S8-4 Novel In Vivo Laser Sensing in Biomedicine: Laser Computed Tomography and Functional Monitoring

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Introduction

Laser sensing in biomedicine is a unique concept with extensive applications in medical diagnostics, agriculture and environmental sciences. In a broad sense, however, this emerging area is an extension of the principles and practices of remote sensing. As a result, interesting phrases such as "optical ranging in biology", "coherence radar" and "spectral radar" are commonly used in the biomedical optics community. But that's where the similarities end. In reality, serious problems are encountered when biological tissues are the targets to be investigated. Biological tissues are a highly structured heterogeneous media with building blocks of various shapes, ranging from a few nanometers to hundreds of microns that act as potential scattering centers. The presence of a large quantity of water and absorbing pigments in the tissues, further compound our understanding of light propagation in tissues. In essence we are encountered with a complex target and are limited in terms of the wavelength and incident power.

Various optical gating methods have been proposed to select the information bearing photons emerging from the highly scattering biological tissues, and it is generally agreed that the maximum information is preserved in those photons that retain the characteristics of the incident photons. These photons would constitute the minimally scattered directional photons that ideally travel along the line of sight between the source and the detector. To discriminate and select the highly directional maximum information bearing emergent photons, our group proposed and demonstrated the coherent detection imaging (CDI) method [1,2] that is based on the optical heterodyne detection technique for transillumination laser computed tomography and functional monitoring of biological tissues. Here, we describe some our recent results that are obtained with the CDI method using human and plant tissues, *in vivo*.

Experimental arrangement

The experimental arrangement as shown in Fig. 1 is based on a Mach-Zehnder interferometer with continuous wave and single frequency laser sources such as the Ti:Al_2O_3 laser and LD pumped Nd:YAG lasers operating at 1064 nm and 1319 nm, respectively. Collimated output of the lasers is split into the signal beam and the local oscillator beam. Acousto-optic modulators are used to frequency shift the signal beam and the local oscillator beam to 80.1 MHz and 40.0 MHz, respectively. The signal beam after passing through the target sample is mixed with the local oscillator and impinges on a photodiode (silicon/InGaAs) generating a signal at the intermediate frequency (i.f.) of 40.1 MHz. The i.f. signal is then mixed with a clock frequency of 40.05 MHz and the resultant 50 kHz signal is fed to a FFT spectrum analyzer that is interfaced to a personal computer. The sample is mounted on translational-rotational stepping motor stages that are controlled by a personal computer. Dynamic range of the measurement system is ~140 dB and the minimum detectable optical power in our system was about 10^{-17} W.

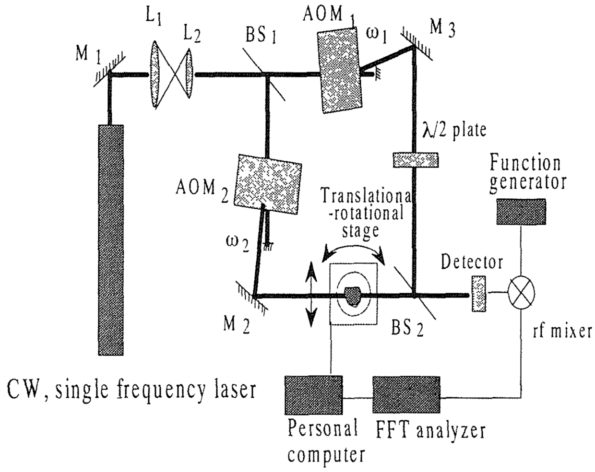

Fig.1

Results

Laser CT of human fingers

Fig. 2 (a) is the laser CT image of the midphalanx region of a healthy volunteer's forefinger, obtained at the wavelength of 715 nm. The image was reconstructed with 30 projections, the measurement period being ~25 min. The incident power on the finger was 15 mW and the base of the finger was lightly bound with a silicon tube to reduce blood flow in the finger. The central region in the image corresponds to the bone cortex and tendon sheath complex, and it is clearly differentiated from the surrounding regions. The estimated resolution of the image is ~0.5 mm. For comparison, MRI (T_1 weighted) image of the same region is also displayed in Fig. 2(b). The striking similarities between the images displayed in Fig. 2, demonstrates the potential capabilities of the CDI method for high resolution laser CT of highly scattering tissues *in vivo*.

