A Lidar based on Optical Sampling by Cavity Tuning

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Abstract: We report the demonstration of a lidar based on optical sampling by cavity tuning. Target vibration as fast as 50 Hz has been successfully detected at an equivalent free-space distance of over 2 km.

OCIS codes: (280.3640) Lidar; (120.3930) Metrological Instrumentation; (320.7090) Ultrafast lasers

1. Introduction

Optical sampling by cavity tuning (OSCAT) is a novel scheme enabled by high-repetition rate femtosecond lasers to achieve tunable optical delays [1-3]. OSCAT combines a highly imbalanced interferometer with intracavity tuning of the pulse repetition rate, as illustrated in Fig. 1 (a). Because of the arm-length imbalance, the pulses meeting on the detector come from different parts of the pulse train, which means they have different pulse spacing due to the repetition rate modulation. This allows the relative delay between the pulses from the two different arms to be scanned. The rate of this scan is the rate of the intracavity modulation, which can potentially reach 100 kHz level with today's fast piezo-electric (PZT) actuators. This is sufficient to enable *in situ* biological imaging and dynamic spectroscopy [2]. Compared with traditional mechanical delay lines, OSCAT only requires small mechanical movements to produce large delay modulation depths. This directly translates to higher scanning rates. Compared to another popular optical sampling scheme built upon ultrafast lasers, the asynchronous optical sampling (ASOPS) [4, 5], OSCAT needs only one femtosecond laser and is hence much more compact and cost-effective. In the present work, we explore the application of OSCAT in dynamic range finding and demonstrate an OSCAT-based lidar.

2. Experimental Setup

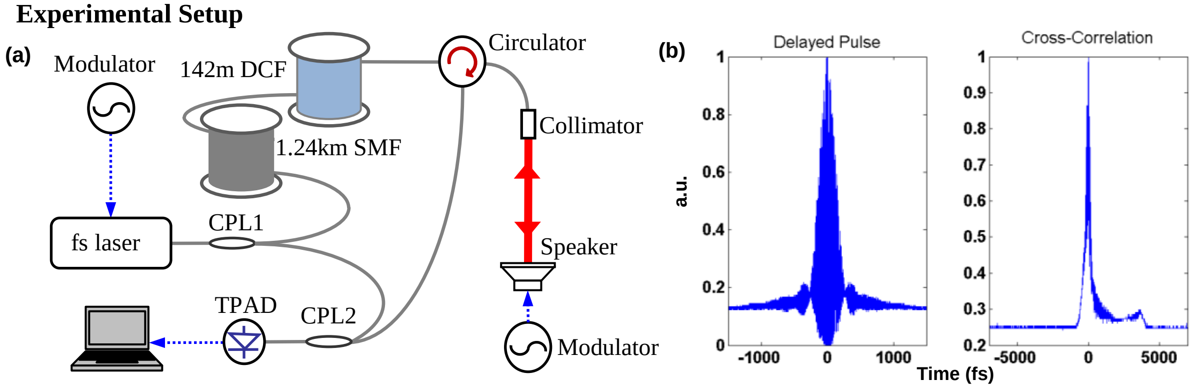

Fig. 1. (a) Schematic of the OSCAT lidar. CPL, optical coupler; DCF, dispersion compensating fiber; SMF, single-mode fiber; and TPAD, two-photon absorption detector. (b) Autocorrelation of the delayed pulse and the cross-correlation of the delayed pulse and reference pulse.

Our experimental setup is shown in Fig. 1 (a). A femtosecond fiber laser (MenloSystems M-Comb) generates a near-IR (1560nm) pulse train with a repetition rate of 250 MHz. The laser is equipped with an intracavity translation stage, which allows the repetition rate to be changed by up to 2.5 MHz, as well as a broadband (up to 30 kHz) PZT, which can vary the repetition rate by 3.6 kHz. The laser output is coupled into a fiber Mach-Zehnder interferometer with an arm-length imbalance of about 1.39 km. The long arm consists of a 1.25-km single-mode fiber delay line followed by 142-m dispersion compensating fiber. A collimator at the end of the long arm launches the beam toward a reflective target about 1 cm away on the vibrating surface of a speaker, which vibrates under the control of a modulation signal. The reflected pulses collected by the collimator are redirected by a circulator and then combined with the pulses from the shorter arm on a second coupler. A nonlinear detector based on two-photon absorption is used to probe the cross-correlation between the two pulse trains.

