Optical Ranging Using Coherent Kerr Soliton Dual microcombs with Extended Ambiguity Distance

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Abstract: We propose a dual-comb ranging method using coherent dual microcombs generated by single pump and thermo-optic tuning of resonances. This scheme provides the compatibility of low-bandwidth detectors and potential of real-time processing. © 2024 The Authors

1. Introduction

Optical ranging is a key technology in metrology. Dual-comb schemes based on multi-longitudinal mode heterodyne phase detection is established [1], offering high precision and fast acquisition. Due to the generation of microcombs, higher integration and lower power consumption with ultra-high acquisition rate are further achieved [2]. By switching the microcombs, ambiguity distance can be extended to $c/2\Delta f_{\text{rep}}$ according to the vernier effect [1,3], where Δf_{rep} is the dual-comb repetition rate difference. However, existed dual-microcomb ranging schemes based on interference of microcombs still place high demands on the bandwidth of detectors and the amount of recorded data, resulting in high-cost systems and non-real-time processing.

We propose a dual-comb ranging system using coherent Kerr soliton dual microcombs, which is compatible to low-bandwidth detectors and shows the potential of real-time processing. Coherent soliton dual microcombs refer to a couple of single-soliton microcombs with adjustable central frequency difference locked to a RF signal. The interference signal of such microcombs is convenient to be controlled in a low frequency band, which significantly lower the cost of detectors and the amount of data. Combining coherent dual-microcomb ranging system with special FPGA provides a route to enable microcomb-based real-time ranging system with high-precision for applications such as industrial process monitoring.

2. Coherent Kerr Soliton Dual-microcomb Generation

The difficulty in coherent dual-microcomb generation is to simultaneously match the pump frequency with the resonance of two resonators. Limited by the manufacturing process, even resonators processed according to the same structure are shown to have independent resonance. Thermo-optic tuning of resonances can precisely adjust the resonance and provide a convenient route to generate coherent dual microcombs. Dual-pump method [4] is applied with TECs under chips in our microcomb generation system. The experimental setup for microcomb generation is presented in Fig.(a), which is an upgraded version of a standalone soliton microcomb prototype [5]. We measure the redshift of the resonance of the microresonator with 95GHz free spectral range as shown in Fig.1(b). The entering and leaving of the resonance are marked respectively by emergence of first pair of four wave mixing sidebands and the disappearance of the chaotic comb. For every 1°C increase, the redshift is approximately 4.8GHz, showing a linear trend with temperature.

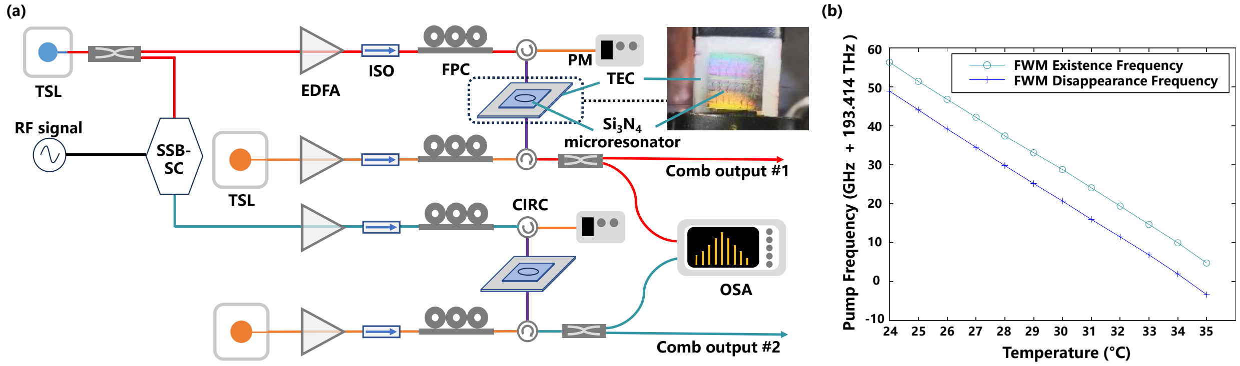

Fig. 1. (a) Coherent soliton microcomb generating system. The red lines show the route of the pump laser. The green lines show the route of the pump laser with 3 GHz frequency shift. The orange lines are the routes of auxiliary lasers. The purple lines are the mixture of pump and auxiliary laser. TSL: tunable semiconductor laser; EDFA: Er-doped fiber amplifier; FPC: fiber polarization controller; BS: beam-splitter; OSA: Optical spectrum analyzer; Circ: circulator; PM: power meter. (b) Resonant frequency as a function of temperature when changing from 24°C to 35°C.

The pump laser is set at 1557.73 nm and split into two parts, one of which generates a single sideband with 3 GHz frequency shift by a single-sideband suppressed carrier (SSB-SC) modulator. The pump lasers are boosted to 27 dBm.

The TECs are set as 34°C and 24°C to match the resonances to the pump lasers. The two auxiliary lasers are set at the wavelength of 1550.03 nm, amplified to 30.5 dBm and injected into the microresonators from the reverse direction. The FPCs are used to control the polarization, which is necessary for soliton generation.

