Dental diagnostic clinical instrument ("Canary") development using photothermal radiometry and modulated luminescence

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Dental diagnostic clinical instrument ("Canary") development using photothermal radiometry and modulated luminescence

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Abstract. Since 1999, our group at the CADIFT, University of Toronto, has developed the application of Frequency Domain Photothermal Radiometry (PTR) and Luminescence (LUM) to dental caries detection. Various cases including artificial caries detection have been studied and some of the inherent advantages of the adaptation of this technique to dental diagnostics in conjunction with modulated luminescence as a dual-probe technique have been reported. Based on these studies, a portable, compact diagnostic instrument for dental clinic use has been designed, assembled and tested. A semiconductor laser, optical fibers, a thermoelectric cooled mid-IR detector, and a USB connected data acquisition card were used. Software lock-in amplifier techniques were developed to compute amplitude and phase of PTR and LUM signals. In order to achieve fast measurement and acceptable signal-to-noise ratio (SNR) for clinical application, swept sine waveforms were used. As a result sampling and stabilization time for each measurement point was reduced to a few seconds. A sophisticated software interface was designed to simultaneously record intra-oral camera images with PTR and LUM responses. Preliminary results using this instrument during clinical trials in a dental clinic showed this instrument could detect early caries both from PTR and LUM signals.

1. Introduction

Since the first attempts to apply the depth profilometric capability of frequency-domain laser infrared photothermal radiometry (PTR) and modulated luminescence (LUM) toward the inspection of dental defects were reported by Mandelis *et al*.[1] and Nicolaides *et al*.[2], some of the inherent advantages of the adaptation of this technique to early detection of carious lesions in conjunction with modulated luminescence as a dual-probe technique have been reported.[2-5] The generated signals carry sub-surface information in the form of a spatially damped temperature depth integral. In PTR applications to turbid media, such as hard dental tissue, material property and depth information are obtained in two distinct modes: conductively, from near-surface distances (~ 5-500 μm) controlled by the thermal diffusivity of enamel and the modulation frequency of the laser beam intensity; and radiatively, through mid-infrared blackbody emissions from considerably deeper regions commensurate with the optical penetration of the diffusely scattered laser optical field, a diffuse photon-density wave (several mm).[4,6]

By optimizing the wavelength and modulation frequency of the PTR signal one is able to examine and probe at least up to 5 mm below the enamel surface.[3] From thermal-wave theory[7] it is well-known that higher frequency PTR signals contain information on near-surface phenomena and full modulation frequency scans may be used to measure and reconstruct depth profiles of the relevant material properties such as the thermal diffusivity.[8] When used with dental materials, PTR has the ability to provide depth profilometric information on carious lesions.

The introduction of modulated (dynamic) luminescence (LUM) simultaneously with PTR,[2,6] revealed the existence of two relaxation lifetimes originating in the hydroxyapatite composition of dental enamel. Variations in LUM emission fluxes and lifetimes between healthy and carious enamel were shown to have a limited depth profilometric character.[3,4] A combination of PTR and LUM has been developed into an analytical caries detection tool of combined specificity and sensitivity substantially better than the DIAGNOdent, radiographic and visual methodologies as shown in Fig. 1.[3] Furthermore PTR has been shown to have the potential to be a reliable non-invasive tool for the detection of early interproximal demineralized lesions, which cannot be detected by conventional dental X-rays.[5]

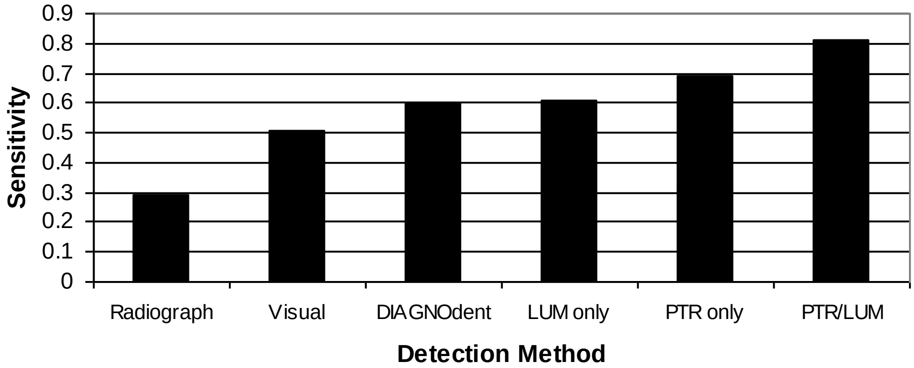

Figure 1. Comparison of the sensitivity of caries detection methods relative to histological examination.[4]

In this paper, a pre-commercial prototype of a dental caries diagnostic instrument using photothermal radiometry and modulated luminescence has been introduced. Some preliminary clinical trial results were also presented.