Our scheme works as follows. Since OSCAT requires a large interferometer imbalance, it naturally suits long-distance ranging, where the distance to be measured can be used as the long arm of the interferometer. For proof of principle, we use the 1.39-km fiber link to simulate a 2-km free-space distance. In the measurement, we first tune the intracavity stage so that pulse overlapping can be probed by the detector. This sets the nominal repetition rate for the nominal distance to be measured. We then rapidly modulate the laser repetition rate with the PZT and measure the displacement of the target around the nominal distance. To determine the absolute distance, we tune the intracavity stage so that two consecutive pulse overlaps are detected, which allow us to find the nominal distance of the target.

3. Results and Conclusion

The displacement measurement critically depends on the cross-correlation detection. Exit pulse widths of about 500 fs from the long arm and cross-correlation traces with a 700-fs FWHM have been achieved as shown in Fig. 1 (b). Each cycle of the PZT scan produces two cross-correlation traces, one for each trip. The separation between the two traces depends on the displacement of the target from the nominal position. Such dependence is demonstrated in Fig. 2 (a), where a constant drift of target position offset is detected by the cross-correlation measurement. With proper calibration, target displacements can be directly read out from such traces. A measurable displacement range of over 10 mm has been achieved without moving the intracavity stage, but much longer total range can be realized with longer PZT actuators or shorter laser cavities. To demonstrate the ability of OSCAT to trace fast movement, we let the target vibrate at about 50 Hz by applying a modulation to the speaker and, at the same time, scan the PZT at a much higher frequency (e.g. 500 Hz). The target displacement is sampled at this frequency via a number of cross-correlation measurements. The recovered displacements are then connected to map out the trajectory of the target, as shown in Fig. 2 (b). This OSCAT-measured trajectory is compared with the modulation signal to the speaker as well as the result from an auxiliary tracing method, which is based on optical power change out of misalignment due to the vibration. Fig. 2 (c) shows a good agreement among the three curves, indicating a faithful recovery of the target motion by OSCAT. The absolute distance of the target is measured to be 1376 m in fiber, 2.02 km in free space. In conclusion, we have developed a OSCAT-based lidar, which is able to trace fast movement of a distant target.

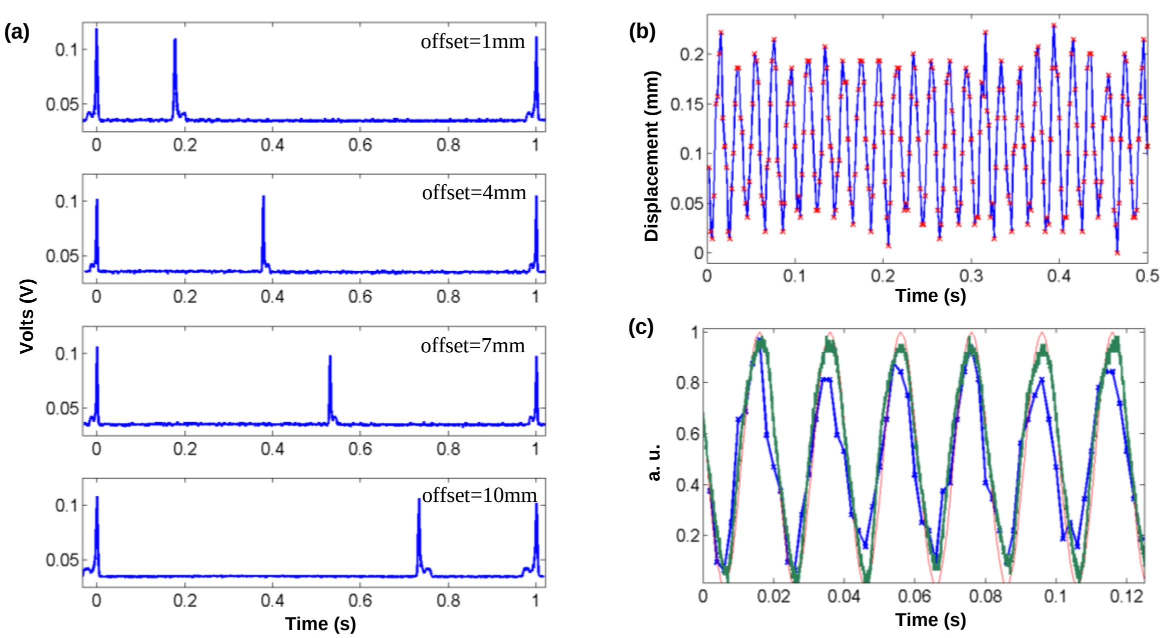

Fig. 2. (a) Cross-correlation traces with various target displacements from the reference point; (b) OSCAT-measured displacements (check markers) when the target oscillates at about 50 Hz along the line-of-sight direction; (c) Comparison between the OSCAT-measured target trajectory (blue) and the trajectory given by the optical power method (green) as well as the modulation signal (red) applied on the speaker.

4. Reference

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