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Development of Optical Coherence Tomography Using KTN Optical Probe

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Abstract

We have developed optical coherence tomography system with KTN optical probe for a diagnosis in the orthopedic surgery fields. The present system demonstrates that biological image was measured by using KTN optical scanner for having degree of freedom in sample arm as optical coherence tomography. In addition, the developed optical coherence tomography (OCT) system has shown feasibility for imaging biological tissue in orthopedics. The system was shown to have a resolution 14.2 μm for biological tissue in few mm depths. The sensitivity to be measured is 92.3 dB.

Keywords

KTN Optical Probe, Optical Coherence Tomography, Imaging System

1. Introduction

Recently, there are many arthritic disease cases in orthopedic surgery fields. Many musculoskeletal diseases were reported in USA [1]. Approximately fifty million adults have been diagnosed with arthritis. They have work limitations [2] [3]. According to statistics, around seven million people have knee osteoarthritis in Japan and the ratio of elderly people has a tendency to increase per year [4] [5]. In the field of orthopedics, high resolution imaging system is necessary for early detection and successful treatment of disease. It focused on optical coherence tomography (OCT) [6] [7] [8] system with optimal OCT probe which is very effective in accurate assessments of arthritis diagnosis. In this study, we demonstrate development of the OCT system, which is capable of performing in diagnosis for osteoarthritis and rheumatoid arthritis.

The present work aims to report the first attempt of OCT system using KTN [9] [10] [11] optical probe for imaging. The purpose at reporting is to mount

OCT probe with two-dimensional KTN scanner on conventional OCT system. The sample arm is based on the use of endoscopic imaging instrument. In order to access internal organ, sample arm was constructed with flexible structure and small diameter OCT probe. It is necessary to visualize exact position of articular joint. Therefore, the sample probe has to approach the articular surface of knee for investigation of joint for accurate diagnosis and treatment in orthopedic field. The KTN scanner with optical probe is suitable for this purpose. Thus, we have developed KTN scanning probe as the sample arm in OCT system.

The system was shown to have a resolution of few micron for biological tissues in few mm depths. The OCT system with KTN optical probe was also applied to medical diagnostic imaging system.

2. OCT System

The optical system mainly consists of a fiber optic Mach-Zehnder interferometer with a swept source in developed OCT system. The light source is swept source in 1300 nm wavelength with the measured output of 12 mW and Mach-Zehnder interferometer configuration employed in SS-OCT system. The schematic view of the OCT system with KTN optical probe is illustrated in **Figure 1**.

A swept source as light source is connected to the polarization controller (PC). A fiber optical PC after swept source output was used to maintain the polarization states of the two arms. A 90/10 coupler divides the PC output into a reference arm and a sample arm. One arm of interferometer is introduced into a reference mirror and the other is introduced into the sample of interest. Reflections from two arms are combined at 50/50 coupler and detected by means of balanced detector.

The sample arm is used to KTN optical scanner, which has included optical probe for biological sample. Furthermore, the KTN scanner is designed to be

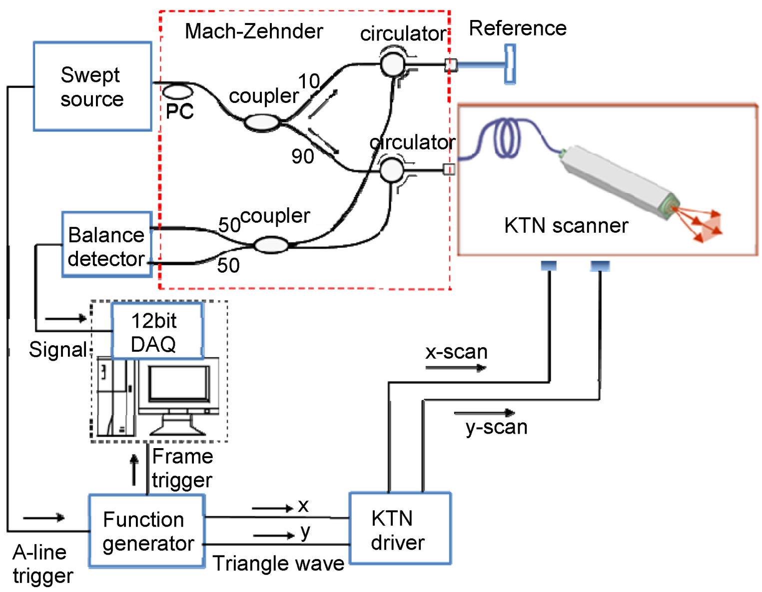

Figure 1. OCT system with KTN optical scanner. PC: polarization controller, DAQ: data acquisition system.

endoscopic probe, which connect flexible optical cord as clinical instrument *in vivo*. The incident beam to KTN scanner is necessary to linearly polarize. As the polarized beam generated by KTN scanner was linear, the use of polarization maintaining optical fiber of interferometer is essential in this optical system.