2. Development of a prototype

As shown in Fig. 2(a), the prototype consists of a handpiece, an intra-oral camera, detectors and control system. The handpiece is held by a dentist for tooth inspection and caries diagnosis in a patient's mouth. It consists of a laser diode with a focusing lens, an electric laser shutter, electric switches, a sapphire lens, a gold-coated mirror and optical fibers. Aluminum housing holds the structure together. Initially the laser diode was designed to be placed in the control box with an optical fiber as shown in Fig. 2(a), but in order to minimize the laser power loss due to an optical fiber, it has been moved into the handpiece. A fluoride fiber (IRphotonics) was used for transporting IR from a tooth to the detector and a plastic fiber (Edmund optics) was used for the luminescence delivery.

The intra-oral camera was connected to the computer through a USB port to capture tooth images which are stored in the hard drive along with measured data and the patient's information. The steel box (254mm (W) × 165mm (H) × 455mm (D)) houses a computer motherboard, an LCD monitor with a touch panel, a data acquisition board (NI, 6221-USB-OEM) with a function generator, a thermo-electric cooled IR detector (Vigo, PVI-2TE-5), a photodiode (Thorlabs, PDA36A), a laser diode driver (Wavelength Electronics, LDD200-1P), and a power supply. Figure 2 (b) shows a picture of the control box of the prototype and Fig. 2(c) shows a test run of the prototype.

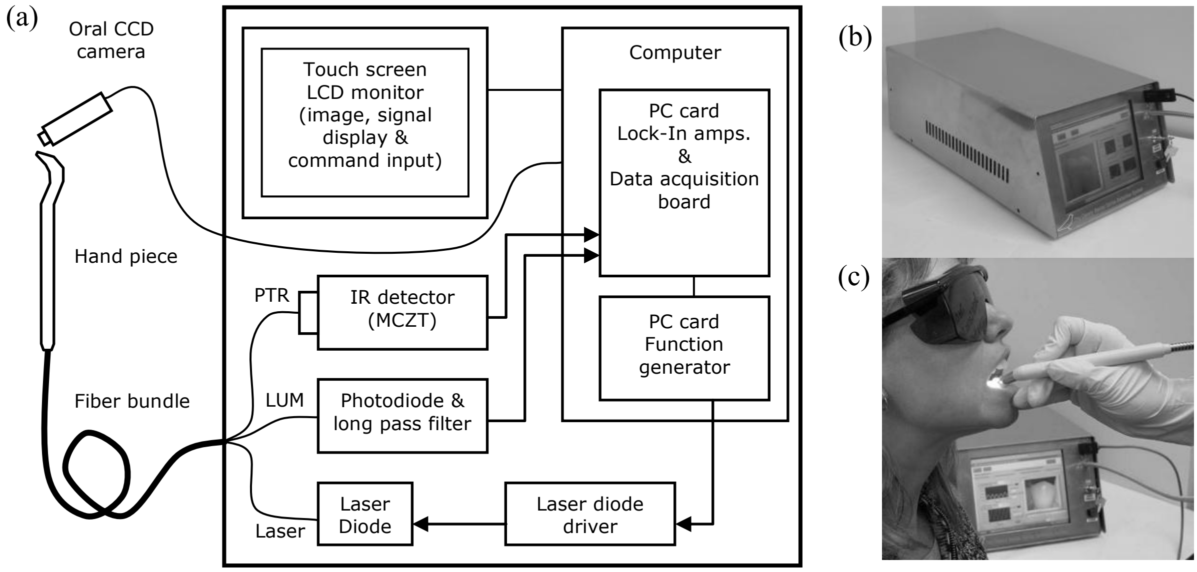

Figure 2. Schematic diagram of the prototype (a); a picture of the prototype (b); and a picture of a field test run (c)

Using 1 analog output channel of the data acquisition board for modulation signal generation and 3 analog input channels for detector signal input, a Labview (National Instrument) software program was developed to replace the hardware lock-in amplifiers and a function generator. In order to develop a faster software lock-in technique for clinical application, first variable sampling time was selected similar to the swept sine sampling time, then simultaneous PTR and LUM responses were captured. Finally data processing was performed. Using this technique, total sampling time for a frequency sweep or line scan takes only about a minute (2-1000 Hz, 10 steps) for simultaneous measurement of amplitude and phase of both PTR and LUM signals. Intra-oral camera images were captured through the USB interface. Using digital input and output channels of the data acquisition board, PTR-LUM data acquisition, automated video camera and laser shutter control are all sequenced by the software upon receiving a trigger signal from electric switches on the handpiece. The software was also designed to store all patient related information with voice assistance.

3. Test results

Figures 3(a-c) show photographs of sample teeth with a circular mark where the measurements are made. ICDAS (International Caries Detection & Assessment System) ranking numbers which were determined by the dentist's visual examination are also shown in the photographs. PTR and LUM amplitude and phase at different modulated frequencies are shown in Fig. 3(d). As expected in image 3(b) and ICDAS reading, tooth 3(b) exhibited relatively larger PTR and LUM amplitude. However, differences between the early caries stages of teeth 3(a) and 3(c) measured with the PTR/LUM instrument ("Canary") were very distinguishable (PTR and LUM amplitude readings), but not with ICDAS reading. Unlike the PTR response, LUM amplitude was larger for tooth 3(a) than tooth 3(b) because stains due to biological films on the tooth surface tend to contribute more to the LUM responses than to the PTR responses. As shown in Fig. 3(d), unlike PTR and LUM amplitude responses, PTR phase was very sensitive to lower SNR. Due to this, larger PTR phase errors from repeated measurements are excluded in the PTR phase plot. Due to the internal reflection of some photons from the sapphire window, the effective LUM response of the tooth sample was digitally computed after subtracting the corresponding internal reflection contribution from a mirror.

