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# Optical frequency comb profilometer for a large depth object

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To know a surface profile of an object with a large depth is very important, especially in industrial aspects. The requirement of the fast and high accuracy profilometry is growing day by day. Recent years, the development of optical frequency comb (OFC) generated by a mode-locked femtosecond laser has been used in optical measurements for the refractive index and thickness of an object, which are specified by resolving interferometry, profilometry and tomography. Especially, the OFC can achieve a very precise and wide dynamic range in an absolute distance measurement.

Additionally, compressive sensing (CS) that is known as a new digital signal processing technique has designed to acquire and recover the physical signal from relatively few measurements with potential of high resolution. The combination of sparse representation and pseudorandom sampling was the original idea of CS.

In this paper, we demonstrate an optical profilometer based on the OFC using the CS. The CS implemented with a spatial light modulation (SLM) displaying encoding patterns was introduced so that the OFC interferometry can perform the imaging measurement without a mechanical scanning. It allows us to reconstruct the entire object surface from relatively fewer measurements than the number of the sampling point.

Figure 1 shows an experiment setup. A femtosecond laser (FEMTOSOURCE™ rainbow™ , Femtolasers) with a carrier envelope phase (CEP) stabilization and a repetition rate of $f_R$ = 76MHz was used. An object wave and a reference wave were sampled by a photo-receiver with the frequency response to 1GHz, respectively. The object wave was modulated with a spatial modulation function on the SLM, and focused on the photo-receiver $D_S$ at the focal point of the lens $L_1$. The reference beam was also detected by $D_R$. One harmonic frequency was selected from a lot of the harmonic frequencies by a frequency selectable system (FSS) that was designed to select the 13th harmonics of $f_R$. The output signal from phase-detector $PD_C$ was filtered by a low pass filter. Before leading into phase-detector $PD_S$, the phase of reference wave was shifted by amount of $\pi/2$ implemented with a phase shifter PS. The phase difference was calculated from two waves.

CS was applied to know the two waves under spatial modulation on the SLM that was a pseudorandom pattern consisted of the random binary elements of Bernoulli matrix. The binary element had a state which blocked or passed the light. In order to reconstruct sparse signals, $l1$ optimization method was selected.

Figure 2 shows the experimental result for an object constructed by three different plane mirrors, which have the distances between the second and third mirrors were located at 30 mm and 50 mm from the first mirror, respectively. The profile was achieved by 26 measurements of 6×6 pseudorandom patterns.

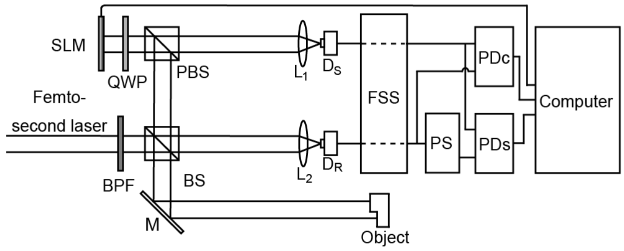


Fig. 1. Experiment setup. BPF, band pass filter; BS, beam splitter; PBS, polarization beam splitter; L, lens; SLM, spatial light modulation; QWP, quarter wave plate; D, fast photo-receiver; FSS, frequency selection system; PD, phase detector.

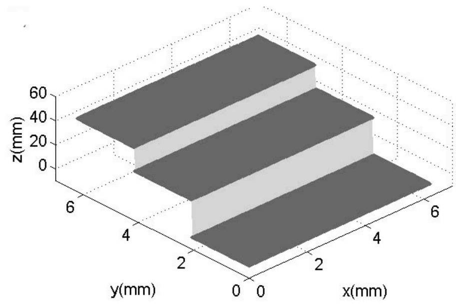


Fig. 2. Object profile with three different depths.

We have proposed a new profilometer with the OPC and the CS. The OPC was to ensure high dynamic measurement. The CS allowed scanning and reconstructing the object profile with measurement fewer than the number of the sampling points. The experiment results demonstrated the feasibility and advantages of the proposed method. The lateal measurement area depended on the size of the SLM. The lateral resolution can be easy to change and the maximum is the maximum of the SLM's resolution. The accuracy was dependent on the number of measurements, when the number of measurement was greater than one required by the CS condition, the RMS error was considered as constant. When the more complicated object is measured, a random mask with smaller pixel size was required to use. In the experiment the selected frequency was 988 MHz, so the object with depth smaller than 152 mm can be detected without any $2\pi$ ambiguity. Finally, this system had no mechanical movement. The accuracy of the system will be improved by the increase of the contrast of the random pattern diplayed by the SLM and by higher sensitivity of the phase detectors.