CDI for diagnosis of Rheumatoid Arthritis

Soft tissue changes in the joint regions are

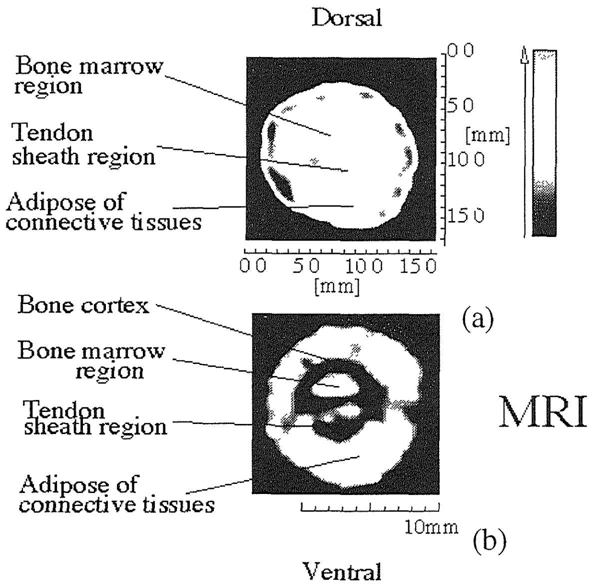

Fig. 2

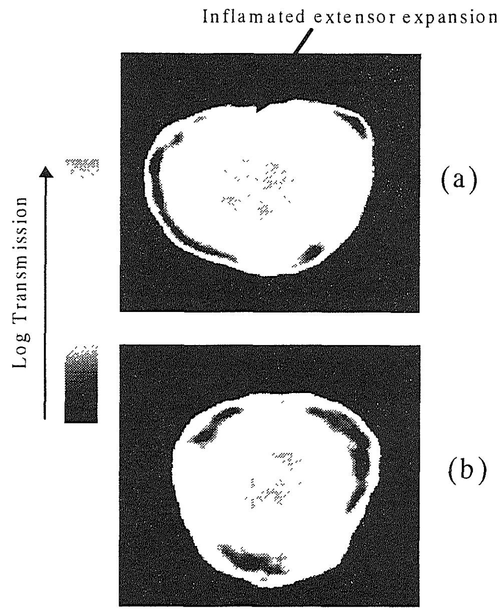

Fig. 3

recogonized markers for the onset of rheumatoid arthritis (RA). Current medical imaging modalities such as the commonly used radiological methods or the recent MRI methods, have limitations in terms of contrast or invasiveness, to reliably detect the soft tissue changes during early stages of rheumatism. In Fig. 3(a) laser CT image at the proximal interphalangeal (PIP) joint region of the RA patient's middle finger obtained at 1064 nm is displayed [3]. The estimated transverse resolution and the slice thickness in these images are ~0.5 mm. The displayed laser CT image was obtained with a relatively safe incident power of ~10 mW. Fig. 3(b) is the laser CT image at the middle finger PIP joint of a healthy volunteer of the same age group and sex as that of the RA patient.

Here again, the central portion in the displayed laser CT images in Fig. 3, correspond to the bone cortex tendon sheath complex. Soft tissues on the dorsal side of the bone cortex corresponding to the extensor expansion tendon is clearly differentiated as swollen in the laser CT image of the RA patient's PIP joint, Fig. 3(a). This clear differentiation of the extensor expansion is not evident in the healthy volunteer's laser CT image, Fig. 3(b). Although the difference in contrast (between RA patient and normal volunteer) with respect to the extensor expansion tendon is not clear at the moment, we suggest that it is due to the inflamation of the tendon with subsequent change in its optical properties.

Monitoring water content and distribution in plants

Water content and its distribution in plant tissues has direct implications on the physiological state of the plants that could serve as useful markers in agriculture and environmental studies. Using near-IR lasers that have differential absorption of water, operating at the wavelengths of 1064 nm and 1319 nm, respectively, we imaged the stem of a potted *Cocos Nucifera* (palm) plant [4]. The results as seen in Fig. 4(a) clearly indicate the location of water vessels when imaged at 1319 nm that has higher water absorption, whereas the same regions are not evident when imaged at 1064 nm as in Fig. 4(b), with relatively lower water absorption. Microscopic section of the imaged region is displayed in Fig. 4(c).

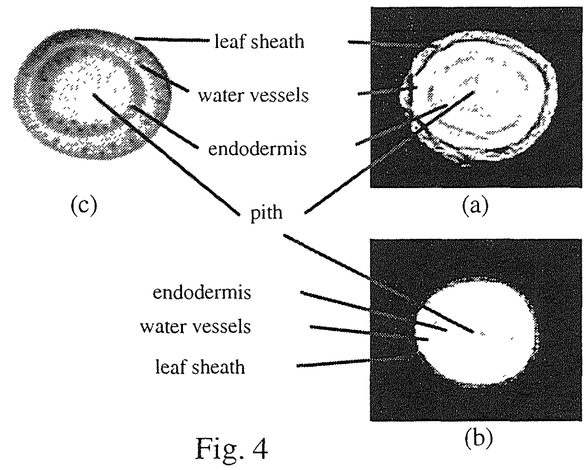

Fig. 4

Conclusions

In conclusion, we describe novel and selective applications of laser sensing techniques in biomedicine with potential applications in medicine as well as agriculture and enviornmental sciences.

References

1. H. Inaba, in Medical Optical Tomography: Functional Imaging and Monitoring, SPIE Institutes for Advanced Optical Technologies Series, G. Müller, et al., Eds.: SPIE Opt. Eng. Press, IS 11, 317-347 (1993). 2. B. Devaraj et al., IEEE J. Selected Topics in Quant. Electron. 2, 1008-1016 (1996). 3. B. Devaraj et al., OSA Trends in Optics and Photonics Series, 21, 338-340 (1998). 4. Y. Sasaki et al., OSA Trends in Optics and Photonics Series, 21, 367-369 (1998).