The swept frequency of light source is 100 KHz and determined to a line acquisition rate of OCT image. The trigger signal from swept source is transferred to function generator. Triangle wave were produced by function generator is fed to a KTN scanner. Consequently, the trigger of swept source is the coincidence to KTN optical scanner of frame trigger. The signal of interference from photodetector is transferred to AD converter, in which installed in PC computer. The data were recorded using an AVALDATA APX5050 analog-to-digital converter. The employed AD converter was transformed analog-to-digital rapidly and that sampling rate is 500 MHz of 12 bit resolution.

3. Two-Dimensional KTN Scanner

The sample probe has two KTN deflectors. The optical system is telecentric [12] arrangements with multi lens to parallel principle axis to the optical axis in KTN optical scanner. The telecentric optical system is useful for measurement of close object such as biological tissue using probe. Top of the KTN probe, the gradient index (GRIN) lens is attached to focusing beam after transmitted to KTN scanner. A 2.0 mm diameter and 21.0 mm length GRIN lens covered by SUS is optimal to biological tissue as endoscopic OCT probe. A layout of KTN scanner used in the present work is illustrated in **Figure 2**. At the position of 1 mm from top of GRIN lens surface, the lissajoue scan has performed using KTN optical scanner. The experimented beam profile from KTN scanner is shown **Figure 3**. The measured scanning area is 2.01 mm × 2.04 mm. We have obtained expected image in scanning region.

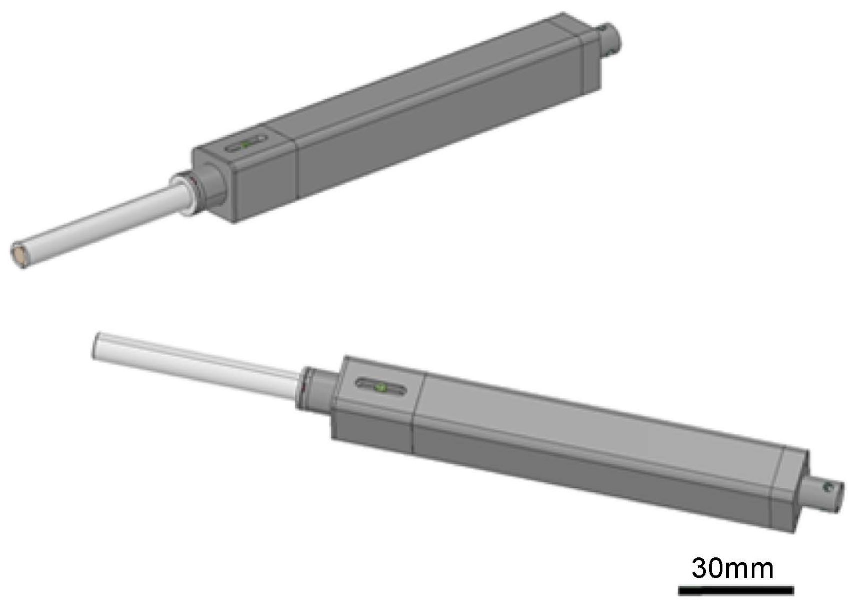

Figure 2. The 3D view of two-dimensional KTN optical scanner.

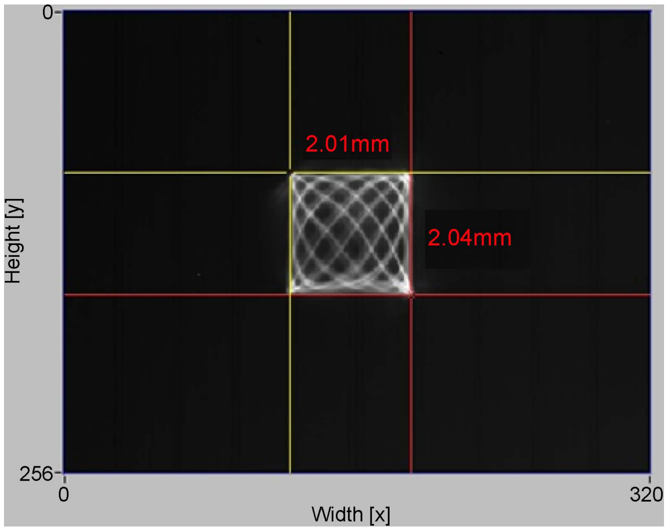

Figure 3. The obtained profile from a Lissajous scan using KTN optical scanner.