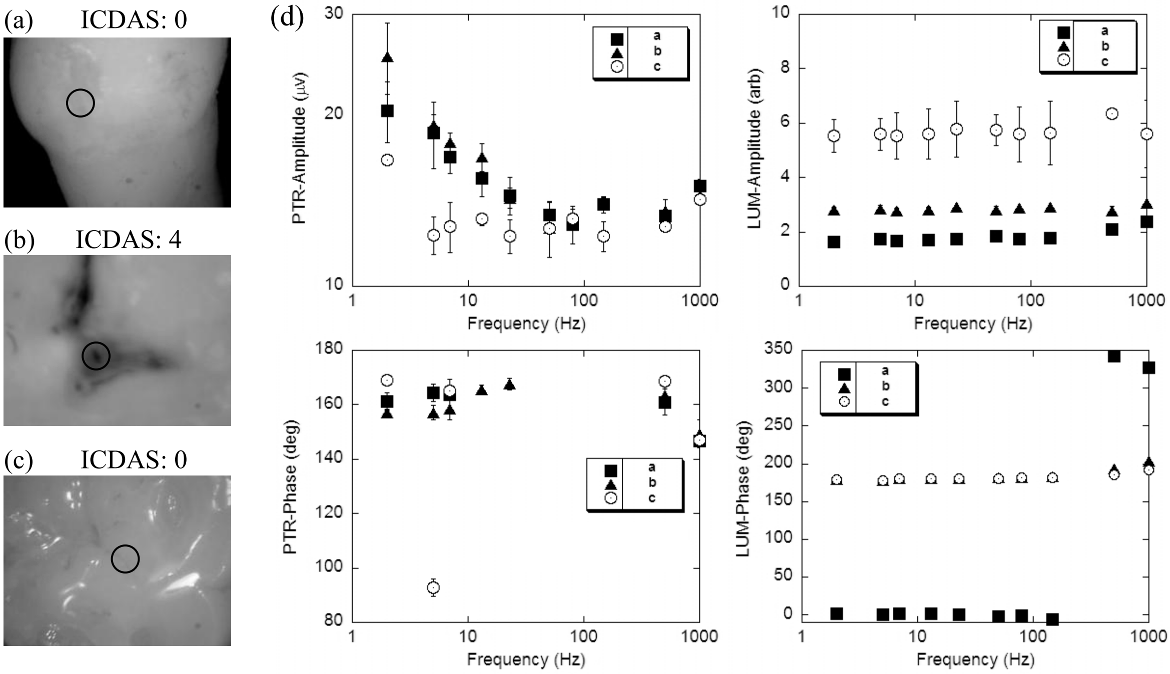

Figure 3. Photographs of sample teeth (a) healthy smooth surface; (b) carious biting surface; (c) healthy biting surface; (d) frequency scan results (PTR amplitude/phase, LUM amplitude/phase).

4. Conclusion

By using of a thermo-electrically cooled IR detector, optical fibers, software lock-in amplifiers and a function generator with a data acquisition board, the pre-commercial prototype of a dental caries diagnostic system using PTR and LUM has been successfully developed and tested. The system showed better sensitivity to the onset of caries than conventional ICDAS readings. Some preliminary PTR and LUM signals measured by the prototype were presented and showed differences between healthy and carious spots on teeth. Currently, further efforts are being expended to improve signal reception at the hand piece and to increase data acquisition speed and to make the system more compact and robust.

References

[1] A. Mandelis, L.Nicolaides, C. Feng, and S. H. Abrams, Proc. SPIE 3916**,** 130-137 (2000).
[2] L. Nicolaides, A. Mandelis, and S. H. Abrams, J. Biomed. Opt. 5, 31-39 (2000).
[3] R. J. Jeon, C. Han, A. Mandelis, V. Sanchez, and S. H. Abrams, Caries Res. 38, 497-513 (2004).
[4] R. J. Jeon, A. Mandelis, V. Sanchez, and S. H. Abrams, J. Biomed Opt. 9, 804-819 (2004).
[5] R. J. Jeon, A. Matvienko, A. Mandelis, S. H. Abrams, B. T. Amaechi, and G Kullkarni, J. Biomed Opt. 12(3) 034028, 2007.
[6] L. Nicolaides, C. Feng, A. Mandelis, and S. H. Abrams, Appl. Opt. 41, 768-777 (2002).
[7] A. Mandelis, “Diffusion-Wave Fields. Mathematical Methods and Green Functions” (Springer, New York, 2001), Chap. 2.
[8] A. Mandelis, F. Funak and M. Munidasa, J. Appl. Phys. 80, 5570-5578 (1996).