3. Dual-comb Ranging Using Coherent Dual-microcombs with Extended Ambiguity Distance

The dual microcombs and the ranging system are presented in Fig.2(a) and (b). An optical switch is utilized to extend the ambiguity distance. The coherent microcombs are amplified to ~6 mW by a pair of C+L-band EDFAs. In the measurement path, one part of the signal comb is routed to the target and back, and then to a balanced photodetector (BPD) after interfering with the LO comb. In the reference path, the other part of signal and LO comb directly interfere with each other and are sent to another BPD, while the FPCs guarantee the premise of interference. The polarization beam spilter (PBS) and PM are used to separate a linear polarization mode to participate in the interference.

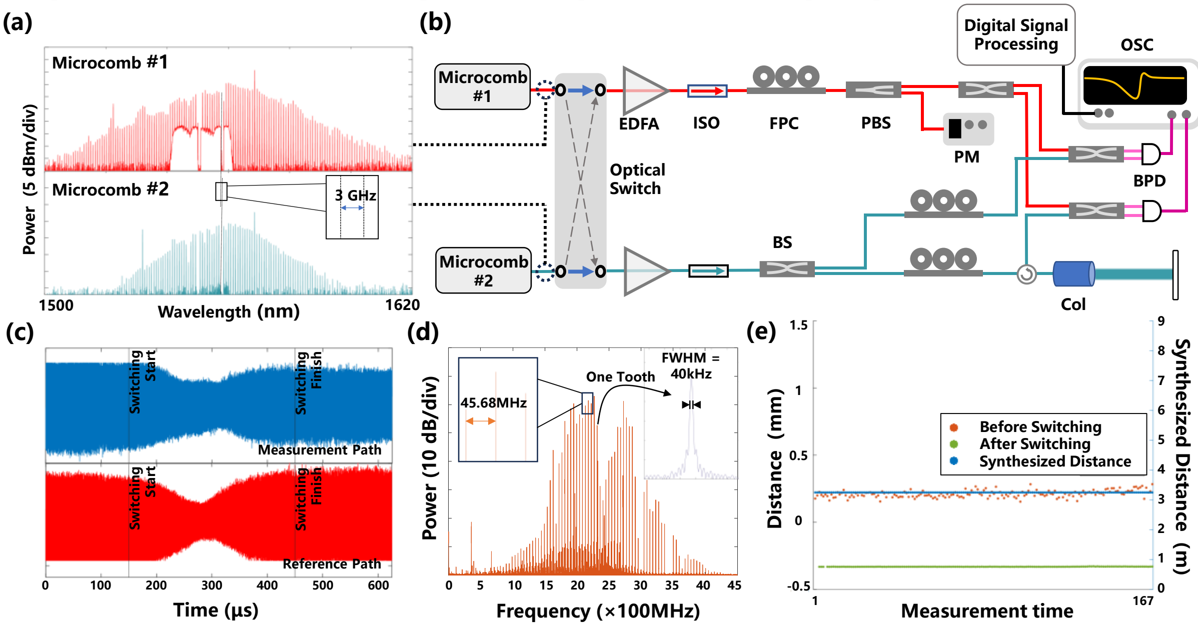

Fig. 2. (a) Coherent dual-comb with 3 GHz pump frequency difference. (b) The dual-comb ranging system. The red and green lines show the route of the reference and measurement microcombs, respectively. (c) The entire recorded signal, including 3 parts: two series of periodic pulses (first and last 150 μs) and a switching process (from 150 μs to 450 μs). (d) The Fourier transform of the measurement path signal. The spacing between the adjacent teeth is 45.68 MHz. The FWHM of one tooth is 40 kHz. (e) The measured distance before (orange) and after (green) switching, and the synthesized distance (blue).

The electro signal is recorded by an oscilloscope (OSC), shown in Fig.2(c). Ranging signal appears as a series of periodic pulse in the temporal domain. Fig.2(d) shows the Fourier transform of the recorded signal in the measurement path, which is an RF comb in the frequency domain. The spacing equals the repetition rate difference and amounts to Δf_{rep}=45.68 MHz. Thereby, the ambiguity distance is $L_{\mathrm{amb}} = c/2\Delta f_{\mathrm{rep}}$ = 3.28 m. At an averaging time of 9.56 μs, the Allan standard deviation is σ=346 nm. The measured distance in one L_{amb} before and after the switching is 0.209 mm and -0.333 mm, while the synthesized distance is 3.24 m. The uncertainty is $\delta=\sigma/L_{\mathrm{amb}}\approx 1.05\times10^{-7}$.

4. Conclusion and Discussion

We propose a dual-comb ranging scheme using coherent dual-microcomb with the advantages of compatibility to low-cost detectors and the potential of real-time processing, which result in higher adaptability and robustness. We believe this method holds significant practical value and can broaden the applications of dual-comb techniques.

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