

# Simultaneous distance measurement at multiple wavelengths using the intermode beats from a coherent supercontinuum

**Conference Paper****Author(s):**

Salido Monzú, David ; Wieser, Andreas 

**Publication date:**

2018

**Permanent link:**

<https://doi.org/10.3929/ethz-b-000304473>

**Rights / license:**

[Creative Commons Attribution 3.0 Unported](#)

**Originally published in:**

Journal of Physics: Conference Series 1065, <https://doi.org/10.1088/1742-6596/1065/14/142020>

PAPER • OPEN ACCESS

## Simultaneous distance measurement at multiple wavelengths using the intermode beats from a coherent supercontinuum

To cite this article: D Salido-Monzú and A Wieser 2018 *J. Phys.: Conf. Ser.* **1065** 142020

View the [article online](#) for updates and enhancements.



**IOP | ebooks™**

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

# Simultaneous distance measurement at multiple wavelengths using the intermode beats from a coherent supercontinuum

**D Salido-Monzú and A Wieser**

Institute of Geodesy and Photogrammetry, ETH Zürich  
Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland

E-mail: david.salido@geod.baug.ethz.ch

**Abstract.** Advances in ultrashort pulse lasers and spectral manipulation enable new approaches to metrological problems in various fields. Dimensional metrology may benefit particularly from this progress, including applications like long distance measurement and 3D laser scanning. Using the intermode beat notes obtained by direct photodetection of a mode-locked femtosecond laser has been demonstrated as a promising alternative to solutions based on actively modulated signals. In this work, we extend the approach to ultra-broadband sources derived from femtosecond lasers, aiming at investigating their potential as a technological basis for multiwavelength distance metrology. We have developed a short-distance experimental set-up for displacement measurement operating simultaneously at two wavelength ranges on both extremes of a 500 nm coherent supercontinuum. The results derived from the phases of the 1 GHz intermode beat notes show that the internal coherence of the source is sufficient to derive distances with an accuracy better than 50  $\mu\text{m}$ . This is a promising first step for the prospective application of this method to develop spectrally-versatile solutions, which is of interest to provide surface material probing capabilities in laser scanning and to increase the accuracy of long distance measurement through dispersion-based refractivity compensation.

## 1. Introduction

Several practical applications for distance metrology in non-controlled environments would benefit from the development of robust techniques delivering accurate wavelength-dependent distance information. The accuracy of high-end electro-optical distance meters operating outdoors over distances up to a few kilometers is nowadays limited by refractivity errors arising from insufficient knowledge of the integral atmospheric conditions along the beam path. Dispersion is exploited in interferometric set-ups for refractivity compensation with simultaneous observations at two wavelengths [1]. Transferring this method to the non-interferometric techniques required for long distance is highly challenging due to the inherent error scaling introduced by the compensation [2]. Increasing the number of observed wavelengths will allow reducing this scaling, potentially enabling sub-mm accuracies on km ranges. This, in turn, relies upon the development of a robust method capable of delivering accurate simultaneous distance measurements at adjustable spectral ranges. Such a solution additionally offers significant perspectives for reflectoreless distance measurement as employed by laser scanners [3]: wavelength dependent depth information can be fused with spectrometry for enhanced remote surface material probing.

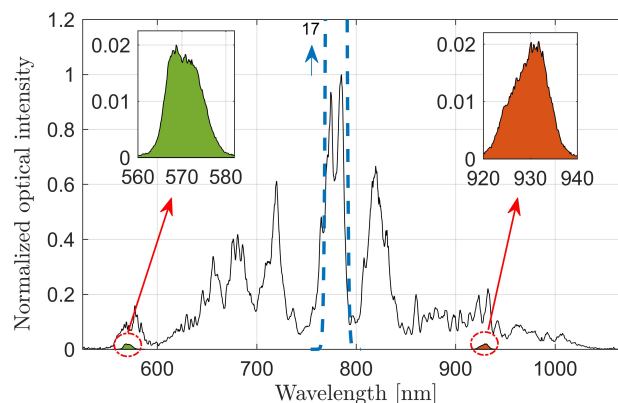
The intermode beat notes generated by direct detection of a mode-locked laser are high-quality RF tones whose phase is proportional to the group delay of the detected signal, providing a versatile



modulation scheme for high resolution and non-ambiguity ranging. This technique has already been demonstrated with femtosecond lasers over several hundred meters as a robust alternative to established approaches for long-distance metrology [4,5]. The absence of actual modulators reduces crosstalk in comparison with conventional techniques, while enabling higher bandwidth, hence increased resolution. We extend this idea to wideband sources obtained by spectral broadening of a femtosecond laser [6]. Microstructured fibers able to generate coherent supercontinua covering several hundred nm are increasingly available. Given that sufficient phase coherence is preserved, intermode beating is applicable to arbitrarily selected regions from these spectra, serving as a promising basis for multiwavelength distance measurement architectures. We demonstrate with this work in a short-distance set-up that sufficiently accurate distance information can be derived from bandpass-filtered regions of a coherent supercontinuum, and identify dominant limitations towards the extension of the method to longer ranges and non-controlled outdoor atmosphere.

## 2. Experimental set-up

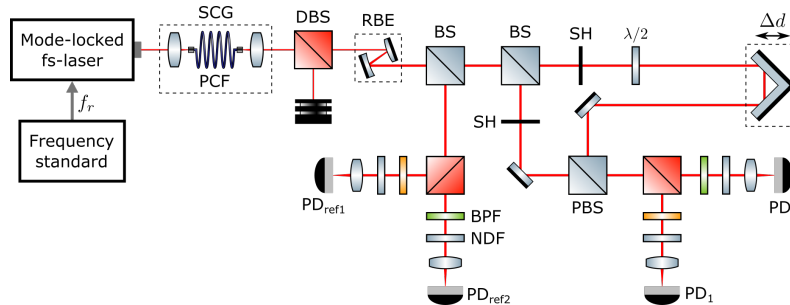
We use a mode-locked erbium fiber femtosecond laser (MenloSystems C-Fiber 780 SYNC100) with 100 MHz repetition rate ( $f_r$ ) locked to a harmonic of an external 10 MHz rubidium frequency standard (SRS FS725). The frequency-doubled output of the laser centered at 780 nm is coupled into the photonic-crystal fiber (PCF) of a supercontinuum generation module (MenloSystems SCG1500), which coherently broadens the pump laser to produce a broadband free-space beam integrating over 100 mW from 550 nm to 1050 nm. The measured spectra of the pump laser and the supercontinuum output are shown in figure 1.



**Figure 1.** Spectrum of our femtosecond laser before broadening (blue), supercontinuum (black) and bandpass-filtered regions used herein (green/red inserts). All intensities are normalized to the maximum value of the supercontinuum.

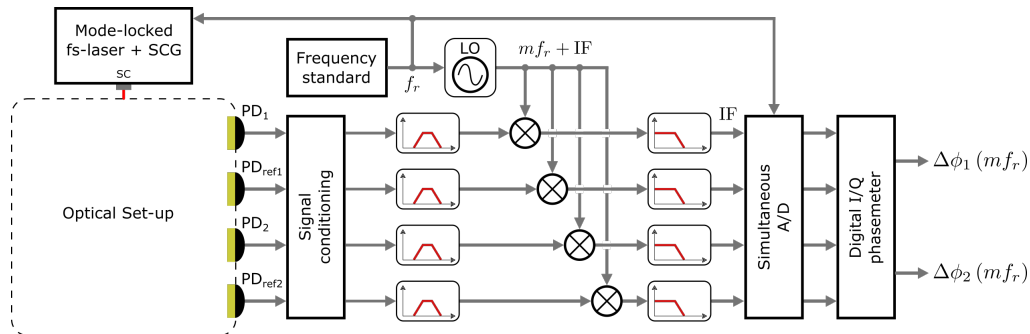
The optical set-up for our experiment is shown schematically in figure 2, where the supercontinuum beam is used to probe the displacement of a 50 mm delay line formed by a motorized translation stage and a broadband retroreflector. The set-up implements both reference and probe paths with two-colour detection stages, including a polarization-based automated bypass of the delay line for fast self-reference measurements compensating drifts in the whole measuring chain of the probe detectors. The measurement bands for the present experiments, also depicted in figure 1, are selected prior detection by dichroic beamsplitters and respective bandpass filters around 570 nm and 930 nm, each one corresponding to about 15  $\mu$ W. These colours have been selected aiming at evaluating performance at both ends of the supercontinuum spectrum away from the original band of the pump laser, while providing a good dispersion factor for prospective refractivity compensation measurements [1]. The filtered beams are detected in silicon avalanche-photodiodes (APDs) with

1 GHz 3dB-bandwidth and temperature-compensated bias, and the distance information for each colour is extracted from the phase difference between the beat notes ( $mf_r$ ) at 1 GHz from the respective probe and reference detectors.



**Figure 2.** Optical set-up for displacement measurements (RBE: beam-expander, BS: broadband beamsplitter, DBS: dichroic BS, PBS: polarizing BS, BPF: bandpass filter, NDF: neutral-density filter, SH: shutter,  $\lambda/2$ : achromatic half-wave plate).

A diagram of the electronic set-up that performs the phase measurements on the detected beat notes is shown in figure 3. The components of interest around 1 GHz are bandpass-filtered and downmixed with a low-noise local oscillator (LO) to an intermediate frequency (IF) of 25 MHz. This IF is selected to balance separation between downconverted components in baseband while avoiding the excess of noise of lower frequency bands. After anti-aliasing filtering, the baseband signals are acquired on a simultaneous 8-bit digitizer (Spectrum M4i.2234-x8) at 1.25 MS/s. The time bases of both the digitizer and the local oscillator for downmixing are also derived from the rubidium standard. The phase information between reference and probe detectors is then extracted from the digital signals by synchronous I/Q demodulation.

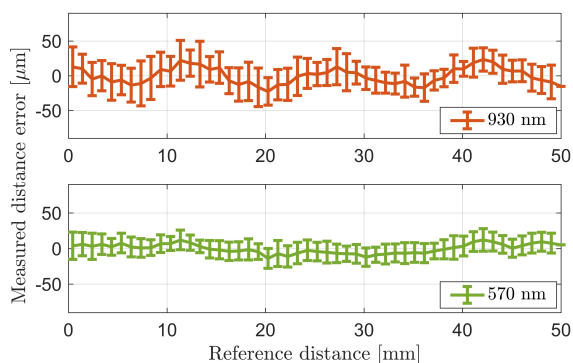


**Figure 3.** Electronic set-up for phase measurement.

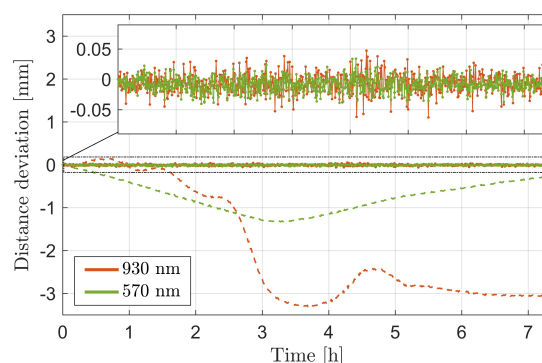
### 3. Results

We have performed displacement measurements at 1 mm steps along the 50 mm delay line. The estimation for every position is calculated by integrating over 27 ms and referencing to an equivalent measurement on the internal fixed path. The distance reference is derived from the internal control loop of the translation stage, which has previously been calibrated with a HeNe Doppler interferometer (Agilent 5529A). Reproducible cyclic errors at the tens of  $\mu\text{m}$  level have been observed associated to the downmixing electronics. In the absence of longer measurements where the error periodicity can be properly modelled, these have been mitigated herein by subtracting a linear trend. Additional tests have also shown that small pointing variations on the detectors introduce significant errors, suggesting the need to stabilize pointing by fiber-coupling the free-space beams to the APDs. The results calculated from repeating the complete measurement cycle 24 times within 48 hours are

shown in figure 4, yielding maximum standard deviations per position of 33  $\mu\text{m}$  for the 930 nm channel, and 19  $\mu\text{m}$  for the 570 nm channel. Figure 5 shows the results from a static test over 7 hours to evaluate stability and precision. Drifts above 3 mm due to spectral instability of the supercontinuum inducing changes up to 6 dB in detected power were observed. Despite the magnitude of these changes, the results show that they are mostly due to common contributions to the probe detectors, hence effectively compensated by the internal reference. Final measurements yield stable values with standard deviations of 16  $\mu\text{m}$  and 12  $\mu\text{m}$  for the 930 nm and 570 nm channels respectively.



**Figure 4.** Mean and standard deviation of residuals between measured distance and reference distance.



**Figure 5.** Deviation of static measurements before (slashed) and after (solid) subtracting the internal reference.

#### 4. Conclusions

We investigate the feasibility of performing simultaneous multiwavelength distance measurement using the intermode beat notes from filtered regions of a femtosecond laser coherent supercontinuum. Our results on short distance show that noise and coherence of the broadband source are adequate for achieving accuracies better than 50  $\mu\text{m}$ , with a potential improvement by accessing higher beat notes. Robustness against large variations in output power was demonstrated. The impact of pointing and differential power variations may be critical for prospective outdoor applications in turbulent atmosphere, and require further investigation for proper assessment of the individual error contributions and development of mitigation solutions. The adaptation of the experimental set-up to longer distances to be tested on a 50 m baseline with an interferometric comparator is now undertaken. We consider this a promising starting point for the further development of flexible multiwavelength solutions applied to refractivity-compensated long-distance measurement and hyperspectral laser scanning.

#### References

- [1] Wu G, Takahashi M, Arai K, Inaba H and Minoshima K 2013 Extremely high-accuracy correction of air refractive index using two-colour optical frequency combs *Scientific Reports* **3**(1894) 1–5
- [2] Guillory J, Šmíd R, García-Márquez J, Truong D, Alexandre C and Wallerand JP 2016 High resolution kilometer range optical telemetry in air by radio frequency phase measurement *Review of Scientific Instruments* **87**(7) 075105–075110
- [3] Hakala T, Suomalainen J, Kaasalainen S and Chen Y 2012 Full waveform hyperspectral LiDAR for terrestrial laser scanning *Optics Express* **20**(7) 422–430
- [4] Minoshima K and Matsumoto H 2000 High-accuracy measurement of 240-m distance in an optical tunnel by use of a compact femtosecond laser *Applied Optics* **39**(30) 5512–5517
- [5] Doloca NR, Meiners-Hagen K, Wedde M, Pollinger F and Abou-Zeid A 2010 Absolute distance measurement system using a femtosecond laser as a modulator *Measurement Science and Technology* **21**(11) 115302–115308
- [6] Salido-Monzú D and Wieser A 2017 A new approach to long distance EDM: Using intermode beating of broadband ultrashort laser pulses In *Proc. Int. Conf. on Engineering Surveying* (Lisbon, Portugal, October 2017) 173–182