Integration of frequency comb measurement and optical coherence tomography

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Abstract An integration of frequency comb measurement (FCM) and Fouier-domain optical coherence tomography (FD-OCT) is demonstrated to extend the axial measurable range. An ordinary OCT can measure the structure of a sample within the range of several millimeters along the axial direction. The axial measurable range of the FCM that is much larger than the OCT is the order of ten centimeters. Therefore, the integrated system can measure the structure of a target by switching between two optical measurement modalities depending on the distance to the target.

Keywords: frequency comb profilometry, optical coherent tomography, endoscope, active liquid lens

Surgery using an endoscope reduces a small amount of burden for a patient. A medical doctor performs a surgery while watching a two-dimensional image from the endoscope. The medical doctor requires high capacity for the judgement that enables the excellent operation with base on the trainings and experiences. If the endoscope gives more information such as depth information, it would surely help to perform better operations. Toward the final target, it will be effective to integrate optical measurement modalities.

An axial measurement range that decides the measurable size of a target and its axial resolution are very important performance indices which optical measurement modality should be selected. The optical measurement has been developing toward maximizing the measurable range and minimizing the axial resolution. Frequency combs in the radio frequency (RF) domain generated by ultra-stable mode-locked femtosecond lasers are becoming very useful for achieving a measurement with a wide axial dynamic range in industrial applications [1-3]. A frequency comb profilometer (FCP) based on a single-pixel camera with an optical frequency comb laser was demonstrated [4]. The single-pixel camera was constructed from two digital micromirror devices (DMDs) and a photodetector (PD), with a mask for encoding the object wave applied to the two DMDs [5,6].

In this paper, an optical coherence tomography (OCT) [7, 8] is integrated to the frequency comb measurement (FCM) for maximizing the axial dynamic range and minimizing the axial resolution of the total system, as shown in Fig. 1. The FCM is used to measure the distance of the target with the maximum measurable range of several 10 centimeters and an axial resolution of a micrometer order. The OCT enables a non-invasive and internal three-dimensional observation of biological tissues with an axial resolution of a micrometer order and the measurable range of micrometer order. The OCT is classified to a time-domain OCT (TD-OCT) and Fourier domain OCT (FD-OCT) [9]. The FD-OCT was implemented in this research, because the same broadband femtosecond laser was used as a light source.

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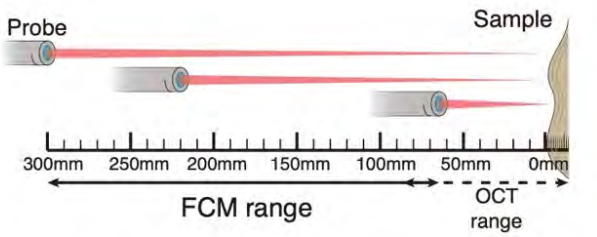

Fig. 1 Axial ranges of optical measurement modalities.

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Outlines

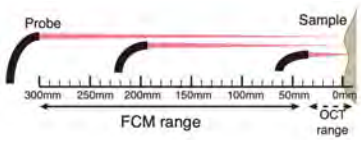
- Abstract
- OCT(Optical coherence tomography)
- FCM(Frequency Comb Measurement)
- Optical frequency comb laser.
- Consideration for integration system.
- Conclusion.

Abstract

Goals

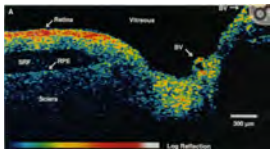
- Integrate two systems in order to help doctors during surgeries when an endoscope is used.
- Get a relievable system to get images and spatial information of the sample under test when doctors are performing a surgery.

EVIS LUCERA ELITE,Olympus
(https://www.olympus.co.jp/technology/technology/luceraelite/?page=technology_way)



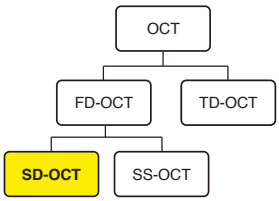
OCT

Optical Coherence Tomography
Interferometric imaging technique.
- non-invasive imaging
- contactless.
- high-resolution.

