criterion limit.

The presentation will conclude with two applications of TC-PCT imaging: One, in non-destructive materials testing, providing 3D visualization of deep (~ 4 mm) subsurface defects in an opaque steel sample, well beyond today's thermography methods. The other, in small animal imaging: Early cancerous tumor detection in a nude mouse thigh with precise measurements of the size and shape of the detected tumor; and *in-vivo* and *ex-vivo* images of a mouse brain which reveal not only vascular structures but also other brain architecture. The key TC-PCT capability for depth selectivity despite the diffusive nature of signals, gives rise to a so-far unattainable wide range of possible applications in science, medicine, dentistry and engineering.