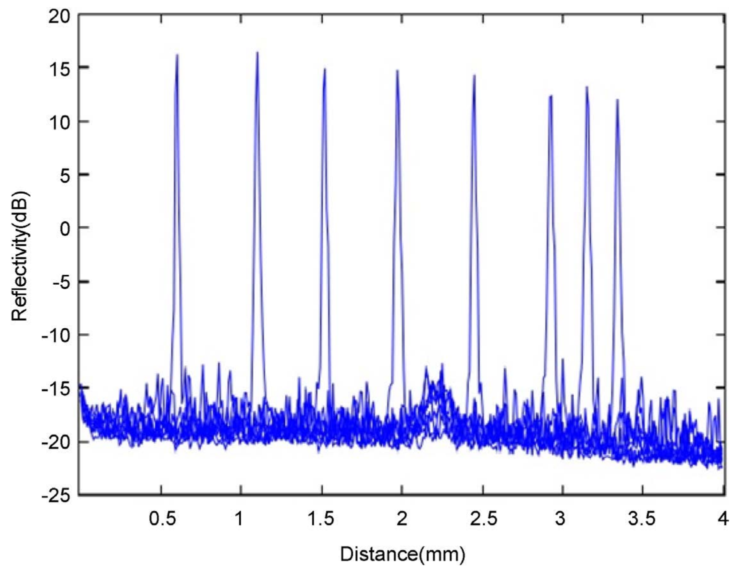

Figure 4. Point spread functions were obtained by using sample mirror in OCT system.

4. Point Spread Function in OCT System

We have carried out the measurements of mirror surface as sample to estimate the characteristics of SS-OCT system. The most important characteristics of SS-OCT are dependence of difference in optical path length as different depth positions. This dependency is estimated to measure point spread function (PSF) [13] [14] as various positions with respect to the difference of length between reference mirror and sample mirror. The PSF means profile of optical axis in OCT system. The PSF of interference signal has measured as shown in Figure 4. The intensity of signal decreases few dB along an increase of moving distances on sample arm. Also a typical PSF was obtained sharp gaussian peaks at various depths. We have derived the coherence length of 7.0 mm employed swept sources on developed OCT system.

5. Results

We have measured human finger image using OCT system by KTN optical probe. We demonstrate that the measurement of finger image in human body using developed OCT system is an accomplishment of the OCT system. The skin surface and eccrine sweat gland was shown in measured finger image in **Figure 5** [15]. The size of measured finger image is 500 pixel × 400 pixel in x-z plane.

The theoretical value of resolution was evaluated from light source that center of wavelength is 1310 nm and the FWHM wavelength is 110 nm [16]. The calculated spatial resolution is 6.8 μm. The OCT system with KTN optical scanner gives sharp peak with spatial resolution of 14.2 μm in mirror image. The theoretical value demonstrated that the absolute value of resolution was in agreement the value measured for the developed OCT system. The lateral FWHM resolution was 15.5 μm by beam profile measurement.

Sensitivity was obtained by using mirror image measured with neutral density filter 0.6, which acts as absorber for saturated interference signal. Sensitivity to be measured by OCT system using KTN optical probe is obtained from the condition that the interference yield exceeds the fluctuation of background in fourier spectrum. Then one gets 92.3 dB.

We have measured scale on x axis in present OCT system using 200 μm slit. The known 200 μm length was obtained 82 pixel. Full scale of finger image was estimated 1.21 mm in x axis. Longitudinal scale in finger image was measured the length from zero pixel to 400 pixel according to moving reference arm. The mean value was calculated 3.42 μm ± 0.20 μm per pixel. Full scale of z axis was estimated 1.37 mm in finger image.

6. Conclusion

It is shown that optical coherent tomography system using KTN optical scanner can be used as sufficient sensitive imaging system for human organ. Actually we have measured to get human finger image by the present system. This type of OCT system can be used for imaging biological tissue of internal organ with a

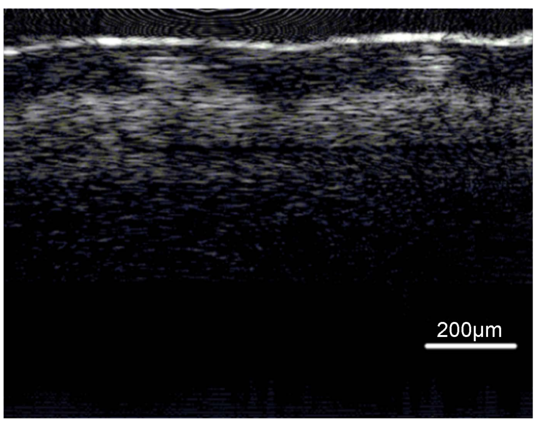

Figure 5. Finger image measured by OCT system using KTN optical scanner.

compact and flexible sample probe in orthopedic surgery fields. The coherence length was kept on maintaining above 7.0 mm distance of measurement point spread function (PSF) in the present system. This development is shown to be possibility of early detection and correct diagnosis in imaging osteoarthritis *in vitro* and *in vivo*.

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