Arpent: a new high accuracy long-range Absolute Distance Meter (ADM)

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Abstract

Accurate absolute distance measurements over several kilometres are of great interest for several applications such as the surveying of geological faults or of large sites: dams, colliders, tunnels, etc… In this framework, we have developed a new telemeter: Arpent.

This telemeter, shaped by several years of research, is able to reach better performances than current commercial ADMs. Nowadays, the most accurate commercial ADM claims an uncertainty of 1.6 mm up to 1 km. However, in the 1990's, better performances have been reached with the Mekometer ME5000 from the former Kern company. This instrument, no longer manufactured, but still used by several geodetic institutes, can achieve an accuracy of 75 µm ± 0.5 ppm, i.e. 575 µm at 1 km, with a recording of meteorological conditions at each end of the line.

The Arpent telemeter is based on the measurement of the phase shift ϕ of a modulation frequency along the measurement path. And as shown by the following formula, this phase shift is directly proportional to distance d:

$$d = \frac{1}{2} \times \left(\frac{\phi}{2\pi} + k \right) \times \frac{c}{n \times f_{RF}}$$

with c is the speed of light in vacuum, n the group refractive index of air, f_{RF} the frequency modulation, and k an integer number corresponding to the number of times that the phase has rotated by 2π during the propagation.

In practice, a 1550 nm optical carrier is emitted by a Distributed FeedBack (DFB) laser diode and intensity modulated by a RF carrier by an Electro-Absorption Modulator (EAM), at 4261 MHz. This fiber-guided optical signal is then emitted in free space and collimated by an off-axis parabolic mirror for a long distance propagation: the spot size of 48 mm (at 1 % power level) is reflected back towards the telemeter by a corner cube. The returned signal is finally directed towards a high speed photodiode and the phase of the photodetected RF signal is measured after a frequency down conversion. This signal is processed digitally by a Field Programmable Gate Arrays (FPGA) and displayed on Matlab. Each individual phase measurement is integrated over 10 ms.

In a first time, our ADM was compared to a 3m-long interferometric bench (LNE, Paris, France), indoor, in a controlled environment where all atmospheric parameters were measured as accurately as possible. The difference between the interferometric distance at 633 nm and the Arpent distance at 1550 nm was finally better than 4 µm with a standard deviation of 1.6 µm.

Then, our ADM was compared to the Physikalisch-Technischen Bundesanstalt's baseline (PTB, Braunschweig, Germany) and to the Finnish Geospatial Research Institute's one (FGI,

Nummela, Finland). This last 864 m long baseline, a reference around the world, is known with an uncertainty of 170 µm (k=1) for all pillar intervals (no scale-dependent).

In the best case, with constant atmospheric parameters, the Arpent telemeter has shown over a short period of 20 s a sample standard deviation as low as 3.3 µm for a distance of 864 m (and 10 ms of integration time). This value corresponds to the instrument resolution. More generally, the reproducibility of the distance measurement over five different days, with temperatures varying from 2.7 to 13.6 °C, and pressures from 999.2 to 1014.7 hPa, was better than 300 µm (k=1) up to 864 m, while the average values differ from FGI of 540 µm in the worst case. Correction from the air index was done from the atmospheric data of three weather stations installed along the baseline.

Lastly, we have tested the Arpent telemeter over 5.4 km between the LNE building in Paris and the Meudon observatory. Two weather stations were installed at each end of the line: the temperatures were 8.2 and 10 °C, pressures 1003.6 and 992.9 hPa (the Meudon observatory is located about 80 m above the LNE building), and relative humidities 57 and 68 % in Paris and Meudon, respectively. The sky was overcast with a ~14 km/h wind. Due to propagation above urban area, the atmospheric disturbances were high. Nevertheless, the short term (15 s) sample standard deviation was between 10 and 40 µm (for 10 ms of integration time).

We moved the 5.4 km distant corner cube by steps of 100 µm thanks to a micrometer screw, from 0 to -1 mm, then from -1 to 0 mm. Between each step, we went back to the distance zero to estimate the distance drift that occurred during the 10 min measurement. Thus, we applied a correction to the distance measurements to compensate the air refractive index fluctuations (we have considered a polynomial drift). The result is depicted in Fig. 1: we can distinguish the distance variations despite the atmospheric disturbances, which demonstrates the performances of the Arpent telemeter.

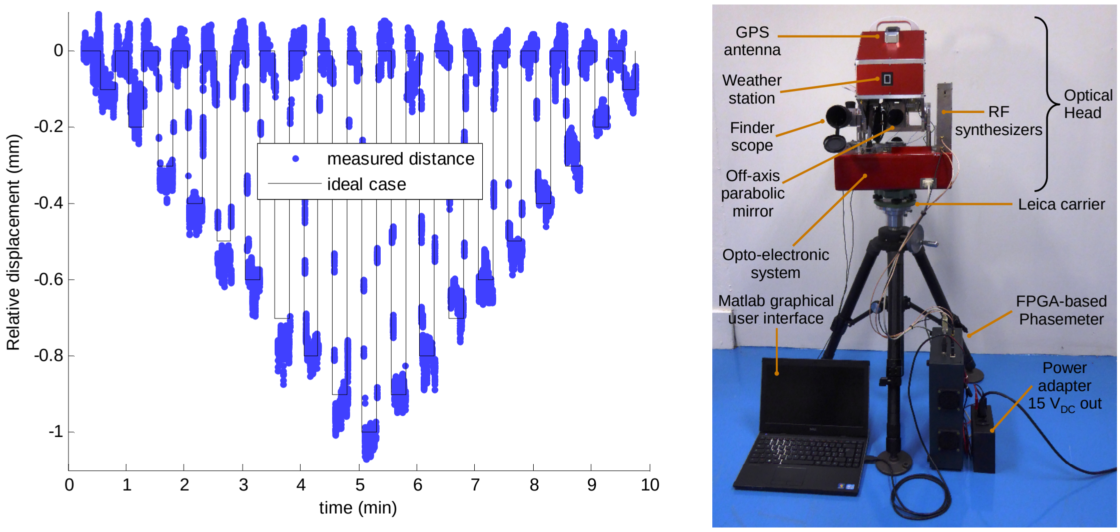

Fig 1. – Measurement of 100 µm steps of the corner cube after an optical propagation over 5.4 km in air on the left, and photograph of the Arpent telemeter on the right.

We will present at the conference more details about the Arpent telemeter. We will first insist on its robust and compact, and so transportable, design. Then, a detailed review of its performances will be done: offsets, then resolution and accuracy over short and long distances, with different weather conditions.

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