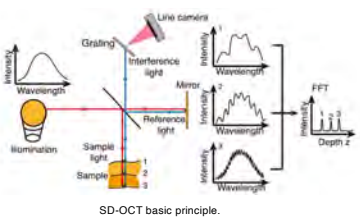


Optical Coherence Tomography

Applications
- manufacturing.
- Medical



SD-OCT



SD-OCT basic principle.

illumination

$$E_i = H(k,\omega)e^{i(kz-\omega t)}$$

Reference

$$E_R = \frac{E_i}{\sqrt{2}} r_R e^{i2kz_R}$$

Sample

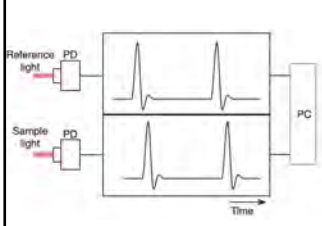
$$E_S = \frac{E_i}{\sqrt{2}} \sum_{n=1}^{N} r_{Sn} e^{i2kz_{Sn}}$$

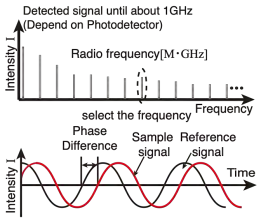
Interference fringe

$$I_D(k) = \frac{\rho}{4}\left[H(k)\left(R_r + \sum_{n=1}^{N} R_{Sn}\right)\right] + \frac{\rho}{2}\left[H(k)\sum_{n=1}^{N}\sqrt{R_r R_{Sn}}\{\cos(2k[Z_R - Z_{Sn}])\}\right]$$

$$+\frac{\rho}{4}[H(k)\sum_{n\neq m=1}^{N}\sqrt{R_{Sn}R_{Sm}}\cos(2k[Z_{Sn} - Z_{Sm}])\}$$

FCM



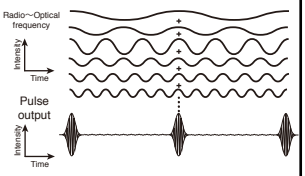


Equation

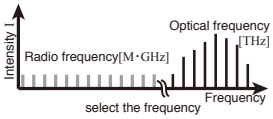
$$d = \frac{c\Delta\phi}{4\pi f}$$

d:distance
c:velocity of light
f:Frequency
$\Delta\phi$:Phase difference

Optical frequency comb laser.



Rainbow(Coherent).
Power:300mW.
Repetition: 76MHz.
Wavelength: 650-950nm
Center wavelength:800nm.

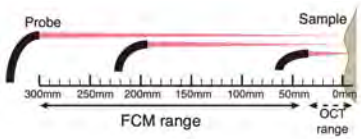


Integration system considerations.

① How to extract the signal for FCM?

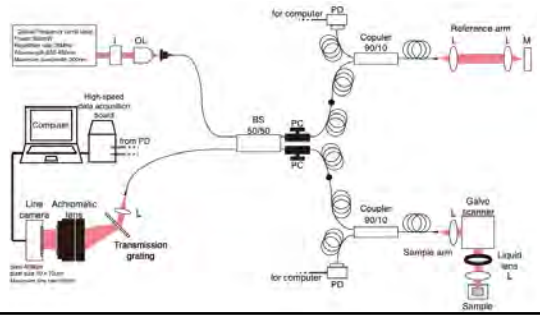
② How to switch the measurement mode?

③ What is difference between normal OCT and integrated OCT?



How to extract the signal for FCM?

Previous setup



Results

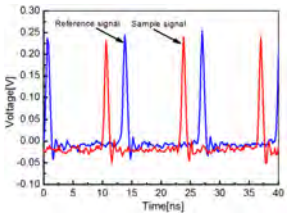


Fig. Detected pulse signal in Photodetector

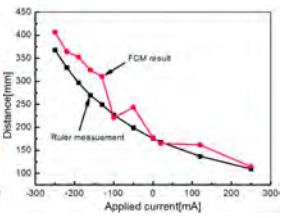
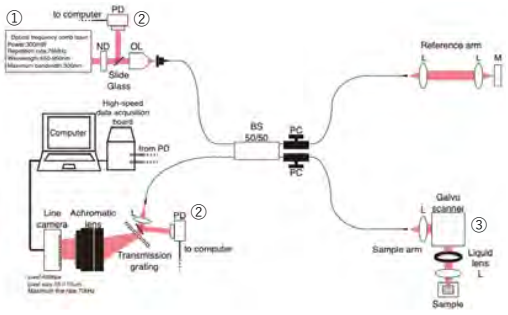


Fig. FCM result at 303.5MHz signal.

We measured the distance information. But accuracy is not good. Addition, in this setup, we cannot see the interference fringe for OCT.(case fiber coupler use)

Setup



How to switch the measurement mode?

When we realize for two modality, focal length have to be changed against sample positions.

Liquid lens(EL-16-40-TC, Optune)

Turning range: -2 to +3[dpt]
(-0.5 to +0.3[m])
Working wavelength: 420~920[nm]
Clear aperture: 16[mm]
Operation source: voltage
Response time: 5 [ms]

Fig. Liquid lens system.

Liquid lens feature.

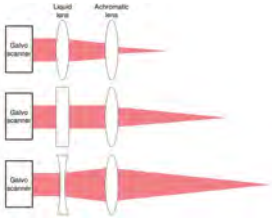


Fig. Liquid lens system.

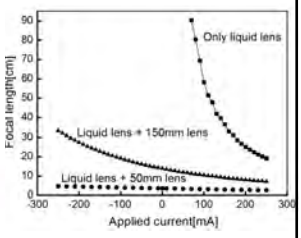


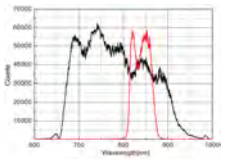
Fig. Variation of focal length as a function of the current applied to the combination of variable focus liquid lens and normal lens.

What is difference between normal OCT and integrated OCT?

Difference point.

- Wavelength range.
- Laser power.
- Realize the two measurement methods.

	SLD	OFCL
Power	25mW	300mW
Bandwidth	80nm	300nm
Center wavelength	840nm	800nm



Signal for OCT

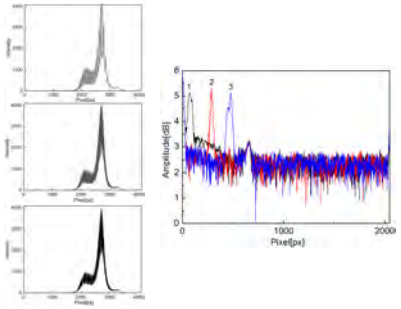
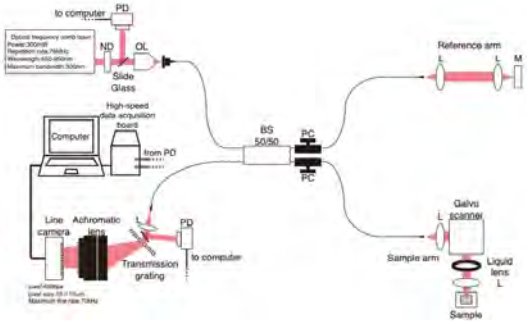
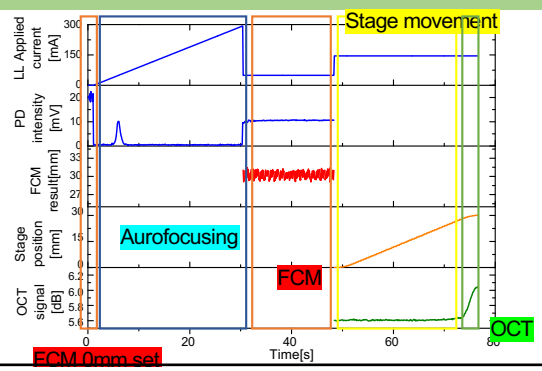


Fig.2.interference fringe of spectrum.

Setup



System operation



Conclusions

- We are building the integration system with OFCL.
- We considered that how to extract the light for FCM.
- We checked the each measurement technique signal